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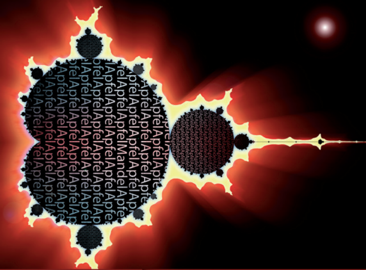
Aura Heydenreich, Klaus Mecke (Hrsg.)

PHYSICS AND LITERATURE

CONCEPTS – TRANSFER – AESTHETICIZATION



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Concepts – Transfer – Aestheticization

Edited by
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Aura Heydenreich and Klaus Mecke

Introduction

“Where are the scientists in Literature and Science?” This question was posed by Jay Labinger in the 2017 issue of the *Journal of Literature and Science* (Labinger 2017). Labinger’s question implies that for a scientific culture that is aware of its social responsibility and wants to focus on scientific and cultural innovations as well as on their social effects, epistemic implications and dangers, a genuine dialogue between science and humanities scholars is crucial and indispensable. Challenging the old topos of the “Two Cultures” this volume pursues the goal of establishing an epistemic discourse community to realize the productive potential of addressing shared problems in science and literature and to reflect on the intercourse between ways of knowledge production in an interdisciplinary way. This volume presents the proceedings of the inaugural conference of ELINAS, the *Erlangen Center for Literature and Natural Science*. With ELINAS Friedrich-Alexander-University of Erlangen-Nuremberg (FAU) hosts a research center based on established cooperation between science (physics, mathematics, medicine) and literary studies (German, English, American and Romance languages and literatures). Within ELINAS the natural sciences and the humanities bring their methodological and epistemological foundations into a constructive and balanced interdisciplinary dialogue. This unifying approach takes into account the interweaving of functionally differentiated discourses and the specific perspectives of literary and scientific methods of inquiry. The investigation of scientific concept formation requires competencies in philosophy of science and linguistics, while the analysis of the transformation and literarization of scientific knowledge requires both the expertise of literary studies and natural sciences. The ELINAS series of publications including this volume provides a platform for this goal: to develop the field of research historically and systematically by bundling together literary, cultural and scientific competences.

This volume examines concepts, categories, and principles in their respective interaction between physics and literature. Historical processes of knowledge transfer and synergy effects between the disciplines are in focus as well as the different linguistic strategies for modeling knowledge in physics and literature. Central questions concern processes of concept formation and concept transfer, epistemological premises, techniques of aestheticization of scientific knowledge in literary texts, as well as the question of how scientific knowledge is framed narratively and metaphorically. By aesthetically shaping the intellectual signatures of its time, literature functions as an interdiscourse that ties

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different areas of knowledge back to life-world horizons. Literature transfers natural science knowledge from mathematical-symbolic forms to complexly coded literary forms by narrating it, dialogizing it, and coupling it back to historical and cultural horizons. In this way, even implicit assumptions of scientific models and their consequences for different world views can be questioned epistemologically.

For its part, natural science is increasingly reflecting on the linguistic constitution and the overall cultural dimensions of its research: On the one hand, physics asks about the knowledge-guiding power of metaphors ("field," "quarks," "uncertainty") and the communicative, political and cultural conditions that determine the goals, priorities and ethical limits of research. On the other hand, physical terms and concepts have been transferred into the theoretical context of literary studies ("literary field," "space-time" / "chronotopos"). Areas of overlap between scientific and literary-cultural practice are a field of research of great relevance. However, the necessary joint interdisciplinary work of two highly specialized expert discourses is still missing on a wide scale.

The present volume examines the reciprocal transfer of knowledge between literature, natural science and literary studies, and the forms of their respective modes of world modeling from both perspectives: that of literary scholars and that of natural scientists. The focus lies both on the theoretical and constructive potential of literary images in scientific texts and on the discursive functions of scientific models and theories in literary texts. A central task before any inherent work is to reach a reciprocal understanding about different truth claims and acceptable arguments for justification based on mutual respect between both communities (Habermas 1981). Only the establishment and habitualization of a shared discourse zone (Galison 1997) makes the interdisciplinary field of literature and natural sciences possible, in which joint research can be conducted, and where semio-ethical perspectives are also considered (Heydenreich 2022).

The increasing relevance of interactions between literature and natural science is attested by a huge number of publications (Beer 1983; Levine 1987; Schatzberg et al. 1987; Cunningham and Jardine 1990; Danneberg and Vollhard 1992; Vogl 1999; Gossin 2002; Vanderbeke 2004; Schmitz-Emans 2008; Klausnitzer 2008; Zehelein 2009; Klinkert 2010; Clarke and Rossini 2011; Breidbach and Burwick 2012; Albrecht 2014; Gamper 2020; Malinowski 2021). The journals *Configurations* (Johns Hopkins University Press 1993) and *Scientia Poetica* (De Gruyter 1997) as well as the annual conferences of the *Society for Literature, Science and the Arts* in the U. S. and Europe continuously demonstrated the relevance of this research topic. Nicholas Pethes (2003), Dirk Vanderbeke (2004) and Olav Krämer (2011) provide reviews of the situation. *The Routledge Companion to Literature and Science* (2011), edited by Bruce Clarke and Manuela Rossini, the *Metzler Handbook of Literature and Knowledge* (2013), edited by Roland Borgards, Harald Neumeyer, Nicholas Pethes and Yvonne Wübben, as well as *The Cambridge Companion to Literature and Science* (2018), edited by Stephen Meyer, offer overviews of theoretical and historical approaches to this research field.

While intentionalist approaches were initially established (Richter 1972; Richter et al. 1997), a correlationist approach was then adopted (Novak 1980; Hayles 1984; Scholnick 1992; Maillard and Titzmann 2002). The cultural studies have favored discourse-analytical approaches based on circulation models (Borgards et al. 2013). Other approaches focused on historical epistemology (Gess and Janßen 2014) or on the practical turn of science and technology studies (Albrecht 2015). Although the importance of physics as a context (Metzner 1979) for literary texts has been recognized (Strehle 1992; Emter 1995; Freese 1997; Clarke 2001; Dilmac 2012; Özelt 2018) and examined from a cultural studies perspective (Gamper 2009; Specht 2010), the questions have not been formulated in dialogue with experts from the fields of physics. And on the physicists' side no systematic research approach to the topic exists to date. In addition to the media-specific epistemological achievements of literary textuality, the proceedings address the aesthetic modeling of scientific knowledge in scientific and literary texts. The volume reunites contributions from the fields of humanities and of natural sciences.

The great challenge of the *Literature and Science* community and in particular of the research center ELINAS is to institutionalize a constructive dialogue between highly specialized disciplines, based on different scientific languages and theoretical foundations. This volume thus counteracts increasing specialization by bridging the gaps between the scientific cultures, and practicing the ability to understand other scientific languages and to learn from one another. In order to build such an interdisciplinary discourse zone, one needs to tie in different approaches that meet the epistemic interests of both literary and natural sciences in different ways: Concept formation and concept transfer theories (Bal 2002; Nersessian 2008; Carey 2011; Vosniadou 2013), philosophy of science (Hacking 1999, 2008; Van Fraassen 1980, 2013; Frigg 2008; Suarez 2009), discourse and interdiscourse analysis (Fohrmann and Müller 1988; Link 1988, 2004, 2005; Keller et al. 2005; Hock and Mackenthun 2012), sociology of knowledge (Latour and Woolgar 1979; Latour 1987; Burke 2012; Nordheim and Antoni 2013), the material/practical turn (Bennett 2010; Albrecht 2015), Science and Technology Studies (Hayles 1984; Jasanoff 2005; Daston and Galison 2007; Daston and Lunbeck 2011), Literature and Science Studies (Levine 1987; Schatzberg et al. 1987; Levine 1993), and Rhetoric of Science (Gross 1990; Fahnestock 1999).

With its focus on (1) the epistemological achievements of literary textuality, (2) the textuality of scientific knowledge production, and (3) the exchange movements and interferences between knowledge cultures (Heydenreich and Mecke 2015a, 2015b, 2015c, 2015d), the volume goes beyond the conventional approaches of the rhetoric of science, and the theory and history of science, to which it simultaneously remains related. Although the history of science already operates with metaphor-theoretical (Haraway 1976; Brandt 2004; Danneberg 2009) or linguistic approaches (Drewer 2003), extensive interdisciplinary research is still needed for an analysis of the linguistic, narrative and, in the broadest sense, aesthetic practices of scientific concept formation and knowledge production.

The volume presents both theoretical-systematic and historical contributions. A common focus is on the conceptualization, categorization and modeling of knowledge in specific disciplinary contexts, on the one hand, and on the conditions and possibilities of interdisciplinary knowledge transfer on the other. Concepts are considered to be dynamic-operative figures of thought, as intellectual tools (Neumann et al. 2012) and operative terms (Welsch 1997), which characterize the knowledge production practice of an epistemic community (Rheinberger 2001) and synthesize central problem complexes. Concepts are thus operationalized not only descriptively but also performatively and programmatically (Bal 2002), thus enabling the structuring of research discourses. To the extent that these concepts cross the boundaries between disciplines and are discourse-specifically adopted and transformed by different epistemic communities, they configure a semantically enriched interdisciplinary sphere of discourse or dissent (Hacking 1999; Heydenreich and Mecke 2015c). In this way, they enable an exchange between different epistemic communities on a meta-level, so that similarities and differences in practices of problem formulation and knowledge generation of different epistemic communities can be discussed.

The contributions in this volume take into account concept formation theories from the philosophy of science (Lenk 2004; Nersessian 2008), history of science (Kuhn 1970; Thagard 1993; Rheinberger 2008), and linguistics (Thielmann 1999, 2008). The cultural-analytical concept-transfer theories of Mieke Bal (2002) and Neumann, Nünning and Horn (2012) are also considered to be important. The analyses focuse on five dimensions of interdisciplinary concept transfer:

- The analysis of the specific practices of conceptualization (basic principles, methodological norms, experimental methods) in epistemic communities, i. e. the reconstruction of the epistemological configuration, the matrix (Kuhn 1982; Hacking 1999) or the interdisciplinary discourse zone (trading zone, Galison 1997), in which the concepts arise (cf. papers of Labinger, Heydenreich, Thielmann, Plotnitsky, and Murphy in this volume).

- The analysis of the specific practices of codification of concepts, i. e. how meaningful signs are created in the process of conceptualization and how these signs are manifested in their specific materiality (text, graphics, mathematical notation, etc.) with their syntactic, semantic and pragmatic dimensions (cf. papers of Malinowski, Vignale, Labinger, and Heydenreich in this volume).
- The analysis of the functions ascribed to the concepts within the framework of the theory or of the literary text, i. e. theory-constructive, model-constitutive, categorizing, explanatory, explorative or narrative-strategical functions (cf. papers of Kompa, Bergengruen, Malinowski, Vanderbeke, and Kasper in this volume).
- The analysis of the concept's co-evolutionary or transformational dynamics in the formation and (re-)organization of different interdisciplinary research fields and for the development of further theoretical perspectives (cf. papers of Plotnitsky, Mairhofer, Mühr, and Özelt in this volume).
- The analysis of the commensurability or incommensurability (Kuhn 1982; Hacking 1999) of transferred concepts, which have been developed within the framework of different disciplines or historical, intellectual, or contextual (Chakrabarty 2008) traditions of knowledge production, literarization and aestheticization (cf. papers of Vanderbeke, Gencarelli, McGovern, and Kasper in this volume).

The volume provides analyses of concepts that are at the center of a particular scientific paradigm, where their introduction has led to theoretical innovations, such as Faraday's concept of 'induction' in Balzac's novels (cf. Murphy in this volume), the concept of 'indeterminacy' in Heisenberg and Musil texts (cf. Plotnitsky in this volume), the concept of "interference" in physics and in Brecht's theatrical poetics (cf. Mairhofer in this volume), the physical concept of possible worlds (cf. Vanderbeke in this volume) in cosmology and quantum theory compared to the transformation of the concept in the science fiction genre.

A particular practical benefit of the analysis of scientific conceptualizations lies in a close reading of scientific language that explores adequate ways of communicating abstract concepts. Desiderata in the natural sciences are science communication and ethics. It is also important for future research that scientists learn more about the general semantic flexibility of scientific terms and mathematical models. The interpretation of abstract quantities and mathematical objects is important not only in quantum theory, but also plays a crucial role for the development of basic concepts in all areas of physics. Linguistic and literary analysis can help to discover the richness of meaning of scientific terms beyond their usual, often quite formal definitions.

Physical knowledge is tied to language. Although applied mathematics is a formal tool and experiments are performed through practical methods, the formulation of ideas and concepts requires language as well as publications and communication with colleagues and the public. Scientific writing is characterized by standards that are imparted in the educational process (Gross 1990, 2002). Some of these norms will be examined from a historical linguistic (cf. Thielmann in this volume) as well as from narratological (cf. Heydenreich in this volume) and metaphorological perspectives (cf. Kompa in this volume). As early as the seventeenth century, a clear, reduced style was demanded so that the universal validity of empirical results would not be compromised by subjective narrative styles. Nevertheless, dramatic historical changes in writing styles can be observed: While in the early modern period there were still aesthetically shaped texts (e.g. Kepler, *Somnium* 1609) and Galileo still used the form of a dialogue that weighs pros and cons (*Dialogo* 1632, *Discorsi* 1638) (cf. Özelt in this volume), today, in the journal *Physical Review Letters* the expert article has become strictly reduced to four pages of formalized argumentation. In this thematic focus, the typical character of the scientific language will be examined in accordance with Winfried Thielmann's study on the technical language of physics as a conceptual instrument (Thielmann 1999). In addition to technical scientific language, it is important for the cultural dissemination of knowledge to take into account the popular language and textbook language of physics: Driven by the interest in appropriately presenting to the public not only its results but also the genesis of research processes, and in addition to present a coherent order of a research area in flux, a separate interest-driven specialist text genre emerged which, as a second-order reflection process, made use of other, often rhetorical, means than the (reducing) specialist article. While easily understandable publications remain marginal in the specialist discipline, they often represent a central source for literary and cultural studies dealing with scientific topics in the general public (Leane 2007; Gwozdz 2016). Despite the important function that these publications have for the dissemination of physical knowledge to the public, there are neither overview studies of the historical development of this genre, nor systematic discussions of the methods of representing physical knowledge or of the specifie media-related strategies of communicating scientific knowledge that are used in these types of text. A desideratum is to examine based on a rhetoric of science (Bazerman 2000; Prelli 1989), which tropes, genre patterns and narratives are used to describe the research process in its cultural context, and which writing strategies are used to help theories to achieve broad resonance and social or scientific-political relevance.

The volume has three sections focusing on (i) the epistemic functions of narration and metaphor in science, (ii) the transfer of concepts between physics and philosophy of physics to literature and history of ideas, and (iii) the aestheticization and literarization of physics.

Nikola Kompa's paper "Insight by Metaphor – the Epistemic Role of Metaphor in Science" takes as a starting point conceptual metaphor theory and investigates the epistemic functions of metaphors as modes of thought. The question arises, why do some metaphors seem to be more successful than others for epistemic pursuits? Kompa proposes criteria for scientifically successful metaphors and claims that metaphors have heuristic, exploratory or explanatory values in scientific discourse. Epistemic metaphor search is purpose-driven: Kompa reviews Ludwig Fleck's theory of thought style and shows how metaphors can aquire heuristic functions by inducing processes of pattern recognition or by leading to inference drawing processes and guiding research. With reference to Evelyn Fox Keller's investigations, Kompa highlights the exploratory functions of metaphor and she examines Darwin's theory of evolution to discuss the explanatory function of metaphors. Kompa underlines that the understanding of how metaphors operate in scientific discourse depends on epistemic positions and on metaphysical background theories.

Aura Heydenreich's chapters aim at illuminating the epistemic value of narrativity in Einstein's theory of relativity. The paper reconstructs both Einstein's scientific modeling process and its narrative strategies for the development of the theory of special relativity. Besides considering the argumentative and descriptive discourse levels, the paper scrutinizes the epistemic functions of narrative strategies and thereby discusses key issues of a here proposed narratology of science. Which would be basic categories of science narratology? How can concepts be transferred from the classic narratology to the narratology of science in order to explore the epistemic functions of narrativity in science? What is the epistemic function of the writing/telling instance as a narrator, as a principle of form-organization in a scientific treatise? Can one elaborate on techniques of internal and external focalization not only in literary texts, but also in Einstein's thought experiments, which are employed as narrative strategies for the demonstration of the relativity of simultaneity? How can one (re-)define concepts of post-classical narratology like eventfulness, experientiality and tellability when adressing scientific discourses? Heydenreich's second chapter focuses on Einstein's same treatise on the theory of special relativity from a different perspective: it aims at analyzing the semiological foundations of the here proposed process of interformation. The paper thus correlates Einstein's fundamental treatise on the special relativity theory with his metatheoretical paper "Physics and Reality."

Giovanni Vignale states, as a physicist, that it is not in the power of physical science to explain reality "as it is," or as it is "empirically perceptible." Vignale shows that it lies in the tradition of physical investigation to discard a great deal of observable information that is not considered to be relevant in order to grasp the essential picture. Physical sciences can make reality understandable, sometimes predictable, through modeling practices and empirically adequate narratives. Vignale proposes the thesis that physics is a kind of mythopoesis by elaborating on a provocative assertion: Although truth and fiction are generally supposed to be mutually exclusive, Vignale states that the binary opposition between truth and fiction is itself fictitious. Vignale draws here on the epistemology of myth as a cultural practice of shaping and understanding the world. He also shows that the principles of mythopoesis are not unrestrained. On the contrary, both discourses have to respect strong internal constraints, as for example the constraints of mathematical language in physics or those of aesthetic composition, symmetry and consistency in literature.

The next section of the book focuses on problems of concept formation in physics and the search for an adequate scientifical terminology from the perspective of linguistics and physical chemistry.

Winfried Thielmann's paper "Concept Formation in Physics from a Linguist's Perspective" investigates the asymmetries between theoretical innovation and the lack of a correlative lexical innovation in theoretical processes of concept formation in physics. The focus lies on the concepts of the "body" of "speed" and "force." Thielmann analyses the successive transformations to which these concepts were subjected in the physics of Galileo and Newton and how they shaped the later development of modern physics. The starting point for Thielmann's considerations is Konrad Ehlich's model of the gnoseological function of language to represent and communicate knowledge (Ehlich 2007). Thielmann shows exemplarily that there is a large discrepancy between the empirical everyday understanding of the word and the way in which the concept of "force" was mathematically formalized and physically conceptualized. Galileo was the first to propose a form of concept formation based on "idealization" or "abstraction" that allowed deductive conclusions in which one no longer needed to take into account the diversity of individual empirical phenomena. As a result, the differences between natural objects and human artifacts were eliminated for experimental purposes. The abstract concept of the "physical body" symbolizes the extinction of this difference. The result is that artefacts are now used as operational concepts to describe laws of nature. The problem Thielmann points out is that this conceptual development was not accompanied by a terminological language innovation in physics. Although the concept of the body is used in physics as an operational concept, it still connotes much of everyday semantics. In Thielmann's view, this suggests proximity to reality, vividness. Newton built on this concept of the body as an artefact and formed "operational concepts of the second degree," "mass" and "force." However, this decisive conceptual shift, which is not reflected linguistically and terminologically, leads to the fact that in modern physics purely operational concepts are ontologized in an unjustified way. A famous example of this is the controversy surrounding wave-particle dualism.

As a chemist, Jay Labinger examines in his essay the question of the impact of his engagement with literature on his scientific thinking and his work in the natural sciences. Or – to put it another way – what is the significance of language in scientific practice? Labinger's thesis is that scientific language, too, is characterized by the use of metaphor, and semantic ambiguities. The task of natural scientists would not be to purge language of this – in the sense of Francis Bacon or the ideal of the Royal Society –, but rather to consciously handle it virtuosically. Labinger deals with this issue in an exemplary case study on the problem of representation in scientific discourse. Using the example of molecular orbitals in chemistry and physics, Labinger refers to the controversy about the adequacy of representation, whereby formal-mathematical, linguistic, and graphic-visual media are available as modeling options: on the one hand the representation of the valence bond, on the other the representation of the molecular orbital. None of these visual representations are perfect reproductions of all the subtleties of the mathematical formalism. They set different accents in representation depending on which aspects of mathematical formalism need to be emphasized: reactivity or the possibility of localizing or specifying electron density. Labinger compares this process of transfer, in which mathematical precision must be dispensed with in favor of concise visual representation, with the process of literary translation. Labinger shows that the question of adequacy must by no means be answered dogmatically, but depends to a large extent on the context, target and addressee. The awareness of the semantic flexibility of scientific language is extremely important – according to Labinger – for adequate contextualization in the mediation of knowledge content.

The next section of the book deals with transfers of concepts between physics and philosophy of physics to literature and the history of ideas. Kieran Murphy's essay "Induction after Electromagnetism: Faraday, Einstein, Bachelard, and Balzac" is dedicated to Faraday's concept of electromagnetic induction and shows how this concept has shaped not only Einstein's scientific theories, but also literary and philosophical discourses, such as the works of Honoré de Balzac, Edgar Allan Poe and Gaston Bachelard. Against the background of Friedrich Steinle's studies on the history of physics, Murphy points out that Faraday's method for discovering electromagnetic induction was that of exploratory experimentation. Faraday did not use the experiments to verify already conceived theories, but rather employed open-ended epistemic experimental methods and used their results to re-conceptualize existing theories. Finally, Murphy deals with Faraday's induction as an illustration of what Gaston Bachelard described in his historical epistemology as an "epistemological break." For Bachelard, Faraday's theory was one of the prime examples of the demonstration of radical breaks or discontinuities in the development of scientific theories based on "dynamic intuitions" or "cognitive induction."

Arkady Plotnitsky investigates the revisions of the concepts of causality, probability and complementarity in the light of the new epistemological problems posed by quantum theory. Plotnitsky also explores the transformations that these concepts have undergone as a response to Kant's philosophy in the nineteenth century in texts by Friedrich Hölderlin, Heinrich von Kleist and Percy Bysshe Shelley. The question arises, of how these conceptual revisions can possibly be paralleled. One starting point that would be worth considering is that Hume's and Kant's philosophies are part of the epistemic genealogy of both Romantic thinking and the philosophical Copenhagen interpretation of quantum mechanics. Plotnitsky regards Robert Musil's *Man Without Qualities* as the literary field that negotiates these controversial epistemic positions.

Stephan Mühr's paper "The Horizon of the Horizon: On the Physical History of Gadamer's Fusion of Horizons" claims that Gadamer's conception of '*Horizontverschmelzung*' relies on a longstanding tradition of travelling optical concepts between disciplines, that have been successively adopted and readapted as figures of thought across disciplinary boundaries. Mühr traces the transformation history of these optical figures at the interface between physics and hermeneutics from Galileo to Chladenius ("skopos," "point of view," "vantage voint") and to Gadamer ("horizon"). Mühr states that in the seventeenth and eighteenth centuries the new emerging paradigm of empirical sciences that is correlated with the development of new optical technologies also involves a reevaluation of the abilities of human senses and the capability of language to describe the new world revealed through optical technologies. Citing Hans Blumenberg, Mühr states that the correspondences between the new reality revealed through the telescope and the Copernican reconceptualization of the cosmological view of the world was not only a matter of empirical observation. As shown in the special case of Galileo Galilei's *Sidereus nuncius*, in order to establish *evidentia* highly abstract processes of thought where required that had to be equated with persuasive rhetorical demonstrations. In the course of these argumentations, visual and optical concepts acquired epistemic connotations and were slowly transformed – through blending processes – into figures of thought.

Lukas Mairhofer proposes the concept of “Interference as a Methodological Metaphor” for the description of interrelations of different fields of knowledge in interdisciplinary interactions. Mairhofer first gives an overview of the experimental phenomenon of interference in the processes of quantum measurement and contextualizes these historically by relating them to the philosophical discussions between Heisenberg, Bohr and Einstein on the ontological and epistemological implications of these measurements. Heisenberg, Bohr and Einstein often used thought-experiments to expound their arguments. Mairhofer argues that Bertolt Brecht uses thought experiments relying on quantum theoretical concepts and functionalizes these for the aesthetics of epic theater. Mairhofer also discusses the use of the concept of interference in Science and Technology Studies by Karen Barad, and possible parallels between the new proposed concept of interference and Fauconnier’s and Turner’s blending theory.

The third book section focuses the processes of aestheticization and literarization of physical theories, models and concepts. Bernadette Malinowski’s study on “Literary Epistemology: Daniele Del Giudice’s Novel *Atlante occidentale*” follows Lyotard’s proposal to see contemporary science as an enterprise that requires the imperceptible reliance on scientific technologies. But then new questions arise at the nexus between the scientific representation of knowledge and the epistemological conceptualization of reality. The core question here concerns the empirical adequacy of the scientifically created image. Problems arise, as stated and reflected in Del Giudice’s *Atlante occidentale,* on the possibilities of perception, on adequate representations and on interpretations of scientific objects investigated at CERN. Malinowski’s study investigates the epistemological functions of literature by showing an intertwining between two experiments performed by the two protagonists of the novel, which can be read as physical and poetological experiments. The novel reflects on the technological premises and aesthetic practices that mediate the generation of scientific images. Read as such, the novel reveals and negotiates the boundaries and the interconnections between scientific investigations and aesthetic experiences. Malinowski’s study examines the levels of both the narrative discourse as well as the action and analyzes the epistemological functions of literature.

Angela Gencarelli’s study “The ‘Poetic Element’ of Science: Particle Physics and the Fantastic in Irmtraud Morgner’s Novella *The Rope*” discusses the montage techniques of Morgner’s novella, which functionalizes particle physics discourse excerpts and mingles them up with literary textual materials in a blending pocedure that creates an intertwined aesthetics of the phantastic prose. Morgner’s novella undermines Tzvetan Todorov’s conception of the fantastic as a narrative structure by incorporating citations of scientific texts. At the same time, it engages with the problems of perceptibility, representation and interpretation of scientific results that arise in the experimental practices of particle physics due to the fact that particles as such are hardly identifiable by the human eye, except by their tracks in bubble chambers. Gencarelli's investigation focuses on the reconceptualization of the fantastic in the novella, as an imaginary modeling practice for the exploration and investigation of reality. As such the real and the imaginary are not dichotomously isolated from one another but rather engage with one another; they become the interconnected poles of a tense relation of mutual interrogations.

Dirk Vanderbeke's paper critically investigates the techniques of literarization of quantum physics concepts in various discourse types: literary fantasy by J. R. R. Tolkien, so-called quantum fiction by Vana Bonta, Terry Pratchett and Ian Stewart, and didactic and popularizing texts, which rely on fantastic literary techniques to explain physics, such as George Gamov's *The Adventures of Mr Tompkins*. Vanderbeke investigates the imaginative techniques employed for the textual construction of counterintuitive worlds, which may adopt the vocabulary of quantum physics but mostly use it metaphorically. Their function seems to be to suggest incomprehensibility in order to avoid other plausible explanations for the narrative construction of possible worlds. More than that, they often rely on rather sophisticated technologies, but simple mechanisms that do not require quantum physics. In these cases, the texts do not engage with the theoretical, operative concepts of physics and do not exploit their epistemological potential. Vanderbeke contrasts these techniques of narrativization with those in Tom Stoppard's *Arcadia*, Thomas Pynchon's *Gravity's Rainbow* and Umberto Eco's *The Island of the Day Before* and shows how physics concepts can be employed either to create unidirectional closed narratives or, on the other hand, open literary texts with divergent interpretations. Here quantum phenomena are not employed as explanatory models that close the possible modes of interpretation, but rather for their potential for open exploratory questing.

Maximilian Bergengruen's contribution is devoted to the dialogical form of the dramatic genre and here the reference to physics is made on a completely different level. Bergengruen is interested in the contribution of physics as a technique in the context of the practice of baroque theater performances. This is analysed by means of two dramas by Gryphius: *Catharina of Georgia* (1657) and *Carolus Stuardus* (1663). Gryphius' era predates the differentiation of scientific disciplines, so that physico-theological and natural-philosophical contexts play an important role. Bergengruen offers a comparative analysis of how the figure of thought of "the imitation of Christ" is textually configured in the two dramas. At this point, the performative theatrical practice of the time is confronted with a dilemma: Although ghosts and ghost appearances are allowed in drama and staging techniques, they are theologically forbidden. Bergengruen proceeds on the basis of the technical staging instructions given by Gryphius, whereby the appearance of ghosts and visions is legitimized in performance practice. The technical-theatrical implementation of the *deus ex machina* machinery reinterprets Gryphius' ghostly phenomena: they are no longer demonic ghosts (Luther), but divine spirits. In this respect, Bergengruen works on the drama of the baroque era with an interesting connection between the mediation of metaphysical ideas and their theatrical representation through the most sophisticated stage technology of the time. These are supported by optical instruments and baroque illusion techniques, which the theater uses widely. An epoch's theatrical staging of metaphysical ideas thus goes hand in hand with its experimental practices of optics and mechanics, Bergengruen concludes.

Clemens Özelt's analysis offers an interesting insight into the epistemic function of the genre of philosophical dialogue in science in its sociohistorical context. Within the culture of the Weimar Republic, the philosophical dialogue played an important discourse-integrative function between politics, literature and physics. Özelt investigates the historicity of the aesthetic, philosophic and scientific debates of the Weimar Republic and their cultural practices. Their forms of argumentation often resort to the scholarly dialogues of the Renaissance, namely Galileo Galilei's *Dialogue Concerning the Two Chief World Systems, Ptolemaic and Copernican* (1632), as a paradigmatic example of the genre. Since its constitutive characteristic is a change of perspective, which can convey an experience of evidence, it is suited in an exemplary way to the cultural mediation of new worldviews. Inspired by this, Einstein also formulates the controversy with the so-called critics of the general theory of relativity according to the Galilean model in his *Dialogue about Objections to the Theory of Relativity* (1918). Özelt focuses on the transfer of these discoursive forms and their epistemic functions in Brecht's conception of the theater of the scientific age and in Döblin's novel cycle *Amazonas*, and discusses the aesthetic, ethical and socio-political implications associated with it.

Lutz Kasper reflects on another aspect of the interrelations between physics and literature: science education. Can narrative forms and techniques provide acces to the process of physics research and enquiry? Can they enhance the process of reflection on the cultural significance of natural sciences? What about reflection on the epistemic role of language and metaphors in the process of research or in teaching and learning science? What about the semantic reinterpretation of concepts due to different historical contexts? What about reflections on the historical contexts of the development of models and theories, or on different, competing perspectives on the same scientific phenomenon? These goals could be achieved by 'unpacking the stories hidden behind the formal condensations.' The goal would be to increase the metaconceptual awareness of students through reflections on real scientific debates. Kasper gives here an historical example of competing answers proposed by Émilie de Châtelet, Voltaire and Euler on the problem of "The Nature of Light, Heat and Fire" posed by the Paris Academy in 1737.

The physicist and poet Ignatius McGovern, takes up the work of William Rowan Hamilton, the Irish mathematician and poet, whose credo was that his mathematical researches on quaternions is an offspring of the interrelations between geometry, algebra, metaphysics and poetry. Quaternions are a number system introduced by Hamilton in order to extend the class of complex numbers. In the twentieth century it was this mathematics that was introduced by Erwin Schrödinger for the Hamilton formulation of wave mechanics in quantum physics. McGovern reflects on this complex genealogy poetically, in his own collection of sonnets *A Mystic Dream of 4*, which is devoted on the one hand to William Rowan Hamilton and his friend William Wordsworth, and on the other hand to number theory. The collection of poems explores for example the value of "4" as a mathematic and aesthetico-poietic principle for the making of sonnets.

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Part I: **Epistemic Functions of Narration and Metaphor in Science**

Nikola Kompa

Insight by Metaphor – The Epistemic Role of Metaphor in Science

Abstract: My aim in this paper is to investigate the epistemic functions metaphors might perform. According to a traditionally influential idea metaphors have, at best, ornamental value; they are poetic or rhetorical devices, used to please or even sway people. Current research in philosophy, linguistics and psychology shows the need for a refined picture of what purposes metaphors might serve. Expressions are commonly used metaphorically in order to conceptualize abstract and mental phenomena. The expressions thereby employed are often taken from the realm of sense experience; we feel *blue*, or complain about someone being *cold*, and so on. Yet even in the natural sciences metaphors have added epistemic value. They direct our attention to phenomena that we did not hitherto notice, make us think thoughts that we did not think before, etc. More specifically, I will claim that metaphors have heuristic, exploratory and explanatory value. Nonetheless, some metaphors are more successful than others. I will close by advancing various criteria for metaphorical success and failure.

> Metaphor, it seems, is a matter of teaching an old word new tricks.
>
> (Nelson Goodman)

1 What is metaphor?

In this paper[1] I am going to explore the epistemic function of metaphors: how they help us understand phenomena we didn't understand before, how they make us notice things we didn't notice before, etc. While traditionally it has often been claimed that metaphors have, at best, ornamental value, I will claim

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that they perform important epistemic functions. The considerations presented here are premised on the assumption that the epistemic function of metaphors will be most evident in contexts where epistemic goals are being pursued. I will, therefore, be particularly interested in the role metaphors play in scientific discourse. The broader project in the background is an epistemology of language; i.e., an investigation into the ways in which language mediates, directs or constrains our epistemic access to the world.

To begin with, let us look as some fairly uncontroversial, or at least popular, examples. Some of them are distinguished by their honorable pedigree; others are more mundane:
- All the world's a stage.
- Juliet is the sun.
- Sally is a block of ice.
- The ship ploughed the sea.
- My lawyer is a shark.

Metaphors can take different syntactic forms. Yet in all those cases, we have an expression that – in the context of the whole sentence – is somehow displaced, inappropriate, alien. The *displacement*, i.e. the use of a word in a context where it is not at home, seems to be a characteristic feature of metaphors. The idea goes back at least to Aristotle; in the *Poetics*, for example, he spoke of a metaphor as the application (*epiphorá*) of an alien word (*allotrion ónoma*; cf. Aristotle, *Poetics*, Ch. 21, 1457b6–1457b9). And as Andreas Graeser explains, the word is alien in that it is at home in another context from which is has been displaced (cf. Graeser 1996, 44). It is transplanted into foreign soil, one might say. It should come as no surprise, then, that many very apt descriptions of the phenomenon of metaphor are themselves metaphorical. The following quote from Nelson Goodman is a case in point: "Briefly, a metaphor is an affair between a predicate with a past and an object that yields while protesting" (Goodman 1976, 69).

Contrary to received opinion, the displacement does not necessarily wreak semantic havoc. In other words, metaphors don't always come out false if taken literally. Although there is often a category mistake in play, this need not be so. There are so called twice-true metaphors. Think of a mother saying to her little son, who is acting particularly infantile: "You are a baby" (cf. Carston 2002, 351). And there is also no denying the truth of John Donne's famous line (and poem) "No man is an island." Still, we can usually tell a metaphor when we see one, although not necessarily by its falsehood. But they somehow trip up our communicative expectations.[2] Whether they are amenable to consensual interpretation is an entirely different matter, though (cf. Fraser 1993).

In order to better grasp the phenomenon in question it may prove helpful to distinguish metaphor from other tropes (– the discussion of tropes provided here is not meant to be exhaustive, of course). Firstly then, metaphor ought to be distinguished from *idiom*; an example of the latter being *to kick the bucket*. In the case of idioms one may understand all the words in the phrase and the grammar completely, and still be at a loss as to what the whole phrase means. Consequently, idiomatic expressions have to be learned as a whole; there is no compositional route to their meaning. The idiomatic phrase has a conventional meaning that has to be learned in just the same way that the conventional meaning of any other basic linguistic expression has to be learned. That is not to deny that some idioms may have started out as metaphors; there may, therefore, be an etymological route to their meaning. But that is a route not many of us will be comfortable with (or capable of) travelling. Metaphors, on the other hand, don't have to be learned *en bloc*. They ought to be interpretable at first encounter; context and background knowledge commonly play an important role, though.

Secondly, metaphor ought to be distinguished from *metonymy*. Quite often, a speaker uses an expression in order to refer not to its literal referent but to something that is saliently related to the literal referent. Imagine a nurse saying to another:

– The hernia in room 46c got angry when I brought his lunch (cf., e.g., Recanati 2004, 26; Borg 2004, 175; Nunberg 1993, 26; or Nunberg 1996 for further examples).

Presumably, the nurse didn't complain about the hernia itself but the person suffering from it. Yet one may succeed in referring to an entity by using an expression for something only accidentally (but saliently) related to the entity. Nonetheless, there are constraints on which relations can be metonymically exploited. A speaker can felicitously say *I am parked out back*, but not *My car-key is parked out back*, although the key stands in a close relation to the car as well (cf. Nunberg 1996). Yet we commonly use a part for the whole (*pars pro toto*) or vice versa (*totum pro parte*), the raw material for the end product, an author for his/her oeuvre, or the container for the contents. We read George Eliot, for example. Or suppose you overhear someone say:

– They drank a whole bottle.

2 Whether metaphor always involves a violation of one of the Gricean maxims (Grice 1989) is a controversial issue; cf., e.g., Gibbs 1993.

It is not too bold a guess that they did not drink the bottle, but its contents. Metonymy is a means of referring. The speaker tries to refer to an entity by using an expression that denotes something saliently related to the thing that, ultimately, she wants to talk about. Consequently, the conditions for success are easily specified: Metonymy is successful to the extent that the speaker manages to refer to the object to which she intends to refer. The conditions for success or failure of metaphor are much harder to specify (if there are any; Davidson famously claimed that "there are no unsuccessful metaphors, just as there are no unfunny jokes." Davidson 1978, 31).

Metaphor ought to be distinguished, thirdly, from *hyperbole*. *He is a saint* may be slightly exaggerated; yet *He is an angel* is, for all we know, simply false. Hyperbolic utterances are false as things stand; but they could have been true. A metaphorical utterance, as we have seen before, need not be false. But if it is false then it could not even have been true, given the way the world is. Juliet could not have been the sun; nor an angel, for that matter.

Fourthly, metaphor is distinct from *irony*, although a metaphor can be used to make an ironic utterance. An ironic utterance is always false (or at least believed to be false by the speaker) when taken literally. But while in metaphor there is a tension between the words within the sentence – due to the displacement discussed above – in irony there is a tension between the proposition expressed by the ironic utterance and the beliefs of the speaker. That is also how we recognize irony in the first place. We realize that the speaker could not have meant what she said, given what we take her to believe.

Fifthly, metaphor ought to be distinguished from *simile*. A simile involves a comparison, as in "He is brave as a lion" or "He is like a lion – in that he is brave." These are explicit comparisons in that the respect in which the two entities are to be compared is made explicit. Yet there are also implicit comparisons ("He is like a lion"), where the point of comparison is left unsaid. Implicit comparisons are almost always literally true, as anything is like anything else in some respect (Goodman 1972); metaphors are mostly false. Explicit comparisons may be literal: "He is like her former husband in that he is also a novelist." They may, therefore, be literally true. But (explicit as well as implicit) comparisons may also be metaphorical: "Sally is like a block of ice; just as cold" (cf. Ortony 1993, 344–345). The latter is a metaphorical comparison in that the property of being cold can be attributed to Sally only metaphorically (at least if meant as a statement about her emotional state, not her body temperature). Conversely, the property of being emotionally unresponsive is not a property of blocks of ice either. Even the lion-utterance given above may be metaphorical, as the property of being brave cannot, presumably, be attributed to lions in a non-metaphorical manner. Still, as John Searle has pointed out: "though similarity often plays a role in the *comprehension of* metaphor, the metaphorical assertion is not necessarily an assertion of similarity" (Searle 1993, 91–92; cf. also Ortony 1993). And Arthur Koestler, in paralleling three domains of creativity – humor, discovery, and art – claims that "[t]he logical pattern of the creative process is the same in all three cases; it consists in the discovery of hidden similarities" (Koestler 1969, 27).

So now it seems that in order to interpret the simile "Sally is like a block of ice," one has to interpret the metaphor "Sally is cold" first. Interpreting the metaphor, in turn, requires that a comparison be made (between Sally and cold objects, for instance). But then, what form does the *comparison* required in interpreting metaphors take? One might venture to guess that it is a form of analogical reasoning. Metaphors make us notice structural similarities, it seems.

This brings us to the question of whether metaphor ought to be distinguished from *analogy*. If by analogy we simply mean "a comparison between two objects, or systems of objects, that highlight respects in which they are thought to be similar" (Bartha 2013, 1), then not much progress has been made yet. It may be more helpful, therefore, to think of analogy as something like an isomorphism, a structure-preserving mapping between two domains (a is related to b just as c is related to d; in Greek, *analogía* means proportion), for metaphors may well turn out to be (or at least be based on) analogies in that sense of the term. We will come back to that below. As Guy Deutscher points out:

> The cognitive mechanism that allows us to draw links between different domains is analogy […] But while analogy is what allows us to think in metaphors in the first place, what lures the stream of metaphors down towards abstraction is nothing other than our need to extend our range of expression. (Deutscher 2005, 128–129)

Another distinction that is difficult to draw is that between metaphor and *polysemy*. Polysemy is a form of ambiguity, understood in a broad sense as "variation in the construal of a word on different occasions of use" (Croft and Cruse 2004, 109). Many expressions allow for slightly different interpretations relative to different contexts of use. And there are as many different uses to which we may put the words of our language, as there are purposes we might pursue in the world (cf. Moravscik 1998).[3] Consequently, we interpret people's utterances in light of common purposes and concerns, and against the background of a shared system of knowledge (cf. Searle 1980, 226–227). The verb *climb* provides

3 Josef Stern developed a semantic account of metaphor – along the lines sketched by David Kaplan (1989) – in which he tries to model metaphors on the case of indexicals and demonstratives; cf. Stern 2000 and 2008.

an example (but almost any other verb, adjective or preposition would do just as well):

- Peter climbed a ladder.
- The plane climbed to 30,000 feet.
- The temperature climbed to 40 °C.
- The price of petrol climbed daily.
- Mavis climbed down the tree.
- Brian climbed into his clothes. (Aitchison 2003, 60; cf. also Carston 2002; Keller and Kirschbaum 2003)

Some of those uses seem slightly figurative. Metaphor (and metonymy as well) is a driving force behind language change, as when we encounter a new situation we tend to conceptualize it by means of familiar vocabulary, even if in so doing the *old meaning* has to be stretched in order for the word to become applicable to the new situation. Some of these uses catch on; as time goes by, the metaphorical use may be lexicalized, issuing in polysemy. Yet lexicalization is a gradual process; the entry in the lexicon is a metaphor's obituary, it has been said.

Consequently, the notion of literal meaning is hard to pin down. Relevance theorists even defend a "continuity view, on which there is no clear cut-off point between 'literal' utterances, approximations, hyperboles, and metaphors, and they are all interpreted in the same way" (Wilson and Carston 2006, 406; cf. also Sperber and Wilson 2008). In any case, the literal meaning cannot be the term's original, i.e., the etymologically prior meaning, as that is something most speakers (unless they are devoted etymologists) are not aware of (cf. Kurz 2009, 12). It might be the meaning that comes to mind first when one hears the expression; but that, too, may occasionally be the metaphorical meaning: just think of bugs and viruses. Also, it may be what we find fixed in the lexicon; but again, many metaphorical meanings have made it into the lexicon; just look up the entry for *hot*, for example. In any case, one ought to distinguish a *diachronic* sense of metaphor from a *synchronic* sense. The former captures the fact that many expressions we use today in a non-figurative manner were metaphors at some point in their history. The structure of language is "a reef of dead metaphors" (Deutscher 2005, 118). Sometimes, the sense of the metaphorical has been lost entirely; the expressions are *stone dead metaphors*. Yet some expressions still have a metaphorical ring to them, as is, arguably, the case in *feeling blue*, for example. But note that

> even 'dead' metaphors that have their own dictionary entry are often not stone dead; they wear their metaphorical histories on their sleeves [...]. [O]rdinary speech is *shot through with* expressions that are metaphorical to a degree even if they are coughing up blood. (Lycan 2013, 7)

Synchronic metaphors, on the other hand, are alive and kicking. They still come with the feeling of *displacement* discussed above. But then, a metaphor may be alive for one speaker and dead for another, or productively *resurrected* in a particular context (for a more dynamic view and a critique of the dead/alive dichotomy cf. Müller 2008). Moreover, whether something is intended as a metaphor also depends on the speaker's epistemic outlook and on his (meta)physical background assumptions (we will come back to this below).

2 A predicament

What purpose do metaphors fulfill? They require some interpretative extra-effort; that has to be justified. According to a traditionally influential idea metaphors have ornamental value at best. Their *raison d'etre* is directly proportional to the aesthetic pleasure they induce. And indeed, there are exquisite, incredibly poetic metaphors. Just recall those famous lines:

> What piece of work is man, how noble in reason, how infinite in faculties, in form and moving how express and admirable, in action how like an angel, in apprehension how like a god: the beauty of the world, the paragon of animals – and yet, to me, what is this quintessence of dust? (Shakespeare, *Hamlet*, Act II, Scene II)

Some metaphors boldly demand an interpretation; some act more coyly. Metaphors are meant to move, to inspire, to enkindle. But they achieve even more than that. Sometimes, they help us out of a conceptual predicament – as Hans Blumenberg (1998) once pointed out. He labels metaphors that accomplish such a feat *absolute metaphors*; they promise us epistemic insights that we could not get otherwise. It is therefore worth our while to inquire into the predicaments they help us out of in a little more detail.

How do we get ourselves into the kind of a predicament that metaphors have to help us out of? Probably the most popular approach to metaphors in recent debates has been addressing exactly that question (for an overview, cf. Hills 2012; for a typology of different theories of metaphor, cf. Rolf 2005). In 1980, George Lakoff and Mark Johnson began to promote the *conceptual theory of metaphor*. They claimed that we find ourselves in a conceptual predicament when trying to talk about abstract and mental phenomena. Metaphors have come to the rescue. More specifically, Lakoff claims that "everyday abstract concepts like time, states, change, causation, and purpose turn out to be metaphorical" (Lakoff 1993, 203). Johnson even claims that "[*a*]*ll* theories are based on metaphors because all our abstract concepts are metaphorically defined" (Johnson 2008, 51). Metaphorical expressions are employed in order to conceptualize abstract and mental phenomena, often borrowing from the concrete realm of sense experience in order to do so. As Deutscher emphasizes: “The mind cannot just manufacture words for abstract concepts out of thin air – all it can do is adapt what is already available” (Deutscher 2005, 127).

That is why we feel *blue*, complain about her being *cold, hard* or *thin-skinned*. And we thereby explain human behavior. We say of a friend that she is feeling up, that her spirits rose, or that, sadly, she sank into a coma; thus employing orientational metaphors. We conceptualize these mental phenomena by giving them a spatial orientation (cf. Lakoff and Johnson 1980, Ch. 4). Abstract phenomena are conceptualized by means of metaphors, too. Theories or arguments are treated linguistically as if they were buildings; they often need more support, or lack a foundation, are in danger of collapsing, etc. (cf. also Keller and Kirschbaum 2003, 36 and 99). Food terms provide another graphic illustration as they are used to describe ideas, emotions, etc.:

> People speak of troubles *brewing*, anger *simmering*, resentment *boiling*, fanaticism *fermenting*, employees *seething* (literally ‘boiling’) with discontent. People *chew* over new suggestions and *digest* new information [...]. (Deutscher 2005, 122)

But then, the *conceptual theory of metaphor* is not so much a theory about linguistic usage; it is primarily about thought. As Lakoff puts it, “metaphor is not just a matter of language, but of thought and reason. The language is secondary” (Lakoff 1993, 208). He adds that he became convinced that “metaphor was not a figure of speech but a mode of thought ... ” (Lakoff 1993, 210).

Those modes of thought are called *conceptual metaphors*. They provide the basis for producing and interpreting metaphorical utterances. We understand metaphorical utterances by availing ourselves of conceptual metaphors. Conceptual metaphors, in turn, are “mappings across conceptual domains” (Lakoff 1993, 203). More specifically, they are mappings from a source domain to a target domain. The former is commonly less abstract; the latter is more abstract; it is what we are trying to better understand. Max Black, in a classic paper from 1954, emphasized that a metaphorical statement has a primary and a secondary subject; the secondary subject is to be regarded as a system; and metaphors work by projecting upon the primary subject a *system of associated commonplaces* (cf. Black 1954, 287; 1993, 27–28).

Here is an example to illustrate the basic idea of the conceptual theory of metaphor. Take the domain of love and the domain of journeys. Elements in the journey-domain can be mapped onto elements in the love-domain. This is what we get:

LOVE IS A JOURNEY

Source: *journey*		Target: *love*
the travelers	⇒	the lovers
the vehicle	⇒	the love relationship itself
the journey	⇒	events in the relationship
the distance covered	⇒	the progress made
the obstacles encountered	⇒	the difficulties experienced
decisions about the way to go	⇒	choices about what to do
the destination of the journey	⇒	the goal(s) of the relationship (Kövecses 2010, 9; emphasis in original)

This mapping is what enables our understanding of metaphorical utterances. If your partner says: *We are stuck* or *Let us not get side-tracked* or *Let's go separate ways from here on*, s/he is thereby exploiting the love-is-a-journey mapping. And the point generalizes:

> It is a system of metaphor that structures our everyday conceptual system, including most abstract concepts, and that lies behind much of everyday language. [...] as soon as one gets away from concrete physical experience and starts talking about abstractions or emotions, metaphorical understanding is the norm. (Lakoff 1993, 204–205)

How *exactly* is "metaphorical understanding" achieved? It is achieved not just by mapping elements from one domain onto elements in the other domain, but also by mapping knowledge about journeys, for example, onto knowledge about love. We try to understand the domain of love in terms of, and by recourse to, what we know about the domain of journeys (cf. Lakoff 1993, 206 –207; for a more psycholinguistic approach cf., e.g., Gibbs and Matlock 2008). In doing so, we use patterns of inferences about journeys to reason about love. We know certain things about journeys. And we can evoke that knowledge in order to better understand what love is. We know, for example, that one encounters obstacles while travelling, that one sometimes has to make detours, may get lost, end up somewhere one did not want to go, etc. Analogously, we may come to realize that in a relationship, one may also encounter difficulties, get stuck, etc. And we may productively elaborate on the metaphor. For example, one may try to engage a psychotherapist as a kind of tour guide. The task would be, therefore, to find and elaborate on structural similarities between the two domains (LOVE, JOURNEY), similarities that justify drawing analogous inferences.

Of course, there are many ways to conceptualize the domain LOVE. But all those metaphors are "significantly constitutive of our concept of love" (Lakoff and Johnson 1999, 71–72). Moreover, certain conceptual metaphors seem to be widely shared across cultures; some may even be universal.[4] How is that to be explained? Lakoff and Johnson are happy to volunteer an explanation. They claim that all complex metaphors are made up of what they call primary metaphors:

> For example, for an infant, the subjective experience of affection is typically correlated with the sensory experience of warmth, the warmth of being held. During the period of conflation, associations are automatically built up between two domains. Later, during a period of *differentiation*, children are able to separate out the domains, but the cross-domain associations persist. These persisting associations are the mappings of conceptual metaphor that will lead the same infant, later in life, to speak of 'a *warm* smile' [...].
> (Lakoff and Johnson 1999, 46)

The resulting primary metaphor will be "AFFECTION IS WARMTH". It can be succinctly characterized thus:

> Subjective Judgement: Affection
> Sensorimotor Domain: Temperature
> Example: 'They greeted me *warmly*.'
> Primary Experience: Feeling warm while being held affectionately (Lakoff and Johnson 1999, 50)

The metaphor is *experientially grounded*. By being held affectionately as children we have experienced affection and warmth occurring together. These associations and correlations explain why we understand those temperature metaphors we often employ in order to talk about emotions. And metaphorical thought, just as with thought in general, is *embodied*:

> Thought is embodied, that is, the structures used to put together our conceptual system grow out of bodily experience and make sense in terms of it; moreover, the core of our conceptual system is directly grounded in perception, body movement, and experience of a physical and social character. (Lakoff 1987, xiv)

Primary metaphors are the building blocks of complex metaphors. The "LOVE IS A JOURNEY" metaphor, for example, is built up of the primary metaphors "PURPOSES ARE DESTINATIONS;" "DIFFICULTIES ARE IMPEDIMENTS TO MOTION;" "A RELATIONSHIP IS A CONTAINER" and "INTIMACY IS CLOSENESS" (cf. Lakoff 2008, 26–27). Whether all complex metaphors can indeed be decomposed into primary metaphors may be a moot question; some may be reluctant to embark on the full empiricist program.

Let us take stock, then. Conceptual metaphors are supposed to map more concrete source domains onto more abstract or subjective target domains. They are embodied and experientially grounded in associations and correlations

4 Still, culture may often act as a filter, too; cf. Yu 2008.

experienced in early childhood. They help us to conceptualize and thereby understand the target domain by exploiting what we know about the source domain in order to reason and talk about the former; we come to use patterns of inference from one domain in the other domain. Appealing as it may seem, the conceptual theory nonetheless encounters various problems and objections.

3 Toward an epistemology of metaphor

Firstly, the mapping is not necessarily a mapping from concrete onto abstract; some of the source domains Lakoff and Johnson invoke are rather abstract. Take two of their favorite metaphors: "TIME IS MOTION" (Lakoff and Johnson 1999, 52) and "THE MIND IS AN ENTITY" (Lakoff and Johnson 1980, 27). Neither "MOTION" nor "ENTITY" seem to be particularly concrete domains. Surely, there are concrete ways of moving through space, but "MOTION" is a highly abstract conceptual domain. A conceptual domain seems to be an abstract entity if ever there was one. Even "JOURNEY" is a rather abstract domain, notwithstanding the fact that the kinds of activities one engages in when undertaking a journey are, presumably, concrete in the sense of being observable, physically manifested activities. So maybe it is not the conceptual domain that is supposed to be abstract or concrete but the thing denoted by the domain. But then, what exactly does "JOURNEY" denote, or "ENTITY?"

Secondly, the claim that conceptual metaphors help us understand abstract concepts, and are *significantly constitutive* of them, is not without its problems. Abstract concepts have to be learned, and not in the way the theory would predict. "What is love?" the little boy asks. "A journey," his father replies. That is no help. The boy is definitely not meant to think that love *is* a journey. He has to separate (and separately grasp) the two concepts in order then to be able to map them onto each other, to perceive the structural similarities and exploit them in reasoning about love, etc. Only distinct domains can be mapped onto each other fruitfully. That is not to deny that in acquiring the concept of love the boy will come across metaphorical expressions; but he has to learn other things, too: that if two people are in love they like each other a lot, and like to see each other often, for example; and similarly for other abstract concepts. The defining properties, therefore, need to be learned separately and independently of any metaphorical mapping. In general, domain knowledge has to precede metaphorical mapping. Ellen Winner and Howard Gardner, for example, argue that children's ability to interpret metaphor is constrained *only* by their domain knowledge: "That is, there are no inherent limits on the kinds of similarities children can perceive. All that is necessary is sufficient knowledge of the domains involved" (Winner and Gardner 1993, 427). Also, it seems that we prefer to exploit *contingent* properties, not *defining* properties, metaphorically. Take the metaphor *Man is a wolf*. The defining properties of wolves and men, that they belong to the family of the *Canidae* and the species of *homo sapiens sapiens* respectively, do not seem to be particularly relevant to its interpretation.[5]

This relates to a third problem. One might wonder whether the target domain is structured by the mapping, or whether it already has structure independently of the mapping. On the one hand, Lakoff claims that abstract concepts are significantly constituted by conceptual metaphors. (If conceptual metaphors were just nice but dispensable means of framing abstract ideas, that claim would be a gross exaggeration – nothing Lakoff could ever be guilty of, of course.) Zoltán Kövecses, who is basically in the same camp, even maintains – with respect to the LOVE-JOURNEY mapping – that the concept of love is *created* by the mapping:

> The domain of love did not have these elements before it was structured by the domain of journey. It was the application of the journey domain to the love domain that provided the concept of love with its particular structure or set of elements. In a way, it was the concept of journey that 'created' the concept of love. (Kövecses 2010, 9)

Yet Lakoff also endorses what he dubs *The Invariance Principle:*

> Metaphorical mappings preserve the cognitive topology (that is, the image-schema structure) of the source domain, in a way consistent with the inherent structure of the target domain. (Lakoff 1993, 215)

Mappings that preserve structure are usually called isomorphisms; metaphors would, therefore, turn out to be isomorphisms. Image-schemas, in turn, are recurrent multi-modal patterns of experience (Johnson 1987). The container image-schema, for example, has a *gestalt* structure: an inside, a boundary and an outside (cf. Lakoff and Johnson 1999, 32). And, as Lakoff points out, the "inherent target domain structure limits the possibilities for mappings" (Lakoff 1993, 216). By exploiting the mapping ACTIONS ARE TRANSFERS, for example, "in which actions are conceptualized as objects transferred from one agent to a patient" (Lakoff 1993, 216), we can speak of someone giving someone else a kick. But then, we know that if we give someone a kick, he will not have it

5 An interesting proposal is made by Sam Glucksberg and Boaz Keysar. They construe metaphors as class-inclusion statements; in saying something like "My surgeon was a butcher" the speaker "alludes to a propotypical or ideal exemplar of the category of bungling and harmful workers, 'butchers,' and simultaneously uses that prototype's name to name the category" (Glucksberg and Keysar 1993, 411).

afterwards because a kick is an action and an action ceases to exist after occurrence (Lakoff 1993, 216). Only certain source-domain inferences carry over into the target domain. (And image-schematic structure has to be preserved.) But how do we figure out what carries over and what has to be preserved in a particular case? Consider again the above example. There seems to be a tension between the mapping and the structure of the target domain (or our knowledge thereof). The mapping asks us to conceive of actions as objects that are transferred from one person to another. The structure forbids us to conceive of actions as objects (as the action *ceases to exists after occurrence*, something objects don't do). Consequently, there is more structure in the target domain (than just image-schematic structure, as that has to be preserved), structure that might cancel certain inferences that will otherwise carry over from source into target domain.

But then it seems that we ought to be able to perceive the structure of the target domain independently of the mapping. What do we gain by mapping them onto each other, then? Conceptual metaphors could no longer be said to be constitutive of abstract concepts, given that these are already structured. Also, only certain mappings ought to be possible or at least fruitful, namely those that respect preexisting structure. (Note that this could help explain why certain mappings seem to be more productive than others. The productive ones are those that preserve preexisting structures.) In short: If the abstract target domain concept isn't sufficiently structured already (before the mapping), then the concept isn't grasped at all and it is not explainable why only certain inferences carry over from source into target domain (any mapping would be arbitrary). If the target domain is already structured, then the mapping will not be constitutive any more. This brings us to another closely related worry one might have.

Fourthly, the productivity of many metaphors – the way they can be elaborated on – seems to be their recipe for success; yet it masks the fact that some metaphors may be more successful than others. We perceive certain structural similarities between two domains, i.e., we see certain things as being similar in certain respects. But then, "[a]nything is in some way like anything else" (Goodman 1972, 440). Consequently, any metaphor will be interpretable. Suppose I say "The University is a playground." You will come up with an interpretation: One can play with other kids, make friends for life, learn to build sandcastles; and sometimes one has to play alone, etc. But if I had said instead "The University is a gym" then you would equally well have managed to interpret the utterance. Even if I had said "The University is a penguin," you would have thought of something ("they make huge sacrifices in bringing up their children" maybe?). Still, one might think that certain ways of thinking about universities are more productive, more insightful than others; they make us notice things that are worth noting. But, again, as far as Lakoff's theory goes, any mapping may be just as good as any other. Even the Invariance Principle leaves ample room for maneuver; in any metaphor, some structure is preserved, something's got to give. The theory doesn't offer much by way of criteria that a mapping has to meet in order to be successful – in light of certain goals or purposes.

For all that, the basic insight provided by the conceptual theory of metaphor strikes me as worth preserving. Metaphors, by highlighting structural similarities between two domains, may foster understanding of the hitherto less well-understood of the two domains. They convey structural information, but they do so by semantic means; they thereby perform important epistemic functions, or so I will argue (as others have done before me, of course). What is missing from the conceptual theory is a better understanding of why we choose certain metaphors over others, how exactly they help us explore new territory and guide research, and whether and in what way certain metaphors are epistemically more successful than others. In short, what is missing is a better grasp of metaphors' epistemic achievements.

So in the remainder of the paper, I will try to take a few tottering steps toward an epistemology of metaphor. In particular, I will try to illustrate their *heuristic*, *exploratory* and *explanatory* value. It will become evident in contexts where metaphors are employed in pursuit of epistemic goals. Consequently, we will look at some examples of metaphorical speech in scientific discourse. Given the discussion above, we ought to expect the following to hold in (at least some of) those cases where metaphors have an epistemic function to perform:

– The mapping is not necessarily from concrete to abstract but rather from a well-understood domain to a less well-understood domain.[6]
– The choice of metaphors is highly purpose-driven and constrained by what we already know; there are particular problems that need to be solved or phenomena that need to be explained. As Ludwik Fleck put it: "What is already known influences the particular method of cognition; and cognition, in turn, enlarges, renews, and gives fresh meaning to what is already known" (Fleck 1979, 38). A certain preliminary understanding of the target domain is achieved as we already have some, albeit inchoate, grasp of the problems or phenomena that we are trying to solve or explain.
– Moreover, certain structural similarities and inference patterns between the two domains will be preserved, others will be ignored; this is, again, a highly purpose-driven enterprise (this is a topic Turner and Fauconnier deal

6 That is not to deny that in other genres, poetry, for example, the mapping might be governed by different mechanisms.

with extensively from the perspective of conceptual blending theory (cf, e.g. Fauconnier and Turner 2002).
– Also, as Dedre Genter and Brian Bowdle point out, "people implicitly prefer analogies that share large, deep relational structures (all else being equal) [...]; and the same is true for metaphors. A major determinant of aptness in metaphor is the presence of a substantial relational match" (Gentner and Bowdle 2008, 110). And Mary Hesse stresses the fact that metaphors (in science at least) "are meant to be internally tightly knit by logical and causal interrelations" (Hesse 1970, 169).

Moreover, if metaphors fulfill epistemic purposes, we ought to expect the following two corollaries to be substantiated by closer investigation, too.

As a *first corollary*, it ought to make a difference which metaphors we employ in conceptualizing a particular domain. This ought to hold good, of course, for ordinary metaphors and scientific metaphors alike. It ought to make a difference whether one thinks of a love relationship as an excursion, an expedition or a pilgrimage. And it ought to make a difference whether one considers universities to be playgrounds, gyms or self-service restaurants; whether one takes animals to be machines or our relatives; whether we see the world as an ordered whole, with all things sitting in their predestined place or as the product of some cosmic accident; etc. Metaphors "provide a perspective from which to gain an understanding of that which is metaphorically portrayed," as Eva Feder Kittay puts it (Kittay 1987, 13) Again, one would expect this to be so in the scientific case as well.

As a *second corollary*, one would expect there to be failed metaphors; metaphors that might lead us astray or unproductively constrain our thinking. And one would expect there to be less successful metaphors, or at least metaphors that have been replaced by new, more productive ones. Consequently, it ought to be possible to come up with some criteria for metaphorical success.

Let us now take a closer look at the roles metaphors play in scientific discourse and the kinds of metaphors employed there (cf. Vanderbeke 2004, 73–91). Let us see whether we will find these corollaries attested to, and whether we will be able to track down a couple of criteria for metaphorical success.

4 Metaphor in science

Firstly, there may be what Richard Boyd calls *exegetical or pedagogical metaphors*, which "play a role in teaching or explication of theories which already admit of entirely adequate nonmetaphorical (or, at any rate, less metaphorical) formulations" (Boyd 1993, 485).

An example of what Boyd has in mind here is the metaphorical description of atoms as small-scale solar systems. The metaphor is amenable to complete, nonmetaphorical explication. It serves pedagogical purposes only (yet cf. Vanderbeke 2004, 78). But there are also what he calls *theory-constitutive metaphors* which "constitute, at least for a time, an irreplaceable part of the linguistic machinery of a scientific theory" (Boyd 1993, 486). In some cases they may, in other cases they may not, "resist complete explication of the relevant respects of similarity and analogy; such explication is often an eventual consequence of successful scientific research" (Boyd 1993, 482). Those metaphors are "invitations to future research" (Boyd 1993, 489). They may even be compared to models in science (Black 1962). And Mary Hesse suggests thinking of theoretical explanation as "metaphorical redescription of the domain of the explanandum" (Hesse 1970, 171; cf. also Ricoeur 1975).

Consider the following example. In 1935, the polish immunologist and philosopher of science Ludwik Fleck (born in Lwow, in 1896) published a book entitled *Genesis and Development of a Scientific Fact* (1979) [*Entstehung und Entwicklung einer wissenschaftlichen Tatsache* (1935)], which anticipates some of Thomas Kuhn's (1962) central ideas. Citing extensively from a then-popular textbook on immunology (by Dr. Julius Citron) Fleck makes plausible the claim that the underlying picture of infectious diseases rests on a particular metaphor:

> The causative agent produces a bad effect (*attack*). The organism responds with a reaction (*defence*). This results in a conflict, which is taken to be the essence of disease. The whole of immunology is permeated with such primitive images of war. (Fleck 1979, 59)

The notion of an infectious disease has been understood, Fleck claims, by means of a warfare metaphor; in terms of attack and defense, that is. The metaphor seems to be highly productive. One might be on the lookout for hostile invaders and their strategies, but also for one's own troops, barriers and defense mechanisms. Metaphors make us ask questions, search for particular things. Again, we exploit our knowledge about warfare (the source domain) in order to conceptualize and thereby to come to better understand the notion of an infectious disease (the target domain). The more we know about the source domain, the more we are able to productively elaborate on the metaphor.

The subtitle of Fleck's book is *Einführung in die Lehre vom Denkstil und Denkkollektiv,* i.e., *Introduction to the doctrine of thought style and thought collective* (my translation; the subtitle somehow got lost in the English translation). A thought collective is "a community of persons mutually exchanging ideas or maintaining intellectual interactions" (Fleck 1979, 39); every individual may belong to several thought collectives at once (Fleck 1979, 45). To the extent that the persons are also united by being embedded in the historical development of a particular field of thought, by a certain stock of knowledge, by a particular intellectual culture, etc., they partake in what Fleck calls a *thought style*. The notion of a thought style slightly resembles Kuhn's notion of a *paradigm* (cf. the foreword by Kuhn to the English edition: Fleck 1979, vii –xi).[7] A particular thought style comprises the set of assumptions taken for granted by its members. And it may be further characterized by the metaphors prevailing in it, as the thought style determines what is conceivable for members of the thought collective, what *gestalts* they are prepared to perceive, what they take to be in need of explanation, etc.:

> Direct perception of form [*Gestaltsehen*] requires being experienced in the relevant field of thought. The ability directly to perceive meaning, form, and self-contained unity is acquired only after much experience, perhaps with preliminary training. At the same time, of course, we lose the ability to see something that contradicts the form. But it is just this readiness for directed perception that is the main constituent of thought style. (Fleck 1979, 92)

By being initiated into a particular thought style, its participants will come to perceive certain structures as gestalts; they will acquire the ability to perceive different situations as being similar, and they will learn to classify certain perceptions as being perceptions of a certain form. But such initiation also makes participants prone to think only certain thoughts (and similar ones at that); a thought style constrains thought:

> Neither the particular coloration of concepts nor this or that way of relating them constitutes a thought style. It is a definite constraint on thought, and even more; it is the entirety of intellectual preparedness or readiness for one particular way of seeing and acting and no other. (Fleck 1979, 64)

In order to break free, alternative metaphors are required that make certain thoughts thinkable that weren't thinkable before. Fleck criticizes the warfare metaphor, therefore, and suggests an alternative metaphor that he takes to be more profitable:

> It is very doubtful whether an invasion in the old sense is possible, involving as it does an interference by completely foreign organisms in natural conditions. A completely foreign organism could find no receptors capable of reaction and thus could not generate a biological process. It is therefore better to speak of a complicated *revolution within* the complex life unit than of an invasion of it. (Fleck 1979, 61; emphasis by NK)

7 Fleck also stressed the social character of cognition: "Cognition is the most socially-conditioned activity of man, and knowledge is the paramount social creation" (Fleck 1979, 42).

Those sketchy remarks on the history of science already make evident a certain *heuristic function* metaphors might perform. They highlight certain aspects of a phenomenon – make them noticeable. They make us perceive certain gestalts, make us recognize certain patterns, make us liable to draw certain inferences and ask certain questions but not others. They may thereby guide research. Which metaphors are chosen in order to talk about (or frame) a particular object is driven by what we know and what we try to explain. Yet they may also constrain thinking. By highlighting certain aspects, they are downplaying others; they make us see certain aspects of a phenomenon but blind us to others. Here we find the *first* and *the second corollary* substantiated.

New metaphors are called for to help us explore new territory, make us discern patterns and *gestalts* we haven't discerned before. Scientific language has to constantly adapt to a "continually expanding world, and metaphor is one of the chief means by which this is accomplished" (Hesse 1970, 176–177). The *exploratory function* of metaphor is also emphasized by Evelyn Fox Keller:

> [S]cientific research is typically directed at the elucidation of entities and processes about which no clear understanding exists, and to proceed, scientists must find a way of talking about what they do not know – about that which they as yet have only glimpses, guesses, speculations. To make sense of their day-to-day efforts, they need to invent words, expressions, forms of speech that can indicate or point to phenomena for which they have no literal descriptors. [...] [M]etaphoric utterances can be scientifically productive just because they open up new perspectives on phenomena that are still obscure and ill-defined [...].
> (Fox Keller 2002, 118–119)

Her favorite example is the notion of a gene that was initially formed by opposing metaphors. As Fox Keller explains, at the beginning of the twentieth century two disciplines emerged: genetics and embryology, the one studying the transmission of traits from one generation to the next, the other one studying the development of an organism from fertilized egg to mature organism. When around 1900 Gregor Mendel's laws were rediscovered, Hugo de Vries (1848–1935) had already been struggling for years to understand what he called *pangenes*. He strove to find the most basic units of biology, analogous to the atoms and molecules in physics and chemistry, in order to explain the combination and inheritance of traits in organisms. But then,

> [o]n the other hand, if such a unit were, as he put it, to 'impress its character upon the cell' (p. 194), to either 'represent' the properties of an adult organism or cause their coming into being, it must obviously be something larger and more complex than a chemical

> molecule. 'These minute granules,' he concluded, 'are more correctly compared with the smallest known organisms' (p. 4).[8] (Fox Keller 2002, 126)

To find *biological atoms* in order to explain the intergenerational transmission of hereditary traits was one *desideratum*; genes ought to be those *biological atoms*. But genes ought also to be the *smallest organism* in order to explain ontogenesis. One might, therefore, see two metaphors at work here, one being "GENES ARE ATOMS," the other being "GENES ARE ORGANISMS" (cf. Fox Keller 2009, 36; emphasis in original). As Fox Keller stresses, the notion of a gene could become so productive exactly because it lacked a precise definition; because it pulled researchers in opposite directions (Fleck speaks of proto- or pre-ideas; cf. Fleck 1979, 23). Metaphors may rescue us from an epistemic-conceptual predicament by helping us grope our way into not-yet-understood territory. Yet, importantly, they may be modified in light of new insights or even replaced by more productive metaphors if such become available (cf. Vanderbeke 2004, 77–87).

5 Success and failure

Biology is a particularly rich source of metaphors (cf. Brandt 2004); just think of the tree-of-life metaphor (cf., e.g., Mindell 2013), or the selfish gene (Dawkins 1976). Yet one of the most successful biological metaphor is, presumably, the one grounding Charles Darwin's idea of natural selection. Of course, nature does not literally select anything; nature is not in the habit of doing much anyway. How did Darwin hit upon the idea?

> Almost from the beginning of his career as a transmutationist, Darwin looked to the work of animal and plant breeders for clues to the mysterious process underlying reproduction, and as is well known, he founded the argument of the *Origin* upon an extended analogy between selection by man and selection by nature. From their factual grounding to particular innovations in theory, from their underlying metaphysics to their argumentative structure, the *Origin* and its offshoots reflect in a variety of ways Darwin's immersion in the world of the Victorian plant and animal breeders. (Secord 1985, 519)

The conceptual metaphor underlying Darwin's conception of natural selection might, therefore, be put thus: *nature is a breeder*. Nature selects just in the way that breeders select. The idea has *explanatory* power. The mechanism of natural selection is thought to explain evolution (otherwise than in Lamarck's theory,

8 Fox-Keller is quoting from Vries 1910.

for example). We explain why certain traits come to prevail in a certain population. They have been selected for because they increased reproductive success and the chance of survival.

But there is a catch; there is such a thing as taking a metaphor too seriously. One might, for example, be liable to overstate the teleological or voluntarist aspect in the underlying analogy. The breeder voluntarily selects for certain traits; so doesn't nature voluntarily select, too? Unfortunately, Darwin himself occasionally wrote in a rather anthropomorphic way about natural selection, making himself liable to misconception. And many of his contemporaries (even those sympathetic to the general outlook provided by his theory) criticized those anthropomorphic, voluntarist descriptions of natural selection (cf. Young 1985, especially ch. 4.).

The anthropomorphic description gives us the wrong order of explanation. Nature hasn't selected for a particular trait because it was evolutionarily advantageous. The occurrence of any trait has to be explained by random mutation and subsequent selection (although the organism's interaction with the environment might play a critical role, too, as is emphasized by niche construction theory; cf. Odling-Smee et al. 2003). Random mutations occurred that yielded variations that then improved survival or reproductive success. Those exhibiting the trait thereby performed better; they adapted better to (changes in) the environment. Their individual abilities to survive and reproduce increased; that is how and why the trait came to prevail. The trait was not selected for because it proved advantageous; rather, because it proved advantageous, it came to prevail in the population. No one had to select anything.

The explanatory power of metaphors is limited; being based on analogies, only certain relations and inferences allow themselves to be mapped onto each other. It is largely an empirical question which relations can be successfully mapped, and which mappings will preserve inferential validity, etc. Here we see the second corollary confirmed again. Metaphors provide us, it seems, only with a partial understanding of the phenomena in question. Fully-fledged theories ought to overcome the limitations of any particular metaphor, one might think.

Boyd, too, discusses another example of a very successful set of metaphors, namely metaphors drawn from the computer sciences in order to talk about and explain mental mechanisms and cognitive phenomena; such as when thinking is described as information processing (cf. Boyd 1993, 486; cf. Semino 2008, 130–140). He takes them to be theory-constitutive:

> Indeed, the utility of theory-constitutive metaphors seems to lie largely in the fact that they provide a way to introduce terminology for features of the world whose existence seems probable, but many of whose fundamental properties have yet to be discovered.

> Theory-constitutive metaphors, in other words, represent one strategy for the accommodation of language to as yet undiscovered causal features of the world.
> (Boyd 1993, 489–490)

Their use presupposes that “natural phenomena of the right sort exist” (Boyd 1993, 494). Whether they make good on the promise seems to be, again, largely an empirical question. (It may, to some extent at least, also be a conceptual or internal question, as the entities postulated are theoretical entities the existence of which may never be proven beyond doubt.) If successful, they acquire a referential function, thereby gaining in explanatory power.

Consequently, how epistemically successful a metaphor will turn out to be depends on various factors. Here is a tentative list of factors; it is not meant to be exhaustive: (i) the extent to which the entities postulated in the mapping have explanatory power; whether they can even be shown to exist; (ii) whether certain patterns of inference observed in the source domain remain valid in the target domain; (iii) the extent of disanalogies; (iv) the extent to which the *gestalts* they make perceivable prove theoretically fruitful (have explanatory or predictive power, for example); (v) the extent to which they downplay the role of other, maybe equally relevant, aspects of the phenomenon to be investigated (or the problem to be solved) and the extent to which they constrain thinking; (vi) their productivity and the extent to which they give rise to new metaphors; and (vii) the extent to which they are amenable to *complete explication*, i.e. admit of a perfectly adequate non-metaphorical articulation.

Metaphors may be more or less successful, given the purpose at hand; some fail altogether. Pseudo-sciences (Thagard 1978) such as astrology, Rosicrucianism, and other esoteric movements may serve as a rich source of failed metaphors. But even the history of science is full of unsuccessful or worn-out metaphors; talk of *life force* or *animal spirits*, for example, has fallen out of fashion; and for good reason, it seems. Another example that may interest natural scientists as well as literary scholars is provided by the theory of elective affinity (*attractio electiva*).[9] Talk of sympathy, harmony, affinity and (especially from Newton onwards) of attraction in order to explain relations between and preferential combinations of particles, chemical substances or bodies has been common throughout the history of ideas. As Jeremy Adler explains, around 1720 Étienne François Geoffroy put forward a law of affinity, later taken up by Torbern Olof Bergman and others, according to which if three substances are mixed, the two with the strongest mutual affinity combine (Adler 1987, 57). The

9 Many thanks to Hauke Kuhlmann for pointing this out to me and drawing my attention to the theory of elective affinity.

theory of elective affinity became increasingly popular in chemistry in the eighteenth century. It was, famously, literarily transformed by Johann Wolfgang Goethe in his *Wahlverwandtschaften* [*Elective Affinities*] (cf. Adler 1987). It is rather *démodé* now.

Yet it is worth emphasizing, again, that at the time those *metaphors* were popular, it needn't necessarily have been intended that they be interpreted metaphorically. They might have been meant to be literal descriptions. Whether it was intended that they be understood as metaphors or as literal descriptions depended on the epistemic position and the metaphysical background theories of those employing them (cf. Bayertz 2012, 324–335). It may be only in hindsight that we feel inclined to interpret them metaphorically.

6 Summing up

My aim in this paper was to investigate the epistemic function metaphors perform. The investigation was premised on the assumption that metaphors' epistemic value ought to become most evident in contexts where epistemic goals are being pursued. Moreover, I took the basic idea of *the conceptual theory of metaphor,* i.e., the idea that metaphors are mappings between conceptual domains, as my starting point. The point of metaphors, it seems to me, is that they convey structural information but do so by semantic means. We then looked into a couple of metaphors in science in order to make plausible the claim that metaphors have heuristic, exploratory and explanatory value. Yet they may also lead us astray (or nowhere, for that matter), unproductively constrain thinking, etc. Consequently, there are more successful and less successful metaphors; a tentative list of criteria for metaphorical success was put forward. Of course, a metaphor is successful (or fails to be so) only in light of certain purposes or goals. Moreover, whether we take something to be a metaphor depends on our epistemic position and our metaphysical background theories.

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Epistemic Narrativity in Albert Einstein's Treatise on Special Relativity

A Narratological Approach to "The Electrodynamics of Moving Bodies". The Process of Interformation (Part I)

Abstract: The following two chapters offer an analysis of the scientific modeling process of Albert Einstein's treatise on special relativity "Zur Elektrodynamik bewegter Körper" from 1905 ["On the Electrodynamics of Moving Bodies" (1989)]. The first chapter reconstructs both Einstein's scientific modeling process and its narrative strategies for the development of the special theory of relativity. Besides considering the argumentative and descriptive discourse levels of Einstein's treatise, my paper analyzes the employed narrative strategies and their epistemic functions. Hereby main issues of a proposed narratology of science are discussed. How can concepts be transferred from classical narratology to science narratology in order to explore the epistemic functions of narrativity in scientific treatises? What is the epistemic function of the factual 'we-narrator' as a principle of form-organization in a scientific treatise? Can one elaborate on techniques of internal and external focalization not only in literary texts, but also in Einstein's thought experiments? How can one (re-)define concepts of post-classical narratology like eventfulness, experientiality and tellability when adressing scientific discourses? The first chapter shows how the techniques of internal and external focalization are employed by Einstein in thought experiments for the reconceptualization of time and space and for the demonstration of the relativity of simultaneity. The second chapter analyzes the same treatise from a systematical perspective and takes Einstein's metatheoretical reflections in "Physics and Reality" into consideration in order to describe the process of interformation, its semiologic foundations and the resulting epistemic transformations.

Einstein's treatise "On the Electrodynamics of Moving Bodies" is considered one of the most important contributions to twentieth-century physics, and as the founding document of special relativity theory. The statements of special relativity theory were fundamental, because they reconceptualized basic categories of space, time, mass and energy in physics. On the basis of Einsteinian principles, in 1908 Minkowski succeeded in showing how space and time could

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be mathematically unified in a four-dimensional space-time continuum (Minkowski 2012 and 1909; cf. also 1908).[1]

In order to be able to examine the processes of modeling[2] in literature and science, it is necessary to define a space of signs and symbols in which both operate. Only when this commonality can be assumed one can examine in a next step the way in which the processes of semiosis differ in literature and natural science and whether there are nevertheless possibilities of intersecting their spheres of modeling practice.

Models are understood here according to Gelfert (2016; cf. 2017) as functional entities that can be configured symbolically, semiotically, mathematically, diagrammatically or aesthetically. With Morgan and Morrison (1999a, 1999b), they exhibit an explorative dimension in theory development and thus function as mediators between denotation and representation up to experimental simulation and the exemplification of new symbolic correlations. With Knuuttila (2005), models can also be understood as "epistemic tools," as epistemic artefacts. They make it possible to configure the knowledge relevant to understanding of a certain area formally, medially, symbolically or materially in order to re-correlate it and reinterpret it accordingly. From the perspective of philosophy of science the correlations between models and fictions have been explored by Roman Frigg (2009, 2010) and Mauricio Suárez (2009, 2010).

From Lotman's (1977) perspective, the arts and sciences operate as secondary modeling systems in the space of the semiosphere. Since Lotman (1973) also mentions the term "scientific languages" (cf. Schönle 2006) in addition to the term "natural languages" in his cultural semiotic theory, I propose to start from the following assumptions: According to Lotman, literature uses the primary modeling system of language as a communication system and secondary modeling processes for its aesthetic modeling design. Physics, on the other hand, I would add, uses language as a communication system, measurement for scale comparison using numbers, and technical experimental methods: This is its system of primary modeling. As a secondary modeling system, physics draws on mathematical operations and codes, which it uses for theoretical modeling. It also seems consequent to investigate the cultural semiotic space

1 I am greateful to Michael Sinding for the translation of this paper. Also I am grateful to thank Klaus Mecke for the exchange of ideas on the process of interformation in physics and literature, to Christine Lubkoll, Alexander Laska, Lothar Ley, Benjamin Specht, Clemens Heydenreich, and Miriam Rückelt for having read and discussed this paper with me thoroughly.

2 The poetics of modeling is also topical in contemporary literary studies: Cf. Erdbeer 2015; Balke et al. 2014; Wendler 2013; Matuschek and Kerschbaumer 2015; Erdbeer et al. 2018a, 2018b.

in which secondary modeling systems operate: the semiosphere proposed by Lotman (2005). Etymologically, the concept of the semiosphere can be derived from the Greek words 'σημεῖον,' 'sêmeion' = 'sign' and 'σφαῖρα,' 'globe,' 'sphere' = 'space.'

> The unit of semiosis, the smallest functioning mechanism, is not the separate language but the whole semiotic space of […] culture […]. This is the space we term *semiosphere*. The semiosphere is the result and the condition for the development of culture; we justify our term by analogy with the biosphere, as Vernadsky defined it, namely the totality and the organic whole of living matter and also the condition for continuation of life.
>
> (Lotman 2000, 124–125)

In the following, the semiosphere shall be defined as a field continuum of signs, sign functions and sign correlations, which comprises: The entirety of all linguistic signs, mathematical, graphic and diagrammatic symbols; the totality of the sign relations and sign functions existing between them; the entirety of the codes that regulate the meaning of signs; finally, all agents as sign users who use sign functions and sign relations in processes of modeling and communication, representation and signification. A field of the semiosphere is a semio-logical manifold that allows correlations. I propose to define physics and literature as different fields of the semiosphere that differ from one another due to their own logic of using signs. That's why in *Physica Poetica* (Heydenreich 2022) I proposed to analyse them as different semio-logical fields. The hyphenated notation of the term "semio-logic" marks that the two fields, physics and literature imply *different logics of using signs*, that means that they use different syntactic, semantic and pragmatic codes and practices for their processes of semiosis. Theoretical physics as well as literature are considered semio-logical manifolds of the semiosphere. I examined the semio-logical practices of both fields at length in my monography *Physica Poetica* (Heydenreich 2022) which is to appear in this series of publications. The aim there was to define the sign-, symbol- and culture-theoretical properties of these semio-logical fields that allow both the analyses of the phases in which the modeling practices of the two fields differ fundamentally from one another *globally*, and the description of those special areas and phases in which the modeling practices of both fields can be intersected *locally*.

An important thesis for this is that although the two fields of literature and physics can be conceptualized on a theoretical level on the basis of their functional difference, certain semio-logic practices (in certain historical contexts, under certain conditions, in concrete individual texts) can be linked locally. This induces crossing a borderline and opening up a field continuum for enabling intersection. The dialectics between system and process dynamics can be observed in the magnifying glass of the dialectic between mathematical codes and narratives (cf. Koschorke 2004). When it comes to the sedimentation and consolidation of the systems, both fields in metasemiotic communication rely on the consolidation of their own rule systems and practices. This is achieved through the metasemiotic communication at the center of the field that propagates the clear demarcation from the other semiotic environment. But it is precisely the boundary that serves to functionally stabilize the identity of the system that registers the essential differences between the two semio-logical fields, and unfolds a countervailing metasemiotic dynamic. It takes note of the rule systems of both semio-logical fields, compares them and plays them off against each other. As Albrecht Koschorke (2018, 86–100) indicated, the boundary thus proves to be a subversive mechanism against the metasemiotic communicative practices of the center of the system. This also includes the implementation of new modeling techniques that have not been practiced before.

I assume that the semiosphere is the space of signs that allows both. On the one hand it allows the specialization of the fields according to their own rules, which are centrally reflected metasemiologically and systematically codified. On the other hand it also allows the selective entanglement of the fields at their borders, where exactly the opposite metasemiological debates are being held – about the possibilities and consequences of crossing borders and entangling them with a different semio-logical field. I suppose that both fields interact with one another in order to test alternative practices of using signs and in order to undermine and interrogate the habitualized frames and epistemic practices. Then it can be shown that by recurring to the epistemic and semio-logic practices of the other field, frames in the own field can be reorganized: namely by new semantic and/or formal correlations and transformation relations. I am going to show that Einstein uses narrative techniques in his relativity paper as complementary techniques to the theoretical modeling in order to de-habitualize former epistemic practices and in order to establish new ones.

In this study I propose the concept of interformation for the processual modeling correlation between spheres of discoursive practice that use different codes: physics and literature. The concept of interformation is to be understood in distinction to that of information. In the case of information, many communication models assume that sender and receiver use the same code, so that the transmission of a message can function without problems. In the case of interformation, however, the transmission of the message does not function according to this well-known model – because the two semio-logical fields use signs differently. Not all syntactic, semantic and pragmatic codes can be considered as given. Some of them emerge during the modeling process, during the intersection between the two fields. That's why interformation is a process of reframing and reconceptualization based on transfers that lead to interchanges between the two fields and their modeling and epistemic practices.[3] Interformation provides the necessary procedures to perform the intersection process between the two different spheres of discursive practice. As we can see in the case of Einstein's theory of relativity, the concept of interformation also functions in crossing the borders between two theoretical paradigms. The analysis of Einstein's texts will allow me to describe this intersection in depth. A question posed is how far features of narrativity can be attributed to Albert Einstein's modeling process of special relativity theory, and especially, which framing and embedding-techniques, which focalizing- and perspectivization-techniques it uses in order to develop the special relativity theory. The thesis here is that Einstein uses descriptive, explicative and narrative techniques as textual strategies and integrates them in order to develop the special theory of relativity. Finally, it remains to be shown how narrative framing techniques are combined with modeling strategies of theoretical physics.

My reading neither provides the logical reconstruction of special relativity theory from the perspectives of either philosophy of science or history of science, nor can it address the mathematical foundations of theoretical modeling, even if it considers certain aspects of these. Here I can only refer to the comprehensive literature on these topics, as well as the works by which my reading is supported. From the field of physics, these are the reconstruction of Max Born in *Einstein's Theory of Relativity* (1965) [*Die Relativitätstheorie Einsteins* (2001)] as well as the textbooks of theoretical physics on special relativity theory by Ulrich Schröder and Claus Lämmerzahl, *Special Relativity* (1990) [*Spezielle Relativitätstheorie* (2014)], and Wolfgang Nolting's *Theoretical Physics* (2017) [*Grundkurs Theoretische Physik* (2016)]. Also helpful is the approach to the presentation of relativity theory from Nicholas Woodhouse (2003, 2016) and Franz Embacher (2010), which stands in the tradition of John Wheeler's (Misner et al. 1973) and Hermann Bondi's (1964) accounts.

From the cultural-philosophical point of view, I base my reading on Ernst Cassirer's epistemological observations in *Einstein's Theory of Relativity* (2003) [*Zur Einsteinschen Relativitätstheorie* (2001)] (cf. Ryckman 2005, 1999). From the point of view of the history of science my work relies on Miller's (1981) comprehensive account, *Albert Einstein's Special Theory of Relativity: Emergence (1905) and Early Interpretation (1905–1911)*, which historically contextualizes the scientific genesis of the special theory of relativity, presents the preliminary work

3 For a detailed theoretical presentation of the concept of interformation and the processes of mutual transfer between the semio-logical fields of physics and literature with historical case studies on scientific and literary texts by Johannes Kepler, Durs Grünbein, Raoul Schrott, Richard Powers, Thomas Lehr, Dietmar Dath, Carl Sagan and Kip Thorne cf. Heydenreich 2022.

of Hendrik Lorentz (1892, 1895, 1904a, 1904b) and Henri Poincaré (1900a, 1900b, 1901, 1902) as well as Walter Kaufmann's (1901, 1902) experiments, and reconstructs the early interpretations of the theory. In addition, I consulted the science-historical studies of Peter Galison, *Einstein's Clocks, Poincaré's Maps: Empires of Time* (2003a; cf. also 2003b) and Klaus Hentschel's *Interpretations and Misinterpretations of Special and General Relativity Theory by Einstein's Contemporaries* [*Interpretationen und Fehlinterpretationen der speziellen und der allgemeinen Relativitätstheorie durch Zeitgenossen Albert Einsteins*] (1990), which reconstructs the reception of the theory through Neo-Kantianism, Critical Realism, the Husserl school of Phenomenology as well as Logical Empiricism.

Bas van Fraassen's essay "Literate Experience: The [De-, Re-] Construction of Nature" was published in an issue of the journal "Versus" (Dusi and Nergaard 2000) devoted to intersemiotic translation: "I am an avid Eco's reader, and never more avid than on the subject of interpretation. [...] My main guiding question will be: does the theory and practice of text interpretation give us, yes or no, a clue, a telling, parallel, or fruitful analogy for the scientific study of nature today?" (Van Fraassen 2000, 331) Building on Eco, he even introduced the concept of "*literate experience*" (Van Fraassen 2000, 331) and asked the question whether literary theory can be made fruitful for the study of scientific texts. In terms of my analysis this also implies to concentrate on the modeling and narrative strategies that can be analyzed in original publications in natural science.[4] Granted, this is an unusual approach. In the professional culture of physics, it is not at all common to read and analyze original historical works. Arthur Miller remarked on this:

> While the works of literary authors are commonly considered to be an integral part of our cultural milieu, this distinction is generally not granted to scientific authors. It is difficult, for example, to imagine a teacher of English who has never read one of Shakespeare's plays. But few people today, including physics researchers, teachers of physical science or philosophers of science have carefully read Einstein's relativity paper of 1905, although it is brief, requires little mathematics, but had immense effects on intellectual and societal pursuits in the twentieth century. While many different in-depth analyses of the works of high literature are available to humanistic scholars, physicists have virtually no access to analyses that guide the reader.[5] (Miller 1981, 5)

4 On this distinction between system-oriented and process-oriented approaches, cf. Van Fraasen's chapter "Measurement as Representation: Relating the views 'from above' and 'from within'" (Van Fraassen 2013, 184–190).

5 This quotation is only intended to prove that this practice of *close reading* of primary texts is unusual in physics. It does not suggest that the existing gaps will be closed through the present work. This is what Miller has done. The literary-critical approach proposes this practice of close readings of original texts, because it concerns the concrete process of modeling and specific narrative practices.

For literary scholarship, Christina Brandt formulated in the De Gruyter Handbook *Narrative* [*Erzählen*] the following research desideratum:

> A deeper narratological analysis of forms of narration in the scientific field remains yet a desideratum. This applies to fundamental analyses of the forms and functions of factual narration in natural-scientific discourse as well as to more specialized sub-fields. Thus for example the historical development of scientific forms of narration in cultural-historical context is a scarcely studied area.[6] (Brandt 2017, 217)

Let's start with the analysis of the argumentation of Einstein's treatise on special relativity theory.

1 The contradiction between mechanics and electrodynamics in "On the Electrodynamics of Moving Bodies"

In the 1905 treatise, which announced the birth of special relativity theory, Einstein compares the rule-guided practices of two distinct, theoretically and experimentally established fields of physics – mechanics and electrodynamics – and identifies possible contradictions between them. Defining principles of these fundamental theories of physics are shown to be incompatible with one another. Einstein claimed that even though there were extensive commonalities between the two fundamental physical theories – mechanics and electrodynamics – there were also great contradictions. For example, the Galilean relativity principle did not apply to Faraday's law of induction.

The first half of Einstein's treatise, the first five sections, are devoted to mechanics, and the second half, with the last five sections, to electrodynamics.

Yet electrodynamics developed from the background of mechanics: Coulomb and Ampère, for example, used the principles and equations of the Newtonian theory of action-at-a-distance when they set out the first theoretical models for describing electricity and the relationships between electricity and magnetism. James Clerk Maxwell, who achieved the complete modeling of electrodynamics

6 Transl. by MS. "Eine tiefergehende narratologische Analyse von Erzählweisen im naturwissenschaftlichen Feld bleibt jedoch weiterhin ein Desiderat. Dies betrifft sowohl grundlegende Analysen von Formen und Funktionen des faktualen Erzählens im naturwissenschaftlichen Diskurs als auch speziellere Teilgebiete. So ist beispielsweise die historische Entwicklung von naturwissenschaftlichen Erzählweisen im kulturhistorischen Kontext ein noch kaum erforschtes Feld" (Brandt 2017, 217).

as field-theory, was also still concerned, in both of the early treatises that later led to the derivation of his famous field equations ("On Faraday's Lines of Force," 1856, and "On Physical Lines of Force," 1861a, 1861b, 1862a, 1862b) with models that stood in the dynamic tradition of mechanics.[7] He later emancipated himself from this and formulated electrodynamics as field theory: "A Dynamical Theory of the Electromagentic Field" (Maxwell 1865, 1881)

Einstein proposed a cross-over of principles: if the speed of light in vacuum had a definitive value in electrodynamics, this and its consequences should also be accepted for the measuring and modeling practices of mechanics, i.e., also apply to moving and stationary bodies in mechanics. If movement and rest were considered relative in mechanics, this relativity principle should also apply to the laws of electrodynamics. In the following I will quote the English version of Einstein's "Electrodynamics of Moving Bodies" in the current text and the German version in the footnotes:

> The considerations that follow are based on the principle of relativity and the principle of the constancy of the velocity of light, two principles that we define as follows:
> 1. The laws governing the changes of the state of any physical system do not depend on which one of two coordinate systems in uniform translational motion relative to each other these changes of the state are referred to.
> 2. Each ray of light moves in the coordinate system "at rest" with the definite velocity *V* independent of whether this ray of light is emitted by a body at rest or a body in motion.[8] (Einstein 1989 [1905], 143)

Einstein already states at the beginning of his treatise that these postulates are seemingly contradictory, but that the modeling process will show why the intersection of two principles is a necessity for the development of the theory:

> We shall raise this conjecture (whose content will be called the "principle of relativity" herafter) to the status of a postulate, and shall introduce, in addition, the postulate, only

7 For the methodology and systematics of these modelings, cf. the presentation by Siegel 1991.
8 "Die folgenden Überlegungen stützen sich auf das Relativitätsprinzip und auf das Prinzip der Konstanz der Lichtgeschwindigkeit, welche beiden Prinzipien wir folgendermaßen definieren. 1. Die Gesetze, nach denen sich die Zustände der physikalischen Systeme ändern, sind unabhängig davon, auf welches von zwei relativ zueinander in gleichförmiger Translationsbewegung befindlichen Koordinatensystemen diese Zustandsänderungen bezogen werden. 2. Jeder Lichtstrahl bewegt sich im 'ruhenden' Koordinatensystem mit der bestimmten Geschwindigkeit *V*, unabhängig davon, ob dieser Lichtstrahl von einem ruhenden oder bewegten Körper emittiert ist" (Einstein 1905, 895).

> seemingly incompatible with the former one, that in empty space light is always propagated with a definite velocity V, which is independent of the state of motion of the emitting body. These two postulates suffice for arriving at a simple and consistent electrodynamics of moving bodies on the basis of Maxwell's theory of bodies at rest.[9]
>
> (Einstein 1989 [1905], 140–141)

I consider the intersection of these two postulates – the relativity principle and the constant velocity of light – which stem from two different theoretical frames, mechanics and electrodynamics – as the first step in the process of interformation. The interformation process is based on the abduction, i. e. the inference, that the intersection of principles and modeling practices will ground a new theory that solves the initial anomaly through a new transformation relation: the Lorentz transformation. I will show in this and the next paper that the process of interformation is mediated by narrative strategies and that its final result is epistemic transformation.

In the following I will examine the narrative functions, representational forms and framing strategies in Einstein's "On the Electrodynamics of Moving Bodies." It has been repeatedly pointed out that the thought experiments (Elgin 2007; Frappier et al. 2013) that are carried out in Einstein's treatise for the reader's imagination have a narrative structure. Bruno Latour (1988) has presented a reading of Einstein's popular-scientific writing on the theory of relativity from the perspective of Science and Technology Studies, which draws on the Greimassian concepts of "shifting in" and "shifting out." Against a sociological background of argumentation, Latour focuses on the practices used by the narrator to gain power. I will focus on Einstein's main scientific treatise on special relativity theory and my argument is not sociological oriented. It relies on cultural-semiotics and narratology and moves in another direction. My analysis aims to illuminate the epistemic function of narration in the process of interformation. From what points of view could one claim that Einstein's paper uses narrative techniques? What function do these narrative techniques have in the epistemic process of interformation?

To clarify this, I first have to problematize the concept of narrativity, in order to discuss, against the background of current research approaches, under

9 "Wir wollen diese Vermutung (deren Inhalt im folgenden 'Prinzip der Relativität' genannt werden wird) zur Voraussetzung erheben und außerdem die mit ihm nur scheinbar unverträgliche Voraussetzung einführen, daß sich das Licht im leeren Raume stets mit einer bestimmten, vom Bewegungszustande des emittierenden Körpers unabhängigen Geschwindigkeit V fortpflanze. Diese beiden Voraussetzungen genügen, um zu einer einfachen und widerspruchsfreien Elektrodynamik bewegter Körper zu gelangen unter Zugrundelegung der Maxwellschen Theorie für ruhende Körper" (Einstein 1905, 891–892).

what conditions narrativity can be attributed to a scientific text such as Einstein's treatise "On the Electrodynamics of Moving Bodies." The concept of narrativity has been travelling since the *narrative turn*, from literary studies to historiography (White 1973, 1978, 1999; Fulda 1996, 2005; Jaeger 2000, 2009), psychology, cognitive science, political science, sociology, anthropology, and medicine (Charon 2006; Brown et al. 2010). This inflationary broadening of the term "narrative" has evoked many skeptical reactions. I cite Gerald Prince as one representative voice:

> One says 'narrative' instead of 'explanation' or 'argumentation' (because it is more tentative); one prefers 'narrative' to 'theory,' 'hypothesis,' or 'evidence' (because it is less scientistic); one speaks of a 'narrative' rather than 'ideology' (because it is less judgmental); one substitutes 'narrative' for 'message' (because it is more indeterminate).
> (Prince 1999, 45)

Peter Brooks attempts, on the other hand, to relativize such skeptical positions somewhat and to develop arguments for why the intense broadening of the concept is understandable:

> While I think the term has been trivialized through overuse, I believe the overuse responds to a recognition that narrative is one of the principal ways we organize our experience of the world – a part of our cognitive tool kit that was long neglected by psychologists and philosophers. (Peter Brooks, quoted in Safire 2004, 36)

The controversy sketched here was taken as an opportunity by the narratological research to problematize the concept of "narrativity." For the classical narratology the core definition of "narrative" rests on two pillars: sequentiality and temporality (cf. Rudrum 2005, 199–200, 202). In Genette's terms: "one will define narrative without difficulty as the representation of an event or sequence of events" (Genette 1982, 127).

H. Porter Abbott points out that the concept of "narrativity" (Abbott) was hardly thematized in the context of classical structuralist narratology. Abbott's conclusion is echoed by Wolf Schmid in his *Narratology* (2010) [*Elemente der Narratologie* (2014)]. Classical narratology concentrated on a minimal condition of a definition of "narrative," namely that "at least *one* change of state must be represented" (Schmid 2010, 2).[10] Forster (1974, 93) had coined the classic example: "The king died and then the queen died." Genette undercut Forster's example and deleted the second sentence. The remaining sentence, "The king died," should suffice for a minimal definition of narrative (Genette 1988, 20; cf. also

10 "dass mindestens *eine* Veränderung *eines* Zustands in einem gegebenen zeitlichen Moment dargestellt wird" (Schmid 2014, 3).

1994, 203). Marie-Laure Ryan (2007, 24) emphasized that while both criteria are indeed necessary for a minimal definition of narrative, they are not yet sufficient to define the category of narrativity; and moreover, the outlined definition should allow one to distinguish between a scientific and a metaphorical use of the term.

In this context, Gerald Prince (2008, 19–20) points to the need to differentiate between two distinct questions. The first is, "What is a narrative?," and aims at an extensional definition. The *explanandum* is here conceived as a noun, refers to entities and indicates a class of objects that can be defined as "narratives." The second question that can be posed is, "What is narrative?" and refers to an adjectival use of the word. It concerns a quality, features of narrativity, and not an entity that is to be defined. This question aims at a gradual definition of narrativity that presents a bundle of relevant features that may be ascribed to a text to a certain degree, without thereby denying that the text can also manifest other features. Thus Jean-Michel Adam (1999) in *Le récit*, for example, identifies a narrative level of signification alongside to other textual levels, the descriptive and the explicative, which can co-exist in the same text. Seymour Chatman also argues in the same vein, distinguishing three types of textual types, which can co-exist in the same text in different dominance-relations: argumentative, descriptive and narrative: "The text-types routinely operate *at each other's service*" (Chatman 1990, 10–11). In this paper I'll refer at the term in its adjectival use.

Marie-Laure Ryan also emphasizes that for contemporary narratology, the definition of structuralist narrative research, which limited its decisive criterion to mere sequentiality, is not sufficient. In the *Cambridge Companion to Narrative*, Ryan proposes a pluricriterial definition of narrativity that unifies various dimensions: the spatial, temporal, mental, formal and pragmatic dimensions.

> Rather than regarding narrativity as a strictly binary feature, that is, as a property that a given text either has or doesn't have, the definition proposed below presents narrative texts as a fuzzy set allowing variable degrees of membership [...]. In a scalar conception of narrative, definition becomes an open series of concentric circles which spell increasingly narrow conditions [...]. (Ryan 2007, 28)

The spatial dimension presupposes that a diegetic world is represented. The temporal dimension includes two criteria, which provide that the diegetic world is situated in a certain time, and undergoes a significant transformation caused by extraordinary events. The mental dimension assumes that the figures represented in the world are intelligent actants, while some of the events represented therein can be attributed to the actants as intentional acts. The fourth, formal and pragmatic dimension subsumes the criterion that the event-sequence be represented as a holistic causal chain. At least some events should be attributable to the "storyworld" as facts. As a last pragmatic communication criterion, it is required that the story should have communicative relevance and a certain significance (Ryan 2007, 29). David Rudrum urges that the pragmatic dimension of narrativity should be somewhat more strongly emphasized. He proposes a definitional approach very strongly oriented to Wittgenstein's *Philosophical Investigations*:

> The question of use is therefore intimately bound up with the question of social practices and conventions. Generally, competent members of a linguistic community are able to recognise the use for which a narrative is intended and respond appropriately [...] Once again, the key factor in making these classifications is the use to which the text is put.
> (Rudrum 2005, 199–200, 202)

2 Epistemic narrativity

The present work also takes the position that narrativity is not to be understood as an essentialist criterion, but rather conceptualized gradually and pragmatically. For the analysis of Einstein's treatise I would like to plead for a functional approach to narrativity. I wish to show how scientific texts functionalize narrativity epistemically, and still argue theoretically. And that's why I propose to speak about epistemic narrativity as one dimension of scientific texts.

Recent research in postclassical narratology, which has opened up phenomenological, cognitive, cultural-studies, context-oriented approaches, discusses the category of "narrativity" very intensively (Prince 1999, 2008; Ryan 1992, 2007). It also has perspectivized it transgenerically and transmedially (Ryan 2013, 2015; Nünning 2002; Wolf 2017). Why should narrativity not be explored from the perspective (Ryan 2011) of a narratology of science? What would a narratology of science look like, one that operates with the concepts of the space-time continuum, the world-lines of observers, the boundaries of their horizons of perception, and with the concept of interformation?

It is interesting to pose this question about a future project of an interformative narratology of science, because it may be observed that Einstein's treatise proposes disruptive concepts that not only contradict everyday common sense, but also contravene many postulates of classical physical theory, which before Einstein were considered reliable knowledge. All the more does narrativity play a decisive role – which raises the question of what kind of *emplotment* is convincing and has mathematical and physical, cultural and pragmatic relevance, in order to give meaning to the new symbolic organization of the experience of reality.

According to Porter Abbott, Greimas is the sole great exception of structuralist narratology because unlike all other classical narratologists he problematizes not only narration but also the category of narrativity. Greimas gives a pioneering definition of narrativity as "*the organizing principle of all discourse*" ["*le principe organisateur de tout discours*"] (Greimas and Courtés 1979, 249; Italics by AH). Groundbreaking, says Abbott, is the crucial Greimasian criterion of narrativity as "disruptivity" (cf. Greimas 1987, 104):

> It is also important to note that, for Greimas, narrativity is a disorganizing as well as an organizing force in that it disrupts old orders even as it generates new ones. It is 'the irruption of the discontinuous' into the settled discourse [...] 'into discrete states between which it sets transformations.' (Abbott, § 9)

This central criterion of narrativity as disorganizing and reorganizing force is decisive for the concept of epistemic narrativity which I propose through the present narratological reading of Einstein's treatise. The concept can be correlated with Goodman's and Elgin's concept of "creation as reconfiguration," which will be discussed in my next chapter in this volume.[11]

Monika Fludernik, Peter Hühn and Wolf Schmid also criticized the definitional approaches of classical narratology, which relied only on temporality and sequentiality as defining features of narrativity, and propose the following criteria. Monika Fludernik introduced the concept of "experientiality" in her "natural narratology" approach: "narrativity should be detached from its dependence on plot and be redefined as the representation of experientiality" (Fludernik 1996, 109). Programatically related to this is Fludernik's critical statement, that she has never been convinced by Forster's (1974, 14) minimal definition "The king died and then the queen died of grief" as an exemplary form of narrativity. For Fludernik (1996, 14), in the context of her "natural narratology" approach, narrativity is not an inherent property of texts, but rather appears as an effect of discourse. In the line of cognitively oriented narratology this is rather a matter of dynamic interaction between text and reader, as Fludernik states: "I concentrate on the structural properties of conversational storytelling [...] and on the dynamic interaction or dialectic between the *news value of the tale* and its impact on the experiencer's retrospective evaluation (reportability vs. narrative 'point')" (Fludernik 1996, 15; italics by AH).

Labov had also earlier drawn attention to the criterion of "reportability," the "narrative point," as Bruner remarks: "Labov's great credit is to have recognized

11 Cf. Aura Heydenreich's paper "Albert Einstein's 'Physics and Reality' and 'The Electrodynamics of Moving Bodies'" in this volume.

that narrative structures have two components: 'what happened and why it is worth telling.'" (Bruner 1991, 12) Fludernik refers to these additional criteria of narrativity, which have found their way into postclassical narratology and are very intensively discussed:

> For the narrator the experientiality of the story resides not merely in the events themselves but in their [...] exemplary nature. The events become tellable precisely because they have started to mean something to the narrator. It is this conjunction of experience reviewed, reorganized, and evaluated ('point') that constitutes narrativity.
> (Fludernik 2003, 245; cf. 1996, 70)

Can we provide criteria for why the facts set out in this scientific article are tellable? Which is their narrative-point? In what respect the concepts of the special theory of relativity have changed the way in which we experience and organize reality?

The thought experiments are designed as narratives in order to propose new ways of measuring time and space, that have not been practiced before, and yet to make them experiencable for the human frame of reference. The reader is the addressee of the immersive thought experiments that are included in Einstein's text.[12] The reconceptualization of fundamental concepts is experimented: the relativity of simultaneity, time dilation, length contraction, the relativity of mass. New measurement narratives and their results are performatively presented to the reader by the actions of observer figures in thought experiments. These are thus experiencable for them and should lead to revision and reorganization of their entire space-time conceptions. The immersive function of experientiality is necessary to cognitively mediate and thus epistemically plausibilize and legitimize the new concepts and the new world-model associated with them. This requires an *emplotment*, which constructs experientiality at least as a discourse effect.

In the following, Matías Martínez's (2017) definition in the De Gruyter handbook on *Narrative* [*Erzählen*], and the features he identifies, will be used in order to discuss how far the criteria that are mentioned in the narrative research for the term "narrativity" also apply to Einstein's treatise. I choose Martínez's definition because it pursues an integrative definitional approach, which takes into account the criteria of classical as well as postclassical narratology, includes the level of *discours* as well as that of *histoire*, and incorporates syntactic, semantic and pragmatic dimensions.

Martínez starts from classical narratology's minimal definition of narrative as event-representation. Under "event-representation" he subsumes three necessary defining features of "narrative:" temporality, concreteness and contiguity.

12 On the narratological category of immersion, cf. Ryan 2001, 2015.

Martínez (2017, 3) extends this minimal definition, however, into a formula with the variable *x*, and summarizes: "narrative = event-representation + *x*." The component "*x*" stands as a placeholder for nine further criteria that are problematized in narrative research – with the aim of arriving at a comprehensive, transgeneric and transmedial definition of narrativity that is sufficiently differentiated to handle the levels of *discours* (criteria 1–2: doubled temporality, focalization), *histoire* (criteria 3–7: causality, intentionality, completeness, emplotment, experientiality) and the pragmatics of narration (criteria 8–9: tellability, conversational constraints such as detailing, relevance, condensation, point, etc.).[13]

In the following, I will explore the above stated criteria where appropriate, and also draw on further relevant positions in narrative research, in order to illuminate the category of epistemic narrativity in science. The first criterion is that of "temporality," as the "event-representation is representation of a time-course. Every event is structured as such through a 'before vs. after,' through a sequence of chronologically ordered events: $e_1 \rightarrow e_2 \rightarrow e_3 \rightarrow \ldots \rightarrow e_n$" (Martínez 2017, 2).[14] Because hardly any literary text can do without a dimension of temporality, it is important to know by which narrative strategies Einstein's text redefines temporality. This aspect is also relevant from the meta-perspective of narratology, which identifies temporality as the fundamental criterion of narrativity. Einstein's treatise breaks with the old definitions of temporality in the old knowledge systems and shows that no chronology can be absolutely given. Temporality is always defined relative to a certain reference system. Einstein makes the proposal of a new symbolic order of organization of temporality, as I will show in section 3.2.

With the criterion of concreteness, Martínez's definition implies that "every narrative represents 'mimetically,' that is, represents singular and concrete objects and situations" (Martínez 2017, 2).[15] This also holds true for the thought experiments that are represented in "On the Electrodynamics of Moving Bodies" as it will be shown in this paper.

13 Cf. Martínez 2017, 3–6 ("Sie beziehen sich auf Aspekte der Darstellung (*discours*, Kriterien 1–2), des Geschehens (*histoire*, Kriterien 3–7) und der Pragmatik (Kriterien 8–9) des Erzählens. (1) *Doppelte Zeitlichkeit* [...] (2) *Vermittlungsinstanz* [...] (3) *Kausalität* [...] (4) *Intentionalität* [...] (5) *Ganzheit* [...] (6) *Ereignishaftigkeit* [...] (7) *Experientiality* [...] (8) *Tellability* [...] (9) *Konversationelle Zugzwänge* [...]").

14 Transl. by MS. "Geschehensdarstellung ist Darstellung eines Zeitverlaufs. Jedes Geschehen ist als solches durch ein ›vorher vs. nachher‹, durch eine Sequenz chronologisch geordneter Ereignisse strukturiert: $e_1 \rightarrow e_2 \rightarrow e_3 \rightarrow \ldots \rightarrow e_n$" (Martínez 2017, 2).

15 Transl. by MS. "Jede Erzählung stellt ›mimetische‹, das heißt singuläre und konkrete Gegenstände und Sachverhalte dar" (Martínez 2017, 2).

Martínez identifies "contiguity" as another necessary criterion: "The represented events must […] be related to one another spatially, temporally or causally" (Martínez 2017, 2).[16] With respect to this criterion too, it is remarkable to observe what is epistemically initiated in Einstein's treatise. The criterion of contiguity therefore acquires a very profound new meaning, because Einstein succeeds in demonstrating, on the basis of considerations of mathematical symmetry, that space and time are not to be conceptualized as separate, but rather as related to one another mathematically and physically as a spacetime-continuum – as demonstrated by the symmetry relations of the Lorentz transformation. The following analysis is devoted to this logical and equally narrative-performative demonstration, step by step.

A further crucial feature of narrative is the existence of a narrative voice. For factual texts the narratological theory proposes the initiation of a factual pact (Fludernik 2020, 62) in analogy to Philippe Lejeunes (1989) "autobiographical pact" and to the "fictional pact" of the institutional theory of fictionality (Köppe 2014). The factual pact describes the "default assumption that a text […] as a [scientific] treatise is, by definition, taken to be making statements about the real world" (Fludernik 2020, 62; added by AH).

Genette (1990) states that one clear distinction between factual and fictional narration is the identity between author and narrator (A = N) in case of factual narration and the distinction between the empirical author and the textually encoded narrator (A ≠ N) for fictional texts. The narratological analysis of scientific texts has to deal with the problem, that both the position of the "intellectual creator of the text written for [scientific] communicative purposes" (Schönert, § 1; added by AH) and the narrative voice as the "inner-textual (textually encoded) highest-level speech position" (Margolin, § 1) have to be adressed with appropriate, well differenciated terms. Since I analyse Einstein's treatise as an argumentative text type that displays features of epistemic narrativity besides the argumentative and the descriptive dimensions of the text, I propose to use the term writing/narrating instance to adress both the descriptive/argumentative and the narrative dimensions of the text.

The following parameters of the narrator are to be observed, in order to describe how it constitutes the principles of form-organization (Bekhta 2017) of the text "On the Electrodynamics of Moving Bodies." A first criterion is the explicitness of voice representation – the "degree of narratorhood" (Chatman 1978), the openness or concealment of the narrative voice. A second criterion is

16 Transl. by MS. "Die dargestellten Ereignisse müssen […] räumlich, zeitlich oder kausal aufeinander bezogen sein" (Martínez 2017, 2).

its relation to the narrated world. To these are added, third, the representational logic of the narrative levels. Fourth, finally, is the question of the presentation of the addressees. All of these parameters help to answer the question of who tells, sees, perceives, mediates on the various narrative levels, and thus conducts the interformative process. At the following point in "Electrodynamics of Moving Bodies" the writing/narrating instance enters the stage of theoretical-physical modeling: precisely at the point at which the process of interformation begins, Einstein states:

> We shall raise this conjecture (whose content will be called the "principle of relativity" herafter) to the status of a postulate, and shall introduce, in addition, the postulate, only seemingly incompatible with the former one, that in empty space light is always propagated with a definite velocity V, which is independent of the state of motion of the emitting body. These two postulates suffice for arriving at a simple and consistent electrodynamics of moving bodies on the basis of Maxwell's theory of bodies at rest.[17]
>
> (Einstein 1989 [1905], 140–141)

Einstein's treatise presents a plural narrative voice in we-form, which in narratological research has so far been rarely problematized, as Uri Margolin (1996), Monika Fludernik (2011) and Natalya Bekhta (2017) have pointed out.[18]

The voice presents itself to be recognized as a "we-instance." It is a voice who opens up a process of factual scientific communication, and acts as mediator for a factual-narrative that sets out well-grounded knowledge (Klein and Martínez 2009). Of course, this is a common gesture for scientific publications around 1900. It would be perceived as *pluralis auctoris* or as a gesture of modesty. Is the scientific authority of already institutionalized expert discourse apostrophized by the "we?" Certainly the collective "we" also implies that scientific expert community that has agreed on common principles, codes and modeling practices, which the we-instance here subsumes under the principles of mechanics and electrodynamics. It stands for the culturally accepted and/or scientifically sanctioned state of knowledge at the time of the beginning of the modeling configuration. It will accompany the reader as a mediator through this process throughout the entire treatise.

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17 "Wir wollen diese Vermutung (deren Inhalt im folgenden 'Prinzip der Relativität' genannt werden wird) zur Voraussetzung erheben und außerdem die mit ihm nur scheinbar unverträgliche Voraussetzung einführen, daß sich das Licht im leeren Raume stets mit einer bestimmten, vom Bewegungszustande des emittierenden Körpers unabhängigen Geschwindigkeit V fortpflanze. Diese beiden Voraussetzungen genügen, um zu einer einfachen und widerspruchsfreien Elektrodynamik bewegter Körper zu gelangen unter Zugrundelegung der Maxwellschen Theorie für ruhende Körper" (Einstein 1905, 891–892).

18 See also the recent Special Issue of *Style*: Bekhta 2020. Therein: Fludernik 2020.

However, this writing/narrating instance asks more of the reader than many other "we-narrators" of its time. For it is precisely this collective "functional-narrator" that organizes the factual narrative discourse in such a way, as it generously integrates the other actors of the scientific field. But in the course of this treatise the same factual narrator will carry out reconceptualizations that will catapult physics into spheres beyond the conceptual frames, codes and modeling practices that held before 1905.

The factual narrator becomes the abstract organizing principle of the discourse, which performatively demonstrates the necessity of reconceptualization of the physical knowledge. The "we-narrator" is thus also a epistemic narrative instance, which formulates the implicit hope that a mathematical form will be found that supports the new relativistic modeling strategy, so that the rhetorical strategy of inclusion through the personal pronoun in the first person plural becomes epistemically plausible. In this respect the "we-narrator" as an epistemic narrator also implies a "you," the addressee. The entire logical and rhetorical argumentation strategy of the text is aimed at this abstract "you." Interestingly, by this scientific discourse strategy, addresser and addressee coincide in the "we" figure, they seem to merge – if only partially. Yet can the reader, the addressee, also truly feel subsumed under this "we?" What mathematical and narrative strategies does the mediating voice use to convince them? How do they complement one another? A "strategy of immersion" for the addressee is needed.

Also: the "we-voice" is ascribed a certain epistemic profile. It is a functional narrator, which continually changes its epistemic profile in the light of new thought experiments and arguments. This epistemic narrator is thereby carefully and complexly configured, as will be shown. One can observe how this epistemic profile is first constituted as a voice in the context of the conventional theoretical frame in the extradiegetic level of narration and then becomes the shaping principle of theoretical frame-transformation within the intra- and metadiegetic narration. It is precisely the introduction of new frameworks that gives it the possibility to continually reconfigure itself as an epistemic narrative voice. This change in the narrator's epistemological profile will be traced through the following reading. At the same time, this will show the narrative framing techniques through which interformation is accomplished.

3 Narrative levels

Narrative levels (also referred to as diegetic levels) are – according to John Pier – "an analytic notion whose purpose is to describe the relations between an act of narration and the diegesis, or spatiotemporal universe within which a story takes place" (Pier 2014, § 1). I'll first give an overview on the levels and then discuss them in detail in a close reading.

The first-order narrative level one can call the "primary level" (with Wolf Schmid) or the "extradiegetic level" (with Gerard Genette). The writing/narrating instance here sets a framework, by crossing the principles from one theoretical frame to the other: the principle of relativity is transferred from the theory of mechanics to that of electrodynamics, while the principle of the constant velocity of light is transferred from the electrodynamics to the measurement rules of mechanics. Then he introduces inertial systems, determines the position of coordinate-systems in space, defines the geometrical structure of space and the necessary conditions for the definition of simultaneity. At the same time, he determines a rule-guided practice for the measurement of times, distances and for the observation and measurement of electromagnetic processes for both observer-figures of the second, the intradiegetic level. The extradiegetic narrating instance speaks from the perspective of a mathematical space that is not yet well-defined, because it oscillates between Euclidean space – that of the Newtonian frame – and a possible non-Euclidean space that is yet to be defined.

The secondary intradiegetic level on which the observers act, sets a new framework, that of the performative thought experiment. The events unfold here directly before the mind's eye of the reader. They involve a special observational and experimental design, in which the constancy of the speed of light becomes the principle of measurement for the re-conceptualization of simultaneity. This new measurement practices have never been used before. Certain conditions are introduced for this reason: a mathematically homogeneous and isotropic space has to be introduced as a setting for this thought experiment. In addition, the reference-frames of the observer-figures who carry out the measurements have to be defined. These reference-frames are inertial systems, uniformly moving or stationary systems that do not accelerate. This is the second framework of experimental arrangement of the intradiegesis, in which observers perceive light-events, make measurements and announce measurement results from their own reference-frames. The criterion of perception points to the text's focalization-structure, in Genette's terminology, or perspective-structure, in Wolf Schmid's (2010; 2014, 132–140) text-inference model. The third level of modeling, on which the Lorentz transformation is introduced, is here designated as the "metadiegetic level" (following Genette), or the "tertiary level" (following Wolf Schmid).

The third metadiegetic level therefore constitutes the turning-point of knowledge, because on this level of theoretical modeling it can ultimately be determined that the space can no longer be Euclidean in its fundamental geometry, as the space has been assumed on the first, extradiegetic level. It will only later – in 1908 – receive a name from the mathematician Minkowski: it is the mathematical four-dimensional Minkowski space. Minkowski's geometry is based on the symmetry of the Lorentz group demonstrated by Einstein in this treatise. Minkowski space is fundamentally different from extradiegetic Euclidean space throughout, in that in this new world, as Minkowski himself called it, space and time unite as dimensions into a four-dimensional space-time continuum. We have to consider here the epistemic transformation of the fundamental space time relations. 1909 Minkowski makes explicit reference to the space-time continuum that Einstein had theoretically constituted in his treatise:

> The views of space and time which I want to present to you arose from the domain of experimental physics, and therein lies their strength. Their tendency is radical. From now onwards space by itself and time by itself will recede completely to become mere shadows and only a type of union of the two will still stand independently on its own.[19]
>
> (Minkowski 2012 [1909], 39)

Here again we have to adress a specific problem of science narratology. While for the "classical narratology" in Genettian terms new diegetic levels are opened by new narrators, I would propose to consider if in this type of texts new narrative levels can be legitimized by fundamentally new conceptions of space and time and implicitly so by the hint of the necessity of the transformation of the epistemic profile of the narrating instance that narrates such a thought-experiment and of its adressee. So while the extradiegetical space has to be conceptualized as a Newtonian space in the Newtonian theoretical frame, the intra- and metadiegetic spacetime relations have to be conceptualized as relativistic spacetime relations.

Furthermore, I would like to show that this ternary architecture of narrative levels, so carefully designed by Einstein, undergoes a metaleptic transgression at the end of the treatise: The metadiegetic inner level is turned outwards. It becomes indeed the point of departure, the so-called 'extradiegetic level' for all important theories that operate in the frame of relativistic physics after Einstein's treatise from 1905. In order to constitute themselves as fundamental laws of nature, they can no longer avoid considering non-Euclidean, Minkowskian space geometry, and have to be covariant under the Lorentz transformation. These are lasting requirements that Einstein settled with his treatise on the special relativity theory.

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19 "Die Anschauungen über Raum und Zeit, die ich Ihnen entwickeln möchte, sind auf experimentell-physikalischem Boden erwachsen. Darin liegt ihre Stärke. Ihre Tendenz ist eine radikale. Von Stund' an sollen Raum für sich und Zeit für sich völlig zu Schatten herabsinken und nur noch eine Art Union der beiden soll Selbständigkeit bewahren" (Minkowski 1909b, 1).

3.1 Primary level: Extradiegetic

3.1.1 The relativistic reformulation of mechanics

The first step of modeling in the text is devoted to reconceptualizing the classical definition of the time-conception in physics. Einstein first asserts that the concept of time in physics is not rigorously logically defined. The way that he chooses here is that of transition from an absolute concept, as Newton had defined it, to a relational functional concept that is appropriate to the new relativistic theoretical frame of physics.

Before the beginning of the definition of simultaneity, Einstein determines the elements that will be incorporated in the construction of the modeling of his theory: these include the kinematics of rigid bodies, clocks, and electromagnetic processes, i.e. light. The extradiegetic level is still situated in the Newtonian space, as the functional, epistemic narrator puts it:

> Consider a coordinate system in which the Newtonian mechanical equations are valid. To distinguish it verbally from the coordinate systems that will be introduced later on, and to visualize it more precisely, we will designate this system as the "system at rest."
>
> If a material point is at rest relative to this coordinate system, its position relative to the latter can be determined by means of rigid measuring rods using the methods of Euclidean geometry and can be expressed in Cartesian coordinates.[20]
>
> (Einstein 1989 [1905], 141)

Although the argumentation aims at repurposing highly abstract concepts, it does so by using a very concrete setting, concrete material objects and reference values and very simple observer figures, who are defined throughout only by the fact that they wear a watch, in order to be able to read out the time. When it comes to the motion of rigid bodies, everything is already understood by the laws of mechanics – so it is claimed. One needs only apply these laws consistently – also taking electrodynamical processes into account. But that's the catch. Michelson and Morley's experiments on the speed of light – revealed that the speed of light remains constant everywhere and is thus independent of the motion of the body that emits it. This principle now had to be unifyed consistently with the

20 "Es liege ein Koordinatensystem vor, in welchem die Newtonschen mechanischen Gleichungen gelten. Wir nennen dies Koordinatensystem zur sprachlichen Unterscheidung von später einzuführenden Koordinatensystemen und zur Präzisierung der Vorstellung das 'ruhende System.' Ruht ein materieller Punkt relativ zu diesem Koordinatensystem, so kann seine Lage relativ zu letzterem durch starre Maßstäbe unter Benutzung der Methoden der euklidischen Geometrie bestimmt und in kartesischen Koordinaten ausgedrückt werden" (Einstein 1905, 892).

remaining principles of mechanics, even at the cost of reconceptualizing some other codes. The solidarity between addresser and addressee is accepted so long as one sticks on the common ground of well-known principles, codes and practices of modeling: “If we want to describe the *motion* of a material point, we give the values of its coordinates as a function of time” (Einstein 1989 [1905], 141).[21] This is a practice that has held in physics since the introduction of the Cartesian coordinate system. Yet now the epistemic narrator begins to reconcepualize the physical signification of time. An empirically adequate concept of time can only be obtained according to Einstein, if one firstly, ties it to events, secondly, correlates it with the concept of simultaneity, and thirdly, measures it with the help of the natural constant light velocity.

> However, we should keep in mind that for such a mathematical description to have physical meaning, we first have to clarify what is to be understood here by “time.” We have to bear in mind that all our propositions involving time are always propositions about *simultaneous events*.[22] (Einstein 1989 [1905], 141)

3.2 Secondary level: Intradiegetic

In order to bring this before the reader’s mind’s eye, the treatise opens a second narrative level: that of a thought experiment. In terms of representational logic, this is an intradiegetic level. Protagonists of this narrative are figures as observers, who carry out measurement actions in their own world, and consider and evaluate the results in their own and different reference-systems. If the primary “we-narrator” had a conative function, which comments on and evaluates the measurement activities of the observers, then the observers have a performative function: they perform the measurements – indeed fictive, but immersive – directly before the eyes of the reader. The mode of distance in which the narrator operates varies with that of the proximity in which the observer figures act. To this extent the passages in which the observers carry out the measurements performatively before the eyes of the reader can be regarded as *mimesis* passages, which are embedded in the overall process of the *diegesis*. Note that this is not a

21 “Wollen wir die Bewegung eines materiellen Punktes beschreiben, so geben wir die Werte seiner Koordinaten in Funktion der Zeit” (Einstein 1905, 892).

22 “Es ist nun wohl im Auge zu behalten, daß eine derartige mathematische Beschreibung erst dann einen physikalischen Sinn hat, wenn man sich vorher darüber klar geworden ist, was hier unter ‘Zeit’ verstanden wird. Wir haben zu berücksichtigen, daß alle Urteile, in welchen die Zeit eine Rolle spielt, immer Urteile über *gleichzeitige Ereignisse* sind” (Einstein 1905, 892–893).

matter of the Platonic concept of *mimesis* as "imitation," but rather of Aristotle's *mimesis praxeos* – a practice that serves to produce and establish evidence. On the specific narrative techniques of "we-narrators" in literary texts, Fludernik (2011, 101) also asserts that it is a characteristic of "we-narrative" to undermine and counteract the systematic border between the extradiegetic and intradiegetic. Fludernik points out refering to Marie Laure Ryan's (2001) concept of immersion:

> One can achieve a sliding scale by noting that in [...] *we* texts the barrier between the diegetic and extradiegetic levels is already porous since the first person narrators [...] share an existential core with a narrator or narratee on the extradiegetic plane. [...] The successful strategy of you and we narratives has been to draw the reader into the text by way of imaginative *immersion*. (Fludernik 2011, 122)

3.2.1 Relativity of simultaneity

From here on, the concept of "simultaneity," previously taken for granted in the history of physics, is put into question. Einstein asks persistently: What does "simultaneity" actually mean? In doing so, he asserts that every judgement about time can fundamentally only be made when one makes a judgement about simultaneity. The comparison of two reference-systems with one another is also necessary for the determination of time, because it always inevitably relates two different events to one another. I cite Einstein's original paper: "If, for example, I say that 'the train arrives here at 7 o'clock,' that means, more or less, 'the pointing of the small hand of my clock to 7 and the arrival of the train are simultaneous events.'" (Einstein 1989 [1905], 141)[23]

Now a new problem arises for Einstein: It is not enough to define the time of an observer's reference-system by the display of his personal clock. It is important to correlate measurements of two observers that observe the same event but are placed in different inertial frames of reference. Would the clock of the first observer suffice as a measuring instrument to indicate the proper-time of another observer who is not located in the same place? Could one correlate two observations of the same event-sequence with one another in this way? The obvious solution would be to provide both observers with their own clocks. However, this, according to Einstein would do nothing but introduce a possibility of

23 "Wenn ich z. B. sage: 'Jener Zug kommt hier um 7 Uhr an,' so heißt dies etwa: 'Das Zeigen des kleinen Zeigers meiner Uhr auf 7 und das Ankommen des Zuges sind gleichzeitige Ereignisse'" (Einstein 1905, 893).

defining the time of the first observer A, on the one hand, and the time of the second observer B, on the other hand. One would still have found no reliable rule that correlated or even related both times with one another. The two time records are thus not only defined independently from one another, they could also be different. The problem is formulated as follows in Einstein's paper:

> Such a definition is indeed sufficient if time has to be defined exclusively for the place at which the clock is located; but the definition becomes insufficient as soon as series of events occurring at different locations have to be linked temporally, or – what amounts to the same – events occurring at places remote from the clock have to be evaluated temporally.[24] (Einstein 1989 [1905], 142)

Next, the presentation makes recourse to techniques of focalization. If one assumes that at point A there is an observer who reads from his clock and marks the point of time at which a beam of light arrives, one finds that he does not arrive to the same measurement result with that of observer B, who reads from his clock the time at which a light signal reaches him. The horizons of perception and knowledge of each observer are – from a narratological perspective – internally focalized. In the language of physics, a science narratology concept of internal focalization is stated like this in the "Electrodynamics of Moving Bodies:"

> To be sure, we could content ourselves with evaluating the time of the events by stationing an observer with the clock at the coordinate origin, and having him assign the corresponding clock-hand position to each light signal that attests to an event to be evaluated and reaches him through empty space. But as we know from experience, such an assignment has the drawback that it is not independent of the position of the observer equipped with the clock.[25] (Einstein 1989 [1905], 142)

Einstein proposes to equip the internally focalized figures with a criterion for time-measurement that allows them to both perform precise time-measurements

24 "Eine solche Definition genügt in der Tat, wenn es sich darum handelt, eine Zeit zu definieren ausschließlich für den Ort, an welchem sich die Uhr eben befindet; die Definition genügt aber nicht mehr, sobald es sich darum handelt, an verschiedenen Orten stattfindende Ereignisreihen miteinander zeitlich zu verknüpfen, oder – was auf dasselbe hinausläuft – Ereignisse zeitlich zu werten, welche in von der Uhr entfernten Orten stattfinden" (Einstein 1905, 893).
25 "Wir könnten uns allerdings damit begnügen, die Ereignisse dadurch zeitlich zu werten, daß ein samt der Uhr im Koordinatenursprung befindlicher Beobachter jedem von einem zu wertenden Ereignis Zeugnis gebenden, durch den leeren Raum zu ihm gelangenden Lichtzeichen die entsprechende Uhrzeigerstellung zuordnet. Eine solche Zuordnung bringt aber den Übelstand mit sich, dass sie vom Standpunkte des mit der Uhr versehenen Beobachters nicht unabhängig ist, wie wir durch die Erfahrung wissen" (Einstein 1905, 893).

relative to their own reference-systems and to correlate these with one another. How is this possible? By first recoding the times of the two observer-figures, and second, correlating them with fundamental physical principles, such as the constancy of the speed of light. The following diagram (Fig. 1), which represents a light-clock, illustrates the arrangement of the thought experiment.

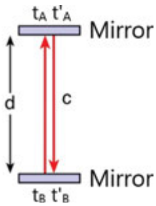

Fig. 1: A photon is sent from the upper mirror to the lower mirror. The observer measures the time for the photon travel from the upper mirror to the lower mirror and back while moving with the photon. "Zeitdilatation." https://physikunterricht-online.de/wp-content/uploads/2017/02/Lichtuhr.jpg. *Physikunterricht Online*. February 2017 (9 Juli 2021).

Thus it is possible to stipulate definitionally that the time required for a beam of light to travel from the first observer-location t_A to the second observer-location t_B, is equal to the time required by a beam of light to return back to point t'_A once it is reflected from t'_B This may be modelled in the symbolic form-relation:

$$t_B - t_A = t'_A - t'_B$$

Equipped with this equation for synchronicity, Einstein examines the validity of the proposed equivalence-relation, which has to fulfil three criteria. First is the criterion of reflexivity (i.e. identity): $t_A = t_A$. Second is the criterion of symmetry: if the clock in A is synchronous with the clock in B, then one can implicitly conclude from this that the clock in B is also synchronous with the clock in A. And finally there is the criterion of transitivity, the transfer of the synchronicity-relation to a third element: If the clock in A runs synchronously with both the clock in B and the clock in C, then the clock in B also runs synchronously with the clock in C.

To summarize: This section of Einsteins's treatise proposes a definition of simultaneity that reconceptualizes "time" as a concept. Einstein converts time into an 'operational concept' of physics.[26] For this sake he has to recode, to re-semioticize it according to a new sign relation. The sign function is not only constituted through one watch, but through two watches, whose informations are correlated through the speed of light. The constancy of the speed of light is the determinant factor that generates the sign function between the two watches. The definition of time can not be realized without a physically reasonable definition

26 Cf. Winfried Thielmann's paper "Concept Formation in Physics from a Linguist's Perspective" in this volume.

of “simultaneity.” However, a rational definition of simultaneity can only be operationalized by resorting to the principle of the constancy of light velocity. The second and fourth sections of Einstein’s paper uses epistemic narrativity in order to perform this re-semioticization, this re-coding of time. More than that, thought-experiment measurements and epistemic narrativity show that the concept of absolute time is not necessary anymore, as well as that of absolute simultaneity.

Through this new definition of synchronization of clocks it becomes clear that two observers will not, as a rule, have the same perception of one and the same event, if they are located in different reference-systems as inertial-systems moving parallel to one another. For it is light that conveys the information about the occurrence of the event. But light has only a limited velocity. The information cannot reach both observers simultaneously if they are located in different inertial-systems, at rest or in motion. Therefore a tertiary modeling level is needed, in order to transform the places and times of the coordinate-axes of the two observation frames into one another and thereby to correlate the observers’ perception and knowledge horizons. As Einstein puts it:

> Here,
>
> $$\text{velocity} = \frac{\text{light path}}{\text{time interval}},$$
>
> where “time interval” should be understood in the sense of the definition in § 1.[27]
> (Einstein 1989 [1905], 143–144)

The epitome of Einsteinian interformation process is conceptually concentrated in the notation of the above-cited fraction, ‘light path / time interval.’ This also signals the change in the codes of the measurement narrative. Although clocks are still in use, another relevant quantity is added, the speed of light. It is the natural constant that enables the comparison between the two running clocks. It stands in the numerator of the upper fraction, while time-interval stands in the denominator. The duration that light takes to travel a certain distance always remains constant in a vacuum, independent of direction and reference-system. This is why the speed of light becomes the relevant quantity for the time measurement, because it is a natural constant. Clock-time is the relevant first-order measurement of the proper-time of the observers in their own frames of reference. But we need a second-order correlation between these two proper

27 “Hierbei ist Geschwindigkeit $= \frac{\text{Lichtweg}}{\text{Zeitdauer}}$, wobei ‘Zeitdauer’ im Sinne der Definition des § 1 aufzufassen ist” (Einstein 1905, 895).

times and their spacetime structure, that means their world-lines, and this is the constancy of the speed of light. Only the second-order correlation that is granted to the intersection of principles of electrodynamics to mechanics opens up the third level of modeling – that of the Lorentz transformation relation.

The speed of light is the relevant second-order correlation, to relate the measured proper-times of the two observers. An epistemic break arises between the new Einsteinian-Lorentzian concept of local-time and the old Newtonian-Kantian concept of absolute time. The determination of the time of occurrence of an event is now dependent on the constancy of the speed of light. The light-path defines the event's duration as relative to the reference-frame of the observer. In this way Einstein demonstrates that there is no absolute simultaneity and he proposes a threefold time-conception: The local-time or proper-time as a first order time indication, the second-order correlation between local times and the third-order transformation relation between the two local times.

3.2.2 Internal and external focalization: Time dilation

The fourth section repeats the thought experiment of the second section, now under the application of the Lorentz transformation. That's why it is titled: "The physical meaning of the equations obtained concerning moving rigid bodies and moving clocks" (Einstein 1989 [1905], 151).[28] Again this concerns the measurement of the amount of time it takes a beam of light to make its way back and forth between two mirrors.

In order to understand the point of this thought experiment let us assume that the above shown clock moves past the earth in an imaginary rocket at a very high velocity (close to the speed of light). Two different observers, as shown in the two graphics below, now observe the path of the light beam and its arrival at the original mirror. In the first graphic (Fig. 2) the moving observer S' performs his time-measurement from inside the rocket, moving with the light-clock. His frame of reference can be defined as internally focalized from within the rocket. Observer S' calculates the path of the light between the two events – the first event of light emission from the first mirror, and the second of the re-arrival of the light beam back at the first mirror – as twice the distance of the path of the light, divided by the speed of light: $t' = \frac{2d}{c}$.

28 "Physikalische Bedeutung der erhaltenen Gleichungen, bewegte starre Körper und bewegte Uhren betreffend" (Einstein 1905, 903).

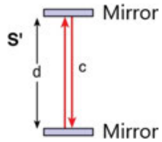

Fig. 2: Internally focalized measurement: A photon is sent from the upper mirror to the lower mirror. The observer measures the time for the photon travel from the upper mirror to the lower mirror and back while moving with the photon.
"Zeitdilatation." https://physikunterricht-online.de/wp-content/uploads/2017/02/Lichtuhr.jpg. *Physikunterricht Online*. February 2017 (9 Juli 2021).

Now the second observer S is shown in the graphic below (Fig. 3), who watches the flight of the rocket from the Earth, as an external observer. He focalizes the rocket-flight and the beam-light measurement externally and measures a different duration for the same event.

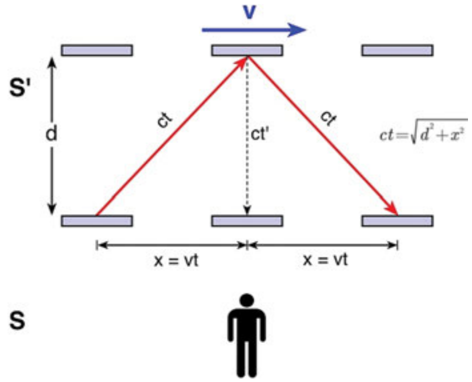

Fig. 3: Second measurement frame, externally focalized: Moving light clock from the perspective of the earth observer.
"Zeitdilatation." https://physikunterricht-online.de/wp-content/uploads/2017/02/Lichtuhr.jpg. *Physikunterricht Online*. February 2017 (9 Juli 2021).

The Earth-observer S fulfills an externally focalized measurement-act from the Earth. Accordingly, the light takes a longer time to travel from the starting-mirror to the end-mirror and back, because the light-clock in the rocket moves in the mean time, as the 'static' observer sees it from earth. For this static observer on the earth, light does not take a straight doubled path $(2ct')$ back and forth as for observer S', but rather a diagonal doubled path $(2ct)$, which is longer than the path (ct') that the moving observer measures. The path that the Earth-observer measures can be calculated using the Pythagorean theorem: $(ct)^2 + (ct')^2 = (vt)^2$. The time-duration t that the light needs to travel from the starting-mirror to the end-mirror and back measured by the externally focalizing observer (S) is longer than the time t' that is measured by the internally focalized observer that is moving with the light-clock (S'), because the latter is in the same inertial reference frame as the rocket. The relation between t (the time measured by the external focalizer) and t' (the time measured by the internal focalizer) is:

$$t = t' \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$$

This is how the relativistic concept of time dilation is explained. The factor on the right side of the above equation is the Lorentz factor, where v symbolizes the velocity of the rocket, c the light velocity. The special relativity theory states that the light velocity is the highest possible velocity that has been ever measured. So the velocity of the rocket v is always smaller as the light velocity c. That's why t, the time measured by he external focalizer will have a longer duration than t', the time measured from the internal focalized reference system. And that's why Einstein can conclude that simultaneity is relative.

Thus it also turns out that clocks carried by observers in moving coordinate-systems read from the external perspective of an observer in a stationary system run more slowly. Light establishes the semiotic sign-correlation by conveying information about the occurrence of an event. But the speed of light is also limited. Information can not reach both observers with equal speed, if one of them is at rest and the other is moving. The observers observe the same event at different time, depending on how far they are from the light source. This difference will always exist. Time information is always given relative to one's own reference-system. For the constancy of the finite speed of light prevents absolute simultaneity and makes clear that each reference-frame has its proper-time.

3.2.3 Event-horizons of the observers and their space-time boundaries

Minkowski showed in 1908 that the causal structure of four-dimensional space-time is defined by space-like, time-like, and light-like vectors marked by the arrows in the graphic below (Fig. 4).

The lower light cone represents the past of the observer, with all events and processes that he could in principle perceive. The upper light cone represents the future. Light forms the light cone, the light-like vectors are identified by the surface lines of the cone. The light-like vectors limit the event-horizon of every observer located on a world-line. The middle axis of the light cone symbolizes the time-like difference-vector. The boundaries of the light cone are the limits of the observer's perception horizon, so they are the limits of the world of the

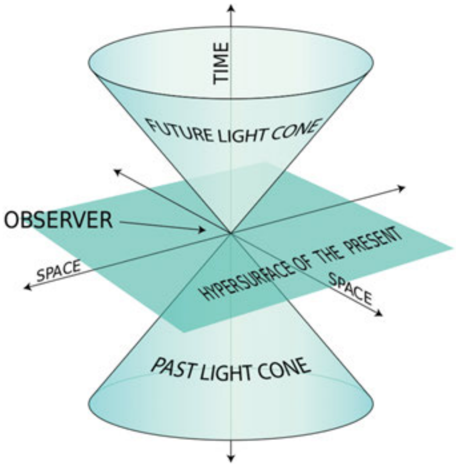

Fig. 4: Diagram: Light cone in 2D space plus one time dimension. The forward-cone is in positive time-direction. The observer of an event E is located at the intersection of past and future cones (present).
"Light cone." https://upload.wikimedia.org/wikipedia/commons/thumb/1/16/World_line.svg/800px-World_line.svg.png. *Wikipedia: The Free Encyclopedia* (9 Juli 2021).

observer. This is the epistemic result of the intradiegetic thought-experiment: It shows the boundaries of the observer's perception. All events that occur within the light cone can reach him. Events that occur outside the light cone cannot reach the observer's perception in principle. An observer who acts only on the level of the empirical, and has no symbolic framing-structure, cannot know what happens outside of his event-horizon, due to the empiric limitation of its event-horizon within the four-dimensional Minkowski world, as described in the above diagram. This is postulated by the theory of relativity.

Thus the thought experiment is necessary as a symbolic fictional narrative which reveals what has to be assumed as factual in the future. The function of the epistemic narrative is to demonstrate the empiric limitations of the perception of the internally focalized observer due to the boundaries of the light cone, that means due to the fundamental structure of the space-time in the theory of relativity. This space time structure sets the limited event-horizon of the internally focalized observer and his measurements. The epistemic narration also shows – immersively – the consequences that are to be drawn from this limitation: the necessity of the existence of a tertiary mathematical, formal modeling level, that allows to transform the empirical coordinates into abstract mathematical coordinates. This puts at disposal a transformation relation that establishes a correlation between the space-time coordinates of the two observers who are situated at different space-time points.

3.3 Tertiary level: Metadiegetic

In Genettian terminology, any further narrative level after the extradiegetic and intradiegetic levels is called a "metadiegetic" level. I will call this third level a tertiary metadiegetic narrative level. What changes here is the semio-logical code for the conceptualization of space and time. While the extradiegetical level is still situated in a Newtonian space-time structure with Euclidian geometry, the metadiegetical level unites time and space due to the Lorentz transformations and their symmetry-group.

3.3.1 Lorentz transformation

The *third section (§3)* of "Electrodynamics of Moving Bodies" demonstrates the compatibility of the two fundamental principles of mechanics and electrodynamics, which initially appeared incompatible: the principle of relativity and the constancy of the speed of light. It then becomes clear that this compatibility is indeed possible, but only on the assumption of an internal recoding: by the replacement of the Galilean transformations of mechanics with the Lorentz transformations of electrodynamics. Under this condition, the principle of relativity can be retained, and also apply to electrodynamics (Schröder 1990 and 2014). For this, one must introduce a different transformation relation from that which originally applied on the extradiegetic-level, in the world of the primary narrator. The transformation relations of the extradiegetic level were still Galilean transformations. The transformation relations of the tertiary narrative level are Lorentz transformations. Where does the difference lie? And why is this important?

According to Einstein, the Lorentz transformations state: if an observer moves with constant velocity in direction x then the coordinates (x, y, z for space and t for time) that he assigns to an event can be correlated and transformed into the coordinates (x', y', z', t') of a second observer of the same event, if the form of the equations that constitute the Lorentz transformation remains invariant. The two reference-systems of the two observers have to coincide with one another at time $t = t' = 0$. Then the two coordinate systems differ from one another in the x' and t' directions by the so-called "Lorentz factor," which is on the right side of the two equations of the Lorentz transformation shown below.

$$t' = \frac{t - \frac{v}{c^2}x}{\sqrt{1 - \frac{v^2}{c^2}}}$$

$$x' = \frac{x - vt}{\sqrt{1 - \frac{v^2}{c^2}}}$$

$$y' = y$$

$$z' = z$$

The system of equations of the Lorentz transformation has several functions: it offers the possibility of operating with different observer-times as proper-times, because the equation-system correlates and transforms them into one another. It justifies the legitimacy of the proper-time of each individual observer-system in his frame of reference as an inertial-system. It also justifies why the phenomena of Lorentz contraction and time dilation are not necessarily paradoxical, but rather each has its validity, even when this contradicts classical mechanics.

The Lorentz transformation stands for a mathematical modeling practice that is inscribed with the fundamental postulate that no observer and no observation-system may be favored in its horizon of knowledge and perception. It postulates principially the equivalence of all inertial systems as far as their observations, perceptions and knowledge concerns, provided that they respect the new rule-governed practice of measurement. Through this transformation relation, the measurement results of both observers can be objectively correlated, even if their event horizons drift apart. Thus, primary context-dependence can be considered together with secondary operational context-independence, and can be integrated into a symbolic configuration on three different levels, while the third level reveals the appropriate transformation relation for the space-time coordinates from one frame of reference to the other. According to this the primary difference of the measurements results is validated as objective due to the different frames of reference and due to the limited event-horizon of the observers. This limit is imposed by the fundamental space-time structure of the universe. This difference on the primary level can be accepted because there is a mathematical transformation relation that establishes objectivity in spite of the differences on the primary level. Thus symbolization in the mathematical code of the secondary level is a necessary condition for context-independent objectivity that is finally achieved through the Lorentz transformation relation on the tertiary level. Later this new theoretical model can become factual, if the mathematical model is validated – i. e. cannot be falsified – by repeated experiments. But this future factuality is also mediated through functional epistemic narrativity, that's what is argued here.

Let's summarize the narrative thought-experiment and its epistemic results: First, there is the internally focalized observer in the rocket and the externally focalized observer on the earth. They observe the occurrence of the light events, perform their measurements and make their time-specifications. Each observer observes, however, not only the events of his own internal frame of reference, but also the occurrence of events in the external frame of reference. The problem is, that the internal and external focalized measurement results of the same event are not identical. The two different observers measure different time-durations: On the one hand there is the internally coded proper-time measured by the observer within the rocket. On the other hand there is another measurement result of the same light-signal-event measured by the earth-observer. This is an externally focalized measurement, from the stationary frame of reference of the earth.

The narative instance functions as "reflector," compares the measuring results of the two observers with one another and demonstrates the conundrum that observers who measured the same light-events happening at the same time have arrived at different interpretations of the measurement results. That's why the epistemic narrator functionally reconceptualizes the concept of simultaneity in physics by defining it in terms of the constancy of the speed of light. The functional epistemic narrator has, however, as a we-narrator, the peculiar quality that he contradicts the conventional categorizations and metaleptically transgresses the boundaries between narrative levels (Fludernik 2011, 122). He thus can show that the two different measurements, which on the first level of modeling diverge empirically, can be correlated objectively through the precise Lorentz transformation that is introduced on a tertiary level. This rule for the transformation of space-time coordinates between the two frames of reference is based on the symmetry-relation that is essentially mathematically coded and that functionalizes the symbolic operations of the secondary modeling level, that of mathematics.

The implied reader in turn observes both the results of the measurement procedures, which are different for simultaneous events, as well as the observation, evaluation and reflection process of the epistemic narrator in relation to the differences between the measurement results. The result of the thought experiment can be specified in three points. A: Simultaneity is relative. B: Time dilation and space contraction exist objectively and can be measured. C: Time specification is only possible relative to one's own reference system. Each observer has an autonomous proper-time, which, however, does not remain monadically uncorrelated, but rather can be related to the proper-times of other observers, without any need to assume the Newtonian absolute time – but through using the Lorentz transformation relations.

Einstein's treatise demonstrates through this thought experiment that first-order quantities – those of primary measurement-modeling – can be different from one another in different reference-systems, on the condition that the second-order operational system based on mathematics opens the formal possibility to apply the third-order transformation rules. From this third order frame of modeling, that of transformation, one can understand why the measurement results of both observers are objective in spite of the difference between them. The delation is due to the reference system of observation, due to the specific structure of spacetime and due to the constancy of the speed of light.

3.3.2 The relativistic reformulation of electrodynamics

The *second part* of the Einsteinian treatise is devoted to electrodynamics. On the one hand, this is confronted with the theory of mechanics. On the other hand, this leads to Einstein's demand that the principle of relativity – now in its form as modified in the third section – is also valid for the Maxwellian equations of electrodynamics, due to the Lorentz transformations. If the requirement of the principle of relativity is correct for the Maxwellian equations, then the same laws would have to apply for moving as well as stationary inertial systems. For this purpose, the demonstration of the covariance of the Maxwell equations with respect to the Lorentz transformation is required and demonstrated. The equations for moving and stationary systems are consistent with one another, except for one factor, the so-called Lorentz factor, which interestingly has the same form as the equations that determine the coordinates of space and time. This results in an important consequence: the Lorentz transformations are valid for both the equations of mechanics, that is, for the movement of bodies in time and space, and for the equations of electrodynamics, that is, for the laws of optics, electricity and magnetism. Thus these fundamental Lorentz transformation relations connect mechanics with electrodynamics. Einstein summarizes the changes that accompany this in the formulation of electrodynamics in the following revision:

1. If a pointlike unit electric pole is in motion in an electromagnetic field, there will act on it, in addition to the electric force, an "electro-motive force" which, if we neglect terms multiplied by the second and higher powers of v/V, equals the vector product of the velocity of motion of the unit pole and the magnetic force, divided by the velocity of light. (Old mode of expression.)

2. If a pointlike unit electric pole is in motion in an electromagnetic field, the force acting on it equals the electric force present at the location of the unit pole, which is obtained by transforming the field to a coordinate system that is at rest relative to the unit electric pole. (New mode of expression.) (Einstein 1989 [1905], 159)[29]

It follows that electric and magnetic fields are subject to the principle of relativity as Einstein formulates it. At the beginning of his treatise Einstein has pointed out that the following asymmetry within the Faradayan law of induction was a problem: That an *electric field* arises *around* a moving magnet when it is moved along a stationary conductor, while an *electromotoric force* would arise *within* a moving conductor when this approaches a magnet. Einstein proves in his treatise that this asymmetry now proves to be relative, too, since the electromotoric force appears only from the view of the moving observer. Because the speed of light is in any case invariant with respect to moving or stationary systems, and because the Maxwell equations show that electromagnetic waves are light, thus Einstein's newly formulated principle of relativity is compatible with the principle of the constancy of the speed of light.

Another important result of the thought experiment within the relativity theory: 'Lengths of objects' can also no longer be described as absolute, but rather only as relative quantities. The length of a body in motion appears to be shortened for a stationary observer, as Einstein demonstrates in this treatise: "A rigid body that has a spherical shape when measured in the state of rest thus in the state of motion – observed from a system at rest – has the shape of an ellipsoid of revolution" (Einstein 1989 [1905], 152).[30] Such descriptions are in principle possible only relative to one's own inertial system. However, there is the

29 "1. Ist ein punktförmiger elektrischer Einheitspol in einem elektromagnetischen Felde bewegt, so wirkt auf ihn außer der elektrischen Kraft eine 'elektromotorische Kraft,' welche unter Vernachlässigung von mit der zweiten und höheren Potenzen von v/V multiplizierten Gliedern gleich ist dem mit der Lichtgeschwindigkeit dividierten Vektorprodukt der Bewegungsgeschwindigkeit des Einheitspoles und der magnetischen Kraft. (Alte Ausdrucksweise.) 2. Ist ein punktförmiger elektrischer Einheitspol in einem elektromagnetischen Felde bewegt, so ist die auf ihn wirkende Kraft gleich der an dem Orte des Einheitspoles vorhandenen elektrischen Kraft, welche man durch Transformation des Feldes auf ein relativ zum elektrischen Einheitspol ruhendes Koordinatensystem erhält. (Neue Ausdrucksweise)" (Einstein 1905, 909–910).

30 "Ein starrer Körper, welcher im ruhenden Zustand ausgemessen die Gestalt einer Kugel hat, hat also im bewegten Zustande – vom ruhenden System aus betrachtet – die Gestalt eines Rotationsellipsoides" (Einstein 1905, 903).

Lorentz transformation, that allows for very precise transformations from one coordinate-system to another, without any observer absolutizing their own observation and ignoring that of others.

The principle of relativity states that primary modeling, measurements and observations can in principle only be made by specifying one's own reference-system. Quantities and lengths then appear differently from the perspective of different reference-systems. There is nothing that needs to be fixed here; it does not endanger the process of objectivization in physics because there exist covariant transformation relations. The fundamental constraint of the theory of relativity is the covariance relation. It states that all reference-systems that move uniformly and without acceleration are aequivalent in their measurements and specification of quantities if there exists a covariant transformation relation. In general relativity theory, this basic postulate of equality will apply to all reference-systems, including all accelerated systems. The differences that arise in the measurements of quantities are only first-order differences that are legitimized by the relativity principle. Due to the relativity principle and the Lorentz covariance relation the differences that arise in the measurements and observations are legitimate because they are conditioned by the structure of space-time. There is no "absolute instance" that provides *one* "correct measurement." All we can have is a covariant transformation relation. Due to the interformation process which includes this tertiary modeling configuration, Newton's conceptions of absolute space and absolute time proved to be just habits of thought and explained to be dispensable.

3.3.3 Reconceptualization of mass: Equivalence between mass und energy

Einstein uses the *ninth section (§9)* to show that the mass of bodies too, which in classical physics was still regarded as unchangeable, can only be specified relative to certain reference-systems, in the conceptual reference-frame of the theory of relativity, and that in addition they appear differently from different perspectives. A body at rest is granted its resting mass. But viewed from a moving body, that same body is ascribed a "dynamic mass" that does not coincide with the resting mass. In this respect, another fundamental law of mechanics of conservation of mass is revised by Einstein. Since it can now be assumed that a moving body also changes its mass, the law of conservation of mass can likewise no longer apply. Along with the length and volume of a body, a further "primary quantity," which Galilei had postulated as an objective quantity for the grounding of physics, now proves to be relative according to the theory of relativity.[31] But in this case too, the argument does not follow that thus "everything" proves relative. Mass is transformed into field-energy. Other quantities are now deemed invariant, laws of conservation of relativistic momentum and the conservation of energy apply here. Invariance is raised to a new level of modeling, at which other symmetry-group-laws apply. The new symmetry-group opens up new freedom of transformation.

Einstein dedicates the last, *tenth section (§10)* of his treatise to this famous statement, the equivalence of mass and energy. The concrete formula, however, which thanks to its formal simplicity became the icon of modern science, $E = mc^2$, is first introduced in a later essay.[32] Yet the recognition remains that in relativistic physics mass can be considered as a special form of (field-)energy, as the "stationary energy," or "resting energy" of a body.

Here finally the interformation process between the two theories, i. e. the intersection of principles and modeling practices stemming from mechanics and electrodynamics mediated through epistemic narrativity comes to a final result. Two concepts, that stem from both theories, "mass" from the mechanics and "energy" from the electrodynamics, are proved to be equivalent through one equation $E = mc^2$ and the mediation relation of the speed of light: when you accelerate a physical object to the speed of light, than its mass transforms into energy.

4 Summary of narratological analysis

Turning back to Martínez' catalogue of criteria of narrativity, another possible feature has to be mentioned, that of causality: "It is often required of well-formed narratives that the events must not only follow upon one another chronologically but also follow from one another causally. Changes of state would thus be motivated through a cause-effect connection" (Martínez 2017, 4).[33] It is beyond question that Einstein's factual narrative also meets this criterion. However, it

31 For a consideration of this problem of primary and secondary qualities in classical and modern physics from the philosophy of science, cf. the chapter by Van Fraassen: "Appearance vs. Reality in the Science" in Van Fraassen 2013, 270–276.

32 Fadner recounts the historical development of the mass-energy relation in Fadner 1988.

33 Transl. by MS. "Von wohlgebildeten Erzählungen wird häufig verlangt, dass die Ereignisse nicht nur chronologisch aufeinander, sondern auch kausal auseinander folgen müssten. Zustandsveränderungen wären so durch einen kausalen Ursache-Wirkungszusammenhang motiviert" (Martínez 2017, 4).

also surprises its readers by undermining the classical causality-relations of Newtonian mechanics and by replacing them with new, surprising causality-relations based on the Lorentz transformation relations: for example, that the mass of a body can decrease and turn into energy due to its increasing acceleration toward the speed of light. This causal relationship was not imaginable to the scientific community before Einstein. The conceptualization of mathematical equivalences between mass and energy and the equivalence between space and time are considered worth telling, i. e. narratable, due to the disruption of previously accepted causality-relations – and indeed not only for the scientific community, but also for the wider cultural semiosphere.

Let's resume the argumentation so far: Considered in terms of representational logic, the first level of narration and argumentation is that of the extradiegesis, in which the we-narrator introduces the problem and sets out the principles that underlie the theoretical modeling and argumentation. In addition, the writing/narrating instance comments and reflects on the different results of the repeatedly varied thought experiments in the intradiegesis, before and after the transformation. The thought experiment is located on the second level of the diegesis. It presents the relativity of measurements of each individual observer and the context-dependency of their horizons of perception and knowledge. The third narrative level is the level of metadiegesis. One can also call it "interdiegesis," because it establishes a connection between the world lines of the two observers. The Lorentz transformation correlates the worldlines of the two reference-systems with one another while preserving the differences of perception.

Considered in terms of functional logic the primary narrative level has a denotative function, the second level of the thought experiment has a performative and exemplificatory function, while the third level has a transformative function. All three together are part of the process of interformation, the process of creation as reconfiguration: Einstein correlates the principles of two theoretical fields, that are in certain respects incompatible, reworks their measurement and modeling practices and recodes them to a new, relativistic theory, through the introduction of the Lorentz transformation relation.

It is important to keep in mind the following: The level of metadiegesis is worked out during the process of modeling. The goal is to legitimize it logically to the extent that it does not remain an internal modeling only. Its mathematical legitimization and its narrative plausibilization through the thought experiment lead it to undergo a metamorphosis through metaleptic transgression. After it is tested and if it cannot be falsified, it becomes the starting point, the theoretical frame, the 'extradiegetic level' for the future. As long as no experiment falsifies the theoretical prediction, the theoretical model can be validated as a fact. It became the standard assumption for all subsequent relativistic theoretical modelings in physics after 1905, which from then on must take into account the relativistic Lorentz transformation. New physical theories can advance to fundamental laws only when they have taken into account this newly established symbolic code of the theory of relativity.

Einstein succeeded in actually operationalizing the definition of time in physical terms, and thus in revising the classical definition of absolute time. By superposing the principle of relativity with the principle of the constancy of light velocity, physics ensures the experimental controllability of the new interformative configuration. Narrative relates the mathematical model to the reference frame of human experienceability and simulates possible experimental designs to test this new emerged view on reality through the theory of relativity. If this succeeds, then the mimesis-dimension of the model can be reversed. Thus it would no longer be a retrospective model of reality, but a prospective model, which offers a new epistemic access to reality. It is in such cases of fundamental conceptual changes that mathematics is complemented by narrative strategies in an interformation process. The function of narrativity is to provide a system of observation that makes visible the epistemic, experiential and experimental structures of the new theoretical conceptions and the structures of creation as reconfiguration.

4.1 Eventfulness and tellability

The feature of "tellability" can indeed be ascribed to the Einsteinian treatise, because the text presents wholly new concepts as: the relativity of simultaneity, time dilation, the fourdimensional space-time and the equivalence of mass and energy. All four are disruptive concepts in the sense of Greimas and Porter Abbott, for they lead to subversion of old physical knowledge systems and implicitly to the reorganization of the experience of reality.

Wolf Schmid and Peter Hühn have declared the criterion of eventfulness to be the most important defining criterion of narrativity. Both build on Lotman's conception of literature as a secondary modeling system and from his definition of the "sujets" of narratives. That is a type of change of state of a special kind, which Lotman defines in terms of the categories of space and with reference to semantic fields: "an event in text is the shifting of a persona across the borders of a semantic field" (Lotman 1977, 233; 1972, 336). Yet as a cultural semiotician, Lotman naturally intends not only the transgression of a topographical border, the border can also be of a pragmatic, ethical, psychological or epistemological nature. Wolf Schmid has adopted and developed Lotman's concept of event:

> In today's narratology the concept of an event is somewhat more widely understood than with Lotman. An event is not necessarily the violation of a norm. It does not necessarily consist in the deviation from what is lawful in a given narrative world, the fulfilment of which maintains the order of this world. […] An event can also consist in a figure making a new recognition, revises a wrong understanding, committing to new values. […].[34]
> (Schmid 2017, 66–67)

Schmid emphasizes in *Narratology* as well as in his *Mental Events: Changes of Consciousness in European Narrative Works from the Middle Ages to Modernity* [*Mentale Ereignisse: Bewusstseinsveränderungen in europäischen Erzählwerken vom Mittelalter bis zur Moderne*] (2017), that this feature of eventfulness applies not only to literary-fictional texts in a narrow sense, but also to argumentative and descriptive texts. Schmid additionally specifies to what extent eventfulness may be attributed to descriptive and factual scientific texts:

> […] the resultant narrativity is related not to what is described but rather to the presence that describes and the way in which it does so. The changes that take place in this case are related not to the *diegesis* but to the *exegesis*; they are changes in the consciousness of the describing authority […].[35] (Schmid 2010, 6)

I deal with the criteria of disruption of knowledge systems, eventfulness and tellability because they are important for the analysis of the epistemic narrativity of Einstein's text, as a mode that complements descriptive and argumentative discourse modes. Einstein's treatise concerns the transgression of a cognitive boundary in the sense that principles and modeling practices that were previously contradictory are intersected in his treatise. The abduction process and the introduced Lorentz transformation led – through the mediation of epistemic narrativity – to epistemic transformation. This is the quintessence of the process of interformation.

Schmid extends the concept of change of state from classical narratology by specifying criteria with which one can identify high eventfulness and a

34 Transl. by MS. "In der heutigen Narratologie wird das Konzept des Ereignisses etwas weiter gefasst als bei Lotman. Ein Ereignis ist nicht notwendig die Verletzung einer Norm. Es besteht nicht notwendig in der Abweichung von dem in einer gegebenen narrativen Welt Gesetzmäßigen, dessen Vollzug die Ordnung dieser Welt aufrechterhält […] Ein Ereignis kann auch darin bestehen, dass eine Figur eine neue Erkenntnis macht, ein falsches Verständnis revidiert, sich zu neuen Werten bekennt. […]" (Schmid 2017, 66–67).

35 "[…] Das ist […] eine Narrativität, die nicht auf das Beschriebene, sondern auf den Beschreibenden und seine Deskriptionshandlung bezogen ist. Die Zustandsveränderungen, von denen hier erzählt wird, beziehen sich nicht auf die *Diegesis*, sind nicht *diegetische* Veränderungen, sondern beziehen sich auf die *Exegesis*. Es handelt sich bei den *exegetischen Zustandsveränderungen* um Veränderungen im Bewusstsein der beschreibenden oder erzählenden Instanz […]" (Schmid 2014, 7).

correspondingly high diegetic tellability. The first condition for Schmid (2017, 68) is that of facticity (in the context of the fictive world, of course, Schmid adds). This criterion of facticity holds true for Einstein's text doubly, perhaps triply. Time dilation and length contraction, both of which violate all possible codes, rules and experiments of physics before 1905, are first presented in fictional thought experiments and then substantiated by arguments. They cause a disruption of the tradition of knowledge systems, a violation of the semantic rules of the entire semiosphere. They are subsequently demonstrated through numerous experiments. The criterion of facticity for eventfulness and tellability would thus not only be fulfilled but also re-interpreted. Through his theory, Einstein forces the reader to a new logical investigation, verification and testing of hitherto assumed facticity. Through the thought experiments represented, he induces a reconceptualization of previous definitions of factuality, a rethinking of what can potentially be declared factual.

Wolf Schmid's second criterion is that of resultativity. Events are "not only begun, but rather are resultative, i.e. in the narrative world of the text they arrive at a conclusion" (Schmid 2017, 70).[36] Insofar as this is possible in an argumentative text of a theoretical nature, in which one cannot carry out any practical experiments, Einstein's text not only presents the relativity of simultaneity, time dilation and length contraction, as well as the non-existence of the ether, it also anchors them epistemologically, at the argumentative level, through the mathematical model of the Lorentz transformation.

The third criterion of narrativity and eventfulness is that of relevance. For Schmid the "concept of relevance is relative," for one must ask, "Relevant for whom? [...] Trivial, everyday changes do not constitute an event." The concept is thus level-specific and context-sensitive. This question also arises, of course, in the case of special relativity theory. For its validity is limited to phenomena that can be attributed a velocity approaching the speed of light. In everyday life one cannot perceive this. That's why these phenomena have long considered to be hardly conceivable for the common-sense intuition. However, on an epistemological basis, time and space are no longer distinguishable from one another. They merge into a four-dimensional space-time continuum, as Einstein showed. Furthermore, the relativity and context-dependency of the proper-time of each observer in each reference-system is of the highest cultural relevance, as the cultural reception of the theory of relativity has demonstrated.

36 Transl. by MS. "nicht nur begonnen, sondern sind resultativ, d. h. gelangen in der jeweiligen narrativen Welt des Textes zum Abschluss" (Schmid 2017, 70).

"The eventfulness of a change of state increases to the degree that a revision of the achieved state is improbable" (Schmid 2017, 79).[37] Thus Schmid defines the criteria of consecutivity and irreversibility. Of course, one could cite whole libraries of literature to prove the consequences of special relativity theory. At this point it is sufficient, however, to state that it has not yet been refuted. As long as special relativity theory is valid, all further fundamental theories of physics will rely on it.

Summing up the previous section, I find it important from the view of literary scholarship to show how physics works with this ternary argumentation-structure on well-defined levels, and argues in a differentiated way, because this makes clear that even for physics the way to objectivity is in principle only possible by taking into account the specific differences of reference-systems and their perspectives.

Einstein's treatise uses functional epistemic narrativity to performatively demonstrate the epistemological consequences of superimposing the principle of relativity with the constancy of the speed of light. The narrative structure first creates the conditions for observation from different perspectives. This grants the addressee epistemic access to the statements of the theory of relativity, so that he can reflect on their epistemological consequences. For the principle of relativity is based on the existence of two reference-systems of observation and the difference between them. Einstein asks then: is there then a possibility of correlating these observations with one another, by taking into account their difference and context-dependency yet nevertheless grant the measurement results objectivity? This possibility exists, as Einstein shows, but it is not guaranteed either by empirical means or by the primary modeling of the measurement narrative. Mathematical modeling in correlation with epistemic narrativity of the thought experiments that legitimate the re-conceptualization of spacetime opens up this view of objectification of two correlated relative observations. It connects the principle of relativity with a principle of covariance, which guarantees the objectification of observation on a tertiary level. This covariance cannot be absolutized either, however. Every covariance always applies, as Felix Klein (1974) has shown in his *Erlanger Programm*, under a transformation group. This transformation relation is symbolically configured on the third level of modeling.

This is the most important aspect showed through the analysis of the process of interformation. That we can observe context-dependency on the primary

37 Transl. by MS. "Die Ereignishaftigkeit einer Zustandsveränderung nimmt in dem Maße zu, wie eine Revision des erreichten Zustands unwahrscheinlich ist" (Schmid 2017, 79).

level of modeling: at the level of denotation, the difference remains. But at the same time it can go beyond denotation on the second level of modeling, on the level of mathematical exemplification. Mathematics and the epistemic narration are the semio-logic premisses for the creation of that correlation that enables the third-level transformation relation between domains that had not previously been connected in this way. This configuration is only valid, however, when the third modeling level[38] exists, which sets up a configuration in which a symmetry-transformation makes comprehensible why the *difference* on the denotation level *as well as the second-order equivalence* on the exemplification level are legitimate, because there exists the Lorentz transformation relation that correlates both measurements in the context of the new theory of special relativity. It shows symmetry-relations that make possible the covariant transformation from one domain to another.

My way of reading the Einsteinian treatise comes to the conclusion that it is important always to jointly conceptualize primary modeling in its relativity and context-dependency, and secondary/tertiary modeling in its covariance and context-independence. They mutually condition one another. The theory as a whole will be successful if the contradiction that exists between the context-dependency of primary modeling and the context-independence of secondary/tertiary modeling is not "resolved," but rather the tertiary meta-level makes recognizable why the differences on the primary level are as necessary as the equivalences due to the existence of the Lorentz transfromation relation.

The Lorentz transformation mediates between the coordinates of the world-lines of internally focalized observers. Thus one can say of the observer-figures that they are indeed internally focalized, but nevertheless could exchange their results with one another through this transformation relation. Through the Lorentz transformation, the horizons of knowledge and perception of the two observers are objectively correlated such that they can retain their subjective observations from their own world-lines, from their subjective horizons of knowledge and perception, without absolutizing relativity into relativism. However, the internal focalization of the first system and the external focalization of the second observer system need not fall apart into opposites, if they contradict one another. For there is a third way, a possibility of mediation, of transformation from one reference-system into the other. This ensures that both reference-systems are held equal in their possibilities of perception as well as knowledge.

38 See the next chapter for a detailed consideration of the systematical and semiological functions of the first, second and third modeling level in physics.

If I repeat the foregoing perhaps somewhat too frequently it is because it seems necessary to me, insofar as many popular-scientific presentations of the theory of relativity portray the first-order differences at the level of primary physical effects, and neglect the associated and simultaneously given, indeed necessary, second-order equivalence relative to the space-time structure conditioned by third-order transformation relation. This is a serious problem, because it leads to the fact that the theory of relativity – partly under the influence of the name that Planck had chosen for it (*nomen est omen*) – in the popular discourse could degenerate to the slogan "everything is relative." Einstein himself warned against confusing the principle of relativity with relativism.

4.2 Towards an interformative narratology of science

In his 1923 Nobel Prize speech, Einstein looks back on the development of the theory of relativity and as a starting-point for his reflections, beyond the already represented principle of relativity, sets an epistemological constraint, which is important for our analysis. It states that one must always be able to attribute meaning and reference to the concepts introduced by theoretical physics. Thus, "concepts and distinctions are only admissible to the extent that observable facts can be assigned to them without ambiguity (stipulation that *concepts and distinctions should have meaning*). This postulate, pertaining to epistemology, proves to be of fundamental importance" (Einstein 1967 [1923], 482; italics by AH).[39]

In the case of special relativity theory, mathematical equivalences are established between the three dimensions of space and one dimension of time, as well as between mass and energy. The quantitative equivalence is established in the symbolic form of numbers, which symbolize in a purely monoplanar way according to Hjelmslev.[40] This is only possible because the system of

39 "Ferner erweist sich das erkenntnistheoretische Postulat als fundamental: Begriffe und Unterscheidungen sind nur insoweit zulässig, als ihnen beobachtbare Tatbestände eindeutig zugeordnet werden können. (Inhalts-Forderung für Begriffe und Unterscheidungen)" (Einstein 1923, 1).

40 For Hjelmslev, the criterion of mono- or bi-planarity is decided by the existence of two levels of language, which are governed by different codes that are not congruent. An example is the verb-form "am," which is coded at the sound-level by phonetic rules, and at the content level by morphological rules (verb, first-person, singular, indicative). "But when we wish to decide to what extent a game or other quasi-sign-systems, like pure algebra, are or are not semiotics, we must find out whether an exhaustive description of them necessitates operating with to planes, or whether the simplicity principle can be applied so far that operation with one plane is sufficient. The prerequisite for the necessity of operating with two planes must be numbers is free from empirical denotation. Numbers establish a quantitative equality between qualitatively different things, due to the fact that modeling by mathematics is monoplanar: there is no referential relation to reality beyond the symbolic form of mathematics. Functional concepts are thereby symbolically defined, they are only mathematically modeled, and receive no adequate semantic correlate. The language of physics in this phase of modeling is submitted somewhat to the monoplanarity of the symbolic system of mathematics.

When it comes to processes of communication, theory presupposes a broad-based concept of semioticization. This encompasses not only symbolically operational mathematics, but also meanings that show correspondences in the world of the language user. Thus this concerns the mathematic, semantic and pragmatic integration of new theoretical concepts. The interformative process makes visible the need to constitute a new frame for the theory of relativity. This new frame is the product of secondary and tertiary modeling, which will now take precedence over the previous measuring practices of experimental physics. Central concepts of space, time and energy have to be re-semioticized. That means, that also the prior primary level of modeling has to be recoded and transformed from Newtonian mechanics into relativistic mechanics, because new measurements and experiments rules have to be introduced here. For the reconceptualization of the measurements and experimental practices epistemic narrativity has a key function. Narrative unifies the double-layeredness of theoretical modeling – between physics and mathematics – in its very own particular way: because it can perform test-simulations that function multi-planarly, according to different sets of rules on the syntactic, semantic and pragmatic level. This is its essential epistemic flexibility. In her definition of narrativity, Marie Laure Ryan states:

> Most narratologists agree that narrative consists of material signs, the discourse, which convey a certain meaning (or content), the story, and fulfill a certain social function. This characterization outlines three potential domains for a definition: discourse, story, and use. These domains correspond, roughly, to the three components of semiotic theory: syntax, semantics, and pragmatics. (Ryan 2007, 24)

This is one of the fundamental problems that a narratology of science or especially the narratology of physics would have to deal with: Can we eventually

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that the two planes, when they are tentatively set up, cannot be shown to have the same structure throughout, with a one-to-one relation between the functives of the one plane and the functives of the other. We shall express this by saying that the two planes must not be *conformal*" (Hjelmslev 1961, 112; cf. also 1974, 108–109).

suppose that the mathematical form of the model could correspond to that, what we call *discourse*, while the semantic "physical meaning" could correspond to the *histoire*? Then we would deal with an intricate problem here: From the perspective of an interformative narratology of science, one could argue that with respect to the development of the theory of special relativity there is a crucial asymmetry between the operations of the so-called "*discourse*" and "*histoire*" level. If we analyze the "discourse" level of the mathematical Lorentz transformation relations one realizes that Einstein continues the tradition established in the electrodynamics. The Lorentz transformations existed in the electrodynamics and had been introduced by the physicist Hendrik Antoon Lorentz. Einsteins transfers them to the mechanics and revises the measurement practices of space and time. On the syntactic level of formal discourse nothing is paradox, the transfer is profoundly logical.

One could claim that the crucial changes in worldview, the essential disruption and the so much discussed paradoxies occur on the level of '*histoire*' of the theory of relativity: The reconfiguration of the physical meaning of spacetime, mass and energy. These concepts have to be re-semioticized according to new sign functions that are not commensurable with the previous semantic codes. The new proposed codes have to incorporate mathematic aequivalence relations whose epistemologic consequences seem paradox from an experimental and an experiential point of view.

The central question is: How can the new concepts be re-semioticized semantically? How can the new semio-logical codes can be made transparent from an experimental and an experiential point of view? Here narrativity plays a key epistemic role, because it can perform both the disorganization of the old sign functions and the reorganization of new sign functions grounded on semio-logical codes that relativity theory establishes. Without these complete semiotic spectrum of physical concepts – with their syntactic, semantic and pragmatic dimensions, the theory cannot be established.

So the seemingly paradox of the special relativity theory is that on the level of '*mathematical discours*' Einstein's modeling process is still partially committed to the theoretical tradition. He preserves the principle of relativity of mechanics, but transfers it to the other theoretical field of electrodynamics. He preserves the Lorentz transformation that was valid for electrodynamics, but requires it also for mechanics. Rule-guided interpolation is ensured, because it is well understood which modeling practices are to be intersected. On the mathematical, formal, *discours* level we analysed this double transfer. But what results from the interformation no longer corresponds to the rules of the discursive formations that have entered the interformation process. How is the result of interformation to be read and interpreted from the perspective of the semantics and pragmatics?

A new framework of symbolic reorganization of reality has been established through exemplification, "representation as" and "creation as reconfiguration" due to the Lorentz transformation relation. To generate this new framework, it was not only necessary to do the maths, but it was also necessary to set up a narrative system of third-order observation that allows to show the following: The new operational concepts, space-time as a four-dimensional continuum, the relativity of time and length, the equivalence between mass and energy, are mathematically modelled within the special relativity theory and re-sort the conceptual categories in new ways by introducing new equivalences and new differences that have emerged from interformation. But how do these new concepts can get adaequate semantic correlations and comply to Einstein's constraint to have "physical meaning?"

Interformation is performed by *mathesis* and *diegesis*. *Mathesis* operates logically-syntactically but mono-planar in Hjelmslev conception. The whole modeling configuration has to follow the same system of rules – coherently. *Diegesis* can operate multi-planarly and display different ruling codes on different levels in order to simulate possible reconceptualizations of the 'physical meaning' of the theory. The operational results in the mathematical setting of the Lorentz transformation are logically comprehensible after the interformation. The tensions and resistances play out at the semantic level. For the concept of space-time can indeed be mathematically unified in a four-dimensional space-time manifold, as Minkowski (2012, cf. also 1909a) demonstrated this in the context of the 1908 lecture before the Mathematical Society in Cologne. But what does the four-dimensional space-time manifold mean for the broader semiosphere? How does one deal with the space-time continuum, given that everyone's primary everyday intuition very well (and with good reasons) continues to distinguish between space and time? The tensions and resistances play out at the semantic level of creating new correspondance relations to the experiential human realm. That is a matter of interpretation. Then of course the question arises: How does one re-establish connections between the operational concepts and the perceptible "phenomena of reality?" Which semiotic codes are now to be applied? How can logical-mathematical operations be semioticized? Does conventional language have the necessary semio-logical repertoire for this?

Mathematical modeling has no claim to semanticity. Primary physical modeling is tied to measurement and facticity. Scientific discourse therefore relies on thought experiments. The narrative thought experiment is performed in order to simulate different transformations and to reflect on their epistemological consequences and their "physical meaning." Although the theoretical model is not yet mature enough to generate experiments for its validation or falsification, it nevertheless suffices to sketch a narrative simulation that performs future experimental practices symbolically. In this way the semanticity of the diegesis comes into play. Narrative techniques makes it possible to construct a simulative symbolic world: a thought experiment that can be verified or falsified later on by real experiments. The semantic and pragmatic rules of correspondence to experimental practices and their empiric referents are established subsequently through new narrative thought experiments that recode and reframe the previous operational definitions of physics. Mathematics configures the objects of reflection on the semio-logical stage of the mathematical discourse, while narratives configure the structure of observation, visualization and reflection on the semio-logical stage that simulates experientiality.

Mathesis and *diegesis* would ideally work hand in hand, to take on the functions of interformation and transformation. *Diegesis* needs mathematics, in order to logically ground the transformation. But *mathesis* in turn needs *diegesis* in order to lend the new model semantic and pragmatic shape. Mathematics does not operate in a multi-planar way, using the syntactic, semantic and pragmatic dimension. *Diegesis*, the narrative process and its framing techniques, proves to be important at this point. *Diegesis* can configure a framing-structure of conceptualization that makes the re-ordering of knowledge systems plausible. Through its technique of *emplotment*, narration adopts this function through the thought experiment. It enacts performatively an imaginative test-simulation of the new theoretical model, even when this still unfolds under the *caveat* of fictionality. And it does so by exemplifying measurement narratives that are potentially accessible from a human experiential frame of reference. This is the epistemic function of narrativity in Einstein's treatise: it provides the discursive form for the exemplification of the transformation of codes – measuring and mathematical modeling codes and practices. It does so "in terms that are assimilable to a human experiential frame of reference" (Walsh 2020, 421). Due to narrativity the semio-logical spectrum that has been split for the purpose of formal theoretical modeling can be reconfigured. It bridges the gap between the scientific theoretical modeling that can not be simulated on the formal syntactic level without a correlation to the semantic and pragmatic frame of reference – that means, in Einstein's terms, without a connection to the new "physical meaning" that reorganizes our view on reality. The correspondence relation changes its direction. One starts to seek empirically for something that hasn't been measured or observed before, but that is predicted by the theoretical model. The theoretical model gives a hint to that what should be sought for, what can finally be found through empiric experiments. The process of interformation supposes a controlled intersection of known principles and practices. But what results logically and semiologically from the cross-over surpasses the earlier modeling levels by one dimension. A new order of knowledge comes forth, although the orders of knowledge that were intersected were known. The emergent order is more than the sum of the previous orders. Thus new codes also emerge through the process of interformation and the process of interformation becomes a matrix of transformation of knowledge-systems; that is its epistemic function.

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Aura Heydenreich

Albert Einstein's "Physics and Reality" and "The Electrodynamics of Moving Bodies"

The Process of Interformation, Semiologic Foundations and Epistemic Transformations (Part II)

Abstract: Now that in the first paper I have analysed the functions of epistemic narrativity for the process of scientific modeling in the follow up paper the analytical perspective will change gears and focus on the semiologic practices of scientific modeling as well as their epistemic functions for the development of Einstein's special theory of relativity. The interformative process, described here can only be understood when multiple levels of modeling are differentiated. We must therefore distinguish three levels of modeling: primary, secondary and tertiary. In order to describe this process of three-fold modeling, I first turn to Einstein's 1936 text "Physics and Reality," which presents a metareflection of epistemic practices in theoretical physics. From this it will become clear that it is necessary to distinguish the modeling levels, because each level comprises its own possibilities and restrictions. This differentiation hopefully leads to a better understanding of theoretical modeling in physics from the point of view of literary studies. In the second part of the paper I focus on the process of interformation in physics and discuss the development of the theory of special relativity from a systematical perspective.

In order to analyse the modeling strategies in theoretical physics, and to describe its various levels, I initially consider in the first paper a meta-theoretical text of Einstein's "Physik und Realität" ["Physics and Reality" (1936a)][1] from 1936.[2] In this text Einstein reflects retrospectively on the process of theory-formation that led to the foundations of the theory of relativity. Three different

1 Einstein's text appeared in the *Journal of Franklin Institute* as an original text in German language and was provided with a translation by Jean Piccard. Here both the original and English versions of the citations are provided.

2 I am grateful to Michael Sinding for the translation of the paper. Also I am grateful to Klaus Mecke for the exchange of ideas on the process of interformation in physics and literature, to Christine Lubkoll, Alexander Laska, Lothar Ley, Benjamin Specht, Clemens Heydenreich, and Miriam Rückelt for having read and discussed this paper with me thoroughly.

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levels of theoretical modeling are distinguished in the analysis: primary, secondary and tertiary modeling. The necessity of the internal differentiation of these levels is required from a semiologic perspective, as each level operates with its own symbolic codes and therefore carries out different epistemic functions. I turn in the next step to the 1905 article "On the Electrodynamics of Moving Bodies." To be shown is how the principles and modeling practices of mechanics and electrodynamics are intersected in a modeling configuration, from which the theory of special relativity results.

In *Languages of Art* Nelson Goodman (1976, 27–31) establishes two modes of symbolic reference and accordingly distinguish two types of representation: 'denotation' or '*representation of*,' and 'exemplification' or '*representation as*.' Catherine Elgin refines these two types of modeling and reflects from the point of view of philosophy of science (Elgin 2009, 2010–2012). Roman Frigg (2017, 2010; Frigg et al. 2009) and James Nguyen (Frigg and Nguyen 2016) argue that "*representation as*" is the typical mode of scientific modeling and argue in the tradition of Goodman for scientific modeling as an anti-mimetic form of representation (cf. also Peschard 2011).

I would like to urge that "*representation of*" and "*representation as*" are not be seen as mutually exclusive. Rather, they can be conceptualized as successive stages in the encompassing modeling process, as the following will demonstrate. Thus I would like to show that "*representation of*" can be attributed to the primary modeling level, while "*representation as*" operates at the secondary modeling level and "*representation through*" (introduced here and to be described below) at the tertiary level. So each level provides a slightly altered symbolic code.

This process-oriented reading is grounded, from a philosophy of science perspective, on Nancy Nersessian's approach of "*model-based reasoning*" (Magnani and Nersessian 2002; Nersessian 1987, 1984) and on Bas van Fraassen's *Scientific Representation* (2013). Nersessian and van Fraassen propose not to follow the way of retrospective logical reconstruction of scientific theories "from above," in a bird's-eye-view, but rather to take on a new analytical perspective and set the focus of the analysis on the process of modeling. Van Fraassen calls this analytical perspective the "*view from within*."[3]

Nersessian takes up the distinction[4] between the "*context of discovery*" and the "*context of justification*" of scientific theories, which goes back to Hans

3 Compare the relevant chapter in Van Fraassen's monograph in the philosophy of science, which is devoted to the problems and paradoxes of scientific representation: "Relating the views 'from above' and 'from within'" (Van Fraassen 2013, 184–190).

4 On the relevance of this distinction in philosophy of science research, cf. Schickore and Steinle 2006.

Reichenbach (1938). The representative of logical empiricism concentrated on the context of justification. Nersessian fully recognizes the validity of this perspective. She proposes additionally to shift the focus and to observe theory-formation itself in the "*context of discovery*." That is, to trace the concrete practices of modeling, to analyze the functions of its acts, and thereby to finally describe the process as a scientific and cultural-semiological practice.

> A [...] recasting of the problem of conceptual change in science shifts the focus of the problem from the conceptual structures themselves to the nature of the practices employed by human agents in creating, communicating, and replacing scientific representations of a domain. That is, it shifts the focus from the products to the processes, from the structures to the practices. Conceptual changes need to be understood in terms of the people who create and change their representations of nature and the practices they use to do so. To be successful in building an account of conceptual change, thus, requires both a model of the scientist qua human agent and knowledge of the nature of the practices actually used in creating and changing conceptual structures.[5] (Nersessian 2008, 5)

1 Creation as reconfiguration

Nelson Goodman and Catherine Elgin describe this kind of epistemic process of generation of new, innovative ideas, which cannot be integrated in the existing epistemic corpus, but rather subvert it, reveal fractures in its foundation and thus trigger a transformation, as a process of "creation as reconfiguration" (Elgin 2002). Elgin points out that this case concerns another route to knowledge than that of gaining new information in the context of an existing theoretical frame:

> Ordinarily, cognitive advancement is construed as the growth of knowledge. It is accomplished by the acquisition of new (justified or reliably generated) true beliefs. A person becomes aware of a hitherto unknown but properly grounded truth and smoothly incorporates it into his epistemic corpus. On this picture, information comes in discrete bits, and the growth of knowledge is additive. To be sure, we learn some things this way. If I was previously ignorant of the atomic number of gold, I learn something new when I find out that it is 79. (Elgin 2002, 14)

According to Goodman and Elgin, the generation of new information through research is important, in order to supplement or complete an already existing

5 Nancy Nersessian has affirmed this research position in the philosophy of science through an entire series of relevant historical case studies: Nersessian 1984, 1987; Magnani and Nersessian 2002.

theoretical model. This is however merely an additive cognitive process, because new information can be unproblematically integrated into the available "epistemic corpus" of theoretical modeling, without codes having to be changed:

> Adding discrete bits of information to one's epistemic corpus does not advance understanding much. The reason is this: That the atomic number of gold is 79 is not at all surprising. No expectations are violated, for the fact fits neatly with what I already knew or reasonably believed. Nor does the information generate fruitful consequences. It does, of course, equip me to infer infinitely many more truths. But they are on the whole pretty insignificant, being logical consequences of things I already know. (Elgin 2002, 14)

While this is indeed important, says Elgin, it is however no special challenge for cognition. That is, there is no disruptive effect, because what the new information does is to confirm what the *epistemic community* had already logically deduced. "Moreover, the newly acquired information creates no ripples. I don't need to reassess formerly accepted conclusions, reconsider my methods, or revise my standards. Rather like a piece in a jigsaw puzzle, the new information fits neatly into a cognitive slot that was already prepared for it" (Elgin 2002, 14).

That's why I propose the term of interformation for that modeling process that puts the scientist in front of a much greater challenge stated by Elgin: to reassess formerly accepted conclusions, to reconsider scientific methods and to revise the standards through the introduction of new epistemic practices that postulate the reconfiguration of fundamental theories. Following such a transformation, the knowledge systems would have to be completely reorganized: This corresponds to the process of interformation I want to illustrate in these two chapters on Einstein's theory of relativity.

As I pointed out at the beginning of the paper, in *Languages of Art* Nelson Goodman (1976, 52–57) distinguished between two forms of reference-relations: denotation and exemplification. Denotation is the conventional form of reference-relation to empirical reality. It is correlated with "modeling of," with the primary modeling in my systematization. Exemplification models its reference-relation itself. It presents characteristics of objects through symbolic self-reference. Therefore it stands for "modeling as," for the secondary modeling. I propose the following systematization: for the level of denotation, of "representation of," primary modeling is to be reserved. For the level of "representation as," of secondary symbolic modeling, the symbolic form of reference of exemplification is to be reserved. Finally, for the tertiary level of modeling, for the level of transformation, the formulation "representation through" is to be reserved: representation through the intersection of modeling practices between mechanics and electrodynamics, whereas the theory of relativity evolves. These intersections are part of the dynamics of the process of interformation. The levels mentioned above can be correlated with the distinctions proposed in my study *Physica Poetica* (Heydenreich 2022): between a) the primary level of modeling, which connects to the empirical world via measurements, b) the secondary level of modeling, which operates in the code-system of mathematics, and c) the tertiary level of modeling, which intersects two previously incongruent modeling practices from which a third practice derives. The latter shows the necessity of the transformation of the laws, premisses and categories of the first two levels and results in the new theory of special relativity.

From the perspective of theoretical physics Klaus Mecke (2015) has proposed a metatheoretical representation of scientific modeling processes in physics, which makes a systematic distinction among measurement-narratives, model-narratives and event-narratives. I will refer to these in my analyses. Mecke's distinction between "measurement-narratives" and "model-narratives" corresponds to my distinction between primary and secondary modeling in physics.

Tensions and resistances arise from the fact that, at the intersection point of tertiary modeling, at the crossroads of interformation, a moment of autonomy and creativity is embedded that might elude rule-guided modeling. At this point, modeling transcends its own presuppositions: in a brief but decisive moment of *inventio*. One may think this the moment of Aristotelian *anagnorisis*, of re-cognition. This is because what one previously held as knowledge suddenly no longer applies: the concepts of absolute time and space. Instead, a new frame of knowledge is revealed based on the constancy of the light velocity and the relativity of simultaneity – the theory of relativity.

Models are understood here according to Gelfert (2016; cf. 2017) as functional entities that can be configured symbolically, semiotically, mathematically, diagrammatically or aesthetically. With Morgan and Morrison (1999b, 1999a), they exhibit an explorative dimension in theory development and thus function as mediators between denotation and representation up to experimental simulation and the exemplification of new symbolic correlations. With Knuuttila (2005), models can also be understood as "epistemic tools," as epistemic artefacts. They make it possible to configure the knowledge relevant to understanding of a certain area formally, medially, symbolically or materially in order to re-correlate it and reinterpret it accordingly. From the perspective of philosophy of science the correlations between models and fictions have been explored by Roman Frigg (2009, 2010) and Mauricio Suárez (2009, 2010). But now let's get started by considering Einstein's metatheoretical reflections in his paper "Physics and Reality."

2 Ternary modeling process in Einstein's "Physics and Reality"

The essay "Physics and Reality" begins with a first section entitled "General Consideration Concerning the Method of Science." Here Einstein addresses the image of the "philosophizing physicist" (cf. Einstein 1936a, 349 and Einstein 1936b, 313) He asks if it would not be better to leave the philosophizing to philosophers. His answer is that this is justified for times in which physics rests on secure foundations, but not for those times, in which "the very foundations of physics itself have become problematic […]" (Einstein 1936a, 349).[6] When this process of reconceptualization of fundamental concepts is at issue, physicists also turn to self-reflective analysis of their own methods of modeling, according to Einstein: "At a time like the present […] the physicist cannot simply surrender to the philosopher the critical contemplation of the theoretical foundations; […] In looking for a new foundation, he must try to make clear in his own mind just how far the concepts which he uses are justified, and are necessities" (Einstein 1936a, 349).[7]

2.1 Primary modeling

In the following, Einstein presents what he calls the "Stratification of the Scientific System" (Einstein 1936a, 352):[8]

> We shall call "primary concepts" such concepts as are directly and intuitively connected with typical complexes of sense experiences. All other notions are – from the physical point of view – possessed of meaning, only in so far as they are connected, by theorems, with the primary notions. […] Science concerns the totality of the primary concepts, i.e. concepts directly connected with sense experiences, and theorems connecting them. In its first stage of development, science does not contain anything else. Our everyday thinking is satisfied on the whole with this level.[9] (Einstein 1936a, 352)

6 "das ganze Fundament der Physik problematisch geworden ist […]" (Einstein 1936b, 313).

7 "In solcher Zeit kann der Physiker die kritische Betrachtung der Grundlagen nicht einfach der Philosophie überlassen; […] auf der Suche nach einem neuen Fundament muss er sich über die Berechtigung der von ihm benutzten Begriffe nach Kräften klar zu werden versuchen" (Einstein 1936b, 313).

8 "Schichtenstruktur des wissenschaftlichen Systems" (Einstein 1936b, 316).

9 "Die mit typischen Komplexen von Sinneserlebnissen direkt und intuitiv verknüpften Begriffe wollen wir 'primäre Begriffe' nennen. Alle anderen Begriffe sind – physikalisch betrachtet – nur insoweit sinnvoll, als sie mit den 'primären Begriffen' durch Sätze in Verbindung gebracht sind.

The "objects" that are described in physics correspond only partially to the "objects" that we encounter as empirical phenomena in everday experience. The latter are not yet physical objects. They first become physical objects when they are assigned an operational definition in terms of measurement units and quantities based on physical theory. Thus these objects are primary-modelled in the conceptual framework of a physical theory. Only by means of these 'operational concepts'[10] – that is indeed what Einstein means by "primary terms" – do they find an access from "reality," the "external world of perceptions," into the semiological realm of physics.

Primary modeling or measurement corresponds in van Fraassen's sense of modeling to the selection of knowledge-relevant aspects of an empirical phenomenon, its measurement, and the symbolic representation of measurement results, which situates them in a theoretical, logical space: "The measurement is an act – performed in accordance with certain operational rules – of locating an item in a logical space" (Van Fraassen 2013, 165; cf. also 141–190).

Van Fraassen, Cassirer and Mecke unanimously explain this with the use of the thermometer for measuring temperature. Temperature is not a substance-concept, nor a 'property of bodies,' but rather a functional-concept. The functional-concept defines a measurement-rule, which determines an equality-relation between two functors that occur in thermodynamic equilibrium.

Klaus Mecke (2015, 61) denominates all processes that belong to primary modeling using the term "measurement narrative." Measurement corresponds there to a conventionally fixed, rule-governed action-instruction with appropriate information for the selection of relevant aspects of the object to be measured, to the establishment of a scale that makes comparison of measurements between the scale and the object to be measured possible and the concrete execution of the measurement. This narrow narrative concept, introduced from the perspective of theoretical physics, corresponds to a minimal definition of narrativity,[11] which presupposes a change of state, and thus temporality and sequentiality (cf. Abbott; Schmid 2010, 2014, 3; Forster 1974, 93). The concept of narrativity has

[...] Die Wissenschaft braucht die ganze Mannigfaltigkeit der primären, d.h. unmittelbar mit Sinneserlebnissen verknüpften Begriffe sowie der sie verknüpfenden Sätze. In ihrem ersten Entwicklungsstadium enthält sie nichts welter. Auch das Denken des Alltags begnügt sich im grossen Ganzen mit dieser Stufe" (Einstein 1936b, 316–317).

10 Cf. Winfried Thielmann's paper "Concept Formation in Physics from a Linguist's Perspective" in this volume.

11 It must be clarified at another point to what extent it can act as a rule-guided illocutionary speech act, but which can also be granted the status of narrative, as Ricœur does with modeling. Cf. here Ricœur's (1973) narrative concept, which in this essay is also oriented to speech act theory.

been examined in the course of the narratological analysis of the Einsteinian treatise in my first paper in this book.

As the measurement narrative plays a decisive role in Einstein's "On the Electrodynamics of Moving Bodies," it is introduced here in greater depth. In Einstein's treatise the measurement is performed to justify the necessity of changing it.[12] Einstein's treatise proposes an alteration of conventional measurement practices of time and space that have considerable consequences for the conceptualization of the space-time structure. Thus let us first briefly explain the tradition of measurement convention using an example.

The measurement process is a comparison: a certain dimension of the body is assessed, for example the length of a rod. This is set against the conventionally agreed scale, which reproduces the SI-mass unit, and compared with it. A number on the scale then establishes the connection between body-dimension and measurement-convention. This measurement result can thus be accepted as objective, because it rests on a social convention and thereby on a code. Yet this convention has emerged from a process of social negotiation. The convention is based on a factual narrative, which enacts the rules, the codes of measurement. For example, the idea of agreeing on a general length-unit of the meter is indeed not yet so old; it dates back to a 1799 decision of the French National Assembly. At that time the original meter was defined. This was a prototype made of platinum, based on the topographic narrative of earth-measurement. Its length corresponded – according to the then-current measurement – to the ten-millionth part of the distance from the North Pole to the Equator. This narrative turned out to be objectifiable around 1800 and became a codified measurement practice.

It replaced earlier measurement narratives, which had human limbs as reference systems: whether finger or hand width, hand span, elbow, foot, step, etc. It is obvious that these were less objective. Yet later the topographic measurement narrative also proved unsuitable. When it was realized that the earth is not a perfect rotational ellipsoid and hence provided only inexact meter-measurement-units, it was necessary to agree on a new convention. The "length" of a rod can thus not be considered as a "substance-property" of itself, because it is fixed by different measurement codes in different historical epochs. The current measurement code for the meter was first set in the international measurement-unit system only in 1983. It is based on the decision to define measurement units in terms of constants of nature. Today's meter-unit

12 Cf. section 3.2.1 of Aura Heydenreich's paper "Epistemic Narrativity in Albert Einstein's Treatise on Special Relativity" in this volume.

corresponds to the length of the path that light in vacuum reaches within 1/299 792 458 seconds. This is a measurement code defined on the basis of the speed of light as a natural constant, as introduced by Einstein in 1905.[13]

As van Fraassen and Mecke emphasize, every measurement is preceded by a physical theory, which sets the conventions for the production of a sign-function. On the basis of such a measurement theory, empirical phenomena can be symbolically represented in the theoretical domain of physics by numbers and physical units. Numbers have the function of connecting the conventionally established measurement system with the measured body. A number creates a connection in the semiotic sense. It is the common third which constitutes the sign-function, which connects the selected body-dimension with the scalar dimension. Relevant knowledge elements are selected and semioticized, i.e. symbolically integrated in the physics semiosphere.

From the semiotic perspective, one may, with Lotman, call the process of selection of extra-discursive elements and their representation in the discursive semiological realm of physics a process of external recoding. Thus "primary modeling" is always accompanied by "external recoding." The term "coding" clarifies that the process of semioticization, the transfer process from the extra-

13 A proof of the conventionality of these measurement-rules was provided in the press release (Simon 2018a) of the German national metrology institute (Physikalisch-Technische Bundesanstalt), which announced that the measurement-rules of nearly all basic physical units were fundamenally revised on 16 November 2018 in Versailles: they would from now on be newly defined in terms of various combinations of natural constants. As of 20 May 2019, new measurement rules and new definitions come into force for the units kilogram, Ampere and Kelvin, which are defined through seven natural constants, including the speed of light in a vacuum, the Boltzmann Constant and Planck's Constant. To this we may add a further explanation from the Federal Technical Institute on the definition of the meter: "The previous definition of the meter, for instance, which was based on a wavelength of light as an elementary length, was an example of such a 'simple attribution.' In contrast, the new SI requires higher intellectual transfer capacities. Nearly all quantities used in mechanics (which are formed on the basis of the units of time, length and mass) are realized via the three constants of a frequency, a velocity and an action" (PTB 2017b; cf. also 2017a). "On the occasion of their 26th General Conference on Weights and Measures (Conférence Générale des Poids et Mesures, CGPM) on 16 November 2018 in Versailles, the signatory states of the Metre Convention resolved to fundamentally reform the International System of Units (SI). This resolution stipulates that, in the future, all SI units will be based on the values laid down for seven selected natural constants. In passing this resolution, the General Conference has followed a recommendation issued by the International Committee on Weights and Measures (Comité international des poids et mesures, CIPM)" (Simon 2018a; cf. also 2018b).

semiotic into the semiotic domain, is a rule-governed process. Epistemic communities agree on these rules of symbolization through lengthy communication and negotiation processes within the research process.

With Eco's semiotic code-theory, this process can be described a little more precisely. If the translation process from the extra-semiotic to the semiotic domain occurs according to conventionally accepted rules, then Eco speaks of a coding-process that is epistemically and communicatively unproblematic: a *ratio facilis* coding-process.[14]

It may also be the case, however, that the coding rules must be changed in the course of modeling. If new rules are introduced, which are as yet unknown to the addressees – in Einstein's case the scientific community – then this, in Umberto Eco's (1987, 145–247) semiotic theory, is a *ratio difficilis* coding-process. This would be a form of coding that supplies its own rules, or intersects them with modeling practices from another theoretical or conceptual frame. This precedes the negotiation process. In the course of modeling it is still open whether it will at some point become conventionalized. Thus in its first application, the formal modeling of the code plays an important role. Here the code itself is the goal – it is not merely a means for the modeling process.

I therefore distinguish between *ratio facilis* and *ratio difficilis*, as I would like to link a hypothesis to the distinction: The greater the proportion of new rules, and the more unconventional the concepts introduced by the exploratory modeling (Gelfert 2018, 2016) procedure, the more important is the *way in which* these are introduced. In such *ratio-difficilis* cases – as I have already argued in my first paper – the factual scientific text itself relies on narrativity and fictionality, on the procedures and techniques of thought experiments, because it models possibilities of changing codes and practices. The new knowledge presented through the exploratory modeling still has to be semioticized via the thought experiment and its narrativization strategies.[15]

As I have already shown in my first paper, this is essentially what Einstein does in his treatise on special relativity theory 1905: He proposes an alteration of the measurement narrative for the dimensions of time and length. He demands that both physical quantities be measured on the basis of the central parameter:

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14 On Eco's semiotic code theory, cf. Eco 1976, 48–150 and 1987, 76–197.

15 Cf. the literary and cultural scholarship on the function of narrative thought experiments: Macho and Wunschel 2004; Davies 2007. On the research perspective of philosophy: Andreas 2011; Behmel 2001; Buzzoni 2007; Gähde 2000. From the perspective of philosopy of science: Bokulich 2001. From the perspective of physics: Bishop 1998. From the perspective of Science and Technology Studies: Brown 2010.

the constancy of the speed of light. The modifications of rules and their experiential implications first have to be narrated in order to make them cognitively accessible for the human frame of reference. The thought experiment is text-strategically designed in a threshold-space, in which old rules – the Galilean transformations and the Newtonian time and space – no longer fully apply and new rules – the Lorentz transformation and the new spacetime conception – are not yet fully established. The thought experiment uses narrative techniques in order to simulate and negotiate discursively alternative practices of measurement – based on the constancy of the speed of light – and new transformation relations from one reference frame to the other. My first paper in this book argues on narrative strategies of physical modeling and discusses them in detail.[16] The result of this was that absolute simultaneity, and therefore also absolute time, cannot longer be logically inferred. In this paper I discuss the semiologic foundations of the modeling strategies and their interpolation during the process of interformation.

But first, back to the paper "Physics and Reality:" Einstein argues that the stratification of the scientific system is necessary because the primary modeling of empirical data is not fully sufficient for the theoretician. "Such a state of affairs cannot [...] satisfy a spirit which is really scientifically minded; because, the totality of concepts and relations obtained in this manner is utterly lacking in logical unity" (Einstein 1936a, 352).[17]

2.2 Secondary modeling

Therefore the theoretician cannot rest here. He must go beyond such a primary – mimetic – modeling, because a modeling grasped on the basis of observational data is only the first stage of selection. At the same time, it is the stage of external recoding, which first situates these observational and measurement data in a theoretical framework in order to analyze them logically, as Einstein states in "Physics and Reality:"

> In order to supplement this deficiency, one invents a system poorer in concepts and relations, a system retaining the primary concepts and relations of the "first layer" as

16 Cf. Aura Heydenreich's paper "Epistemic Narrativity in Albert Einstein's Treatise on Special Relativity" in this volume.

17 "Diese kann [...] einen wirklich wissenschaftlich eingestellten Geist nicht befriedigen, da die so gewinnbare Gesamtheit von Begriffen und Relationen der logischen Einheitlichkeit völlig entbehrt" (Einstein 1936b, 317).

> logically derived concepts and relations. This new "secondary system" pays for its higher logical unity by having, as its own elementary concepts (concepts of the second layer), only those which are no longer directly connected with complexes of sense experiences.[18] (Einstein 1936a, 352–353)

Mathematics sets a new framework, which entails a new "keying," new codes and operative restrictions, but also other possibilities of logical correlation. In this secondary framework, one asks from which systematic point of view the primary modeling data should be considered. According to this question, one decides which correlations can be established between the symbolic configuration of data, and to what end. The goal of theoretical modeling is the logical correlation of terms among each other for the purpose of further logical derivations. The results of this enable a new view of reality that is (re-)presented through the model. For physics, this is accomplished through mathematics with the repertoire of symbolic operations it makes available. This is where the level of secondary modeling follows in the theoretical process. The modeled objects have to comply not only with the correspondence-criterion of the first modeling stage, but also with the requirement of logical coherence according to the symbolic system of mathematics. Sometimes there exist some discrepancies between the two levels of modeling. But at the end the whole modeling process has to meet the criterion of empirical adequacy (cf. Van Fraassen 1980). Yet complex mathematical modeling always goes hand in hand with a loss of semanticity – the possibility of recurring back to the 'immediate complexes of sense-experience' diminishes. Especially since mathematical modeling is symbolic.

Klaus Mecke points out that measurement quantities – which in my approach belong to the primary modeling system – must not be confused with state quantities – which belong to the secondary modeling system. "State variables are physical measurement variables translated into a mathematical model. State variables are not measurement variables, since they are not just numbers, but rather contain a set of mathematical structures […]" (Mecke 2015, 61).[19] State variables are quantities that are linked to mathematical objects so that

18 "Um diesem Mangel abzuhelfen, erfindet man ein begriffs- und relationsärmeres System, welches die primären Begriffe und Relationen der 'ersten Schicht' als logisch abgeleitete Begriffe und Relationen enthält. Dieses neue 'sekundäre System' erkauft die gewonnene höhere logische Einheitlichkeit mit dem Umstande, dass seine an den Anfang gestellten Begriffe (Begriffe der zweiten Schicht) nicht mehr unmittelbar mit Komplexen von Sinneserlebnissen verbunden sind" (Einstein 1936b, 317).

19 Transl. by MS. "Zustandsgrößen sind physikalische Messgrößen, übersetzt in ein mathematisches Modell. Zustandsgrößen sind keine Messgrößen, da sie nicht nur Zahlen sind, sondern eine Reihe von mathematischen Strukturen in sich tragen […]" (Mecke 2015, 61).

they may be operationalized in the framework according to the rules and codes of mathematics. "Thus the measurement variable 'place' [in mechanics] is simply a […] number, the state variable 'place' by contrast [in mathematics], is a continuous and differential function *r*(*t*), when the model-narrative 'point particle' is used" (Mecke 2015, 61; added by AH).[20] In the conceptual framework of field theory, however – for example in the Maxwellian frame – the same variable of place can be assigned a different form of mathematical conceptualization. Thus the secondary modeling of physics takes place in the framework of symbolic, mathematical modeling. The secondary system is a system that largely adheres to a logical, systematic form. In Cassirer's system, this would be the symbolic form of mathematical physics.

I call the modeling of mathematical quantities *secondary modeling*, because the physical quantities cross over into another semiological field. Mathematics works with new structures and operations, codes and conventions, and forms state variables as functional-concepts (cf. Cassirer 2003 and 2000). For the justification of these functional-concepts one can no longer argue essentialistically, because mathematics operates in another frame of modeling. If primary modeling is still linked to "reality" via a conventional denotation system, this is no longer the case with secondary, mathematical modeling. Its system can largely set its own rules. Here correlations can exist, if they are proven to be logically coherent. A certain tension builds up against the primary modeling. On the one hand the recognizability of the "objects" introduced into the semiological space of physics by primary modeling becomes problematic. On the other hand, theoretical modeling – now considered retrospectively – must, firstly, be correlatable with primary modeling, and secondly, prove itself empirically adequate. This is the demand for the possibility of semantic and physical "comprehensibility" (Einstein 1936a, 351),[21] to which Einstein draws attention in "Physics and Reality." In his Nobel Prize lecture Einstein refers to the "principle of signification" (cf. Einstein 1967 and 1923a). Secondary modeling makes it possible to establish new, deeper, mathematical correlations among mathematical state variables. In this way equivalences can be discovered, not between empirical phenomena themselves, but between the mathematically modelled state variables that represent these phenomena in a certain theoretical space.

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20 Transl. by MS. "So ist die Messgröße 'Ort' [in der Mechanik] einfach eine […] Zahl, die Zustandsgröße 'Ort' dagegen eine stetige und differenzierbare Funktion *r*(*t*), wenn die Modellerzählung 'Punktteilchen' verwendet wird" (Mecke 2015, 61; added by AH).

21 "Begreiflichkeit" (Einstein 1936b, 315).

2.3 Tertiary modeling

Thus Einstein argues that in order to do justice to the complexity of modeling, one must introduce an additional tertiary system. "Further striving for logical unity brings us to a tertiary system, still poorer in concepts and relations, for the deduction of the concepts and relations of the secondary (and so indirectly of the primary) layer" (Einstein 1936a, 353).[22] Interestingly, Einstein points here to a possible feedback from the tertiary back to the secondary and primary levels. Moreover, Einstein also disagrees at this point with those who interpret the stages of modeling merely as increasing abstractions. On the contrary, it concerns – as Cassirer also described in his investigation of the scientific practice of theoretical physics in the *The Philosophy of Symbolic Forms* (1957) [*Philosophie der symbolischen Formen* (2010)][23] – the transformation of conventional codes of modeling as a consequence of the identification of possible correlations between mathematical structures, which open up new possibilities:

> An adherent to the theory of abstraction or induction might call our layers "degrees of abstraction"; but, I do not consider it justifiable to veil the logical independence of the concept from the sense experiences. The relation is not analogous to that of soup to beef but rather of wardrobe number to overcoat.[24] (Einstein 1936a, 353)

The connection between wardrobe number and coat can be understood from the semiologic perspective as a three-place sign-function.[25] A symbolic sign,

22 "Weiteres Streben nach logischer Einheitlichkeit führt zur Aufstellung eines noch ärmeren tertiären Systems von Begriffen und Relationen zur Deduktion der Begriffe und Relationen der sekundären (und damit indirekt der primären) Schicht. So geht es fort, bis wir zu einem System von denkbar grösster Einheitlichkeit und Begriffsarmut der logischen Grundlagen gelangt sind, das mit der Beschaffenheit des sinnlich Gegebenen vereinbar ist" (Einstein 1936b, 317).

23 Cf. the third part: "The Function of Signification and the Building Up of Scientific Knowledge," 279–480 / "Die Bedeutungsfunktion und der Aufbau der wissenschaftlichen Erkenntnis," 323–556. Here see especially: "Symbol and Schema in the System of Modern Physics," 447–480 / "'Symbol' und 'Schema' im System der modernen Physik," 518–556.

24 "Ein Anhänger der Abstraktions- bzw. Induktions-Theorie würde die vorgenannten Schichten 'Abstraktions-Stufen' nennen. Ich halte es aber für unrichtig, die logische Unabhängigkelt der Begriffe gegenüber den Sinneserlebnissen zu verschleiern; es handelt sich nicht um eine Beziehung wie die der Suppe zum Rindfleisch, sondern eher wie die der Garderobe-Nummer zum Mantel" (Einstein 1936b, 317).

25 The connection can be represented as a three-place sign-function: between the sought-for object, the coat, and the sought-for position of the hook in the room. A third symbolic sign refers to this, the plate with the wardrobe-number, which points to the location of coat and hook.

for example "42," the number on the brass plate, establishes the connection between the coat and its owner; it refers both to the coat as a sought object and to its position in space. Yet the number alone is useless. It is only a symbol that refers to the general order of natural numbers, to the ordering system that assigns each number a neighborhood, omits no number, and states an ascending series of numbers (Cassirer 2003; cf. also 2000).[26] Based on this order one introduces the concept of the wardrobe.

It is human reason that has introduced this semiological system of sign-functions and its underlying conventions. All positions in space are equivalent, insofar as each has a natural number assigned to it. The order of natural numbers helps the wardrobe attendant to orient himself in space quickly. The number itself as the quintessential concept of mathematical exactitude is Janus-faced, because it unites in itself a dual function: that of equivalence *and* that of difference. Equivalence is set in relation to all other numbers from the set of natural numbers. In this regard the number is an 'equal among equals.' But its numerical value distinguishes it from all other numbers. In this concrete context it also assumes a special function through the founding of an identity relation to the brass plate from the hand of the theater guest. It produces a sign-function with two functors as objects, which correspond to one another: the brass plate from the visitor's hand and the cloak-room hook of the visitor's coat. Plate and coat are ultimately exchanged for one another because they bear the same number.

The sign function relies here on equal numbers and on social codes. These conventional and therefore stable reference relations serve men, as "*animal symbolicum*" (cf. "Vorbemerkung" to Cassirer 2007, 5), for orientation. Yet the modeling game with signs is a possibility that requires prior sign conventions. The task of theory, this point suggests, is to fill out successively the semiotically "amorphous," structureless void with signs, correlations and sign-functions, with multiple layers of structure, so that on the basis of these structures mathematical objects can operate, be correlated with one another and transformed.

The following will show that threefold modeling is necessary because each modeling level opens a new frame. Each frame offers a new ordering system with slightly modified rules and new codes. Therefore each frame also unfolds, due to its rules and notations, its potential for producing correlations. Thus each frame also opens new possibilities for describing and organizing experience. And yet: despite all of the various rules and codes, despite the tensions

26 Cf. chapters on number systems, especially the two chapters "On the Theory of the Formation of Concepts," 1–26 / "Zur Theorie der Begriffsbildung," 1–26, and "The Concept of Number," 27–67 / "Die Zahlbegriffe," 27–70.

and differences between the levels, a succesful modeling is characterized by the fact that its ternary structure shows coherence. The levels mutually relate to one another, condition one another. Yet any new framing reveals new principles of symbolic organization of experience. How can a coherent configuration be constructed that will ultimately prove to be empirically adequate? Perhaps here too the "*principle of minimal departure*" applies, as Marie-Laure Ryan (1991) has shown for narrative modeling.[27] In my reading this would mean that the rules of each successive level of modeling may well differ from the first level onwards, otherwise they would not be justified as new levels.

Morgan and Morrison (1999a), in their approach to "Models as Mediating Instruments," argue for a form of autonomization of modeling from empirical data as well as from theories. This is the function of the tertiary level of modeling. From this point of view it seems reasonable to argue that the process of modeling goes through phases of selection, denotation and finally symbolic (re-) presentation through exemplification and interformation, and thereby becomes autonomous step by step. The clear separation of modeling levels in the present description is to be understood as ideal-typical. It is to be used as a heuristic instrument. The textual reality looks a little different – transitions, overlaps and feedbacks are found here, like Einstein states:

> The layers are furthermore not clearly separated. It is not even absolutely clear which concepts belong to the primary layer. As a matter of fact, we are dealing with freely formed concepts, which, with a certainty sufficient for practical use, are intuitively connected with complexes of sense experiences in such a manner that, in any given case of experience, there is no uncertainty as to the applicability or non-applicability of the statement. The essential thing is the aim to represent the multitude of concepts and theorems, close to experience, as theorems, logically deduced and belonging to a basis, as narrow as possible, of fundamental concepts and fundamental relations which themselves can be chosen freely (axioms).[28] (Einstein 1936a, 353)

In sum: primary modeling is a symbolic mapping from outside of the semiosphere to inside it, whereby the knowledge-relevant variables are situated in a

27 Cf. here especially the chapter "Reconstructing the Textual Universe: The Principle of Minimal Departure," 48–60.

28 "Ferner sind die Schichten nicht klar gegeneinander abgegrenzt. Nicht einmal die Zugehörigkeit eines Begriffes zur primären Schicht ist völlig scharf. Es handelt sich hierbei eben um freigebildete Begriffe, die mit einer für die Anwendung hinreichenden Sicherheit mit Komplexen von Sinneserlebnissen intuitiv verknüpft sind, so dass bei dem Konstatieren des Zutreffens oder Nicht-Zutreffens eines Satzes für einen besonderen Erlebnisfall (Experiment) keine Unsicherheit besteht. Wesentlich ist nur die Bestrebung, die Vielheit der erlebnisnahen Begriffe und Sätze als logisch abgeleitete Sätze einer möglichst engen Basis von Grund-Begriffen und Grund-Relationen darzustellen, die ihrerseits an sich frei wählbar sind (Axiome)" (Einstein 1936b, 317–318).

symbolic framework through a rule-guided modeling practice. The theory determines how this symbolic framework looks like, which parameters are to be symbolized as relevant variables, and how the variables have to be correlated.

Meanwhile in physics and philosophy of science it is common sense that a measurement can hardly be carried out without theoretical assumptions. Thus Van Fraassen also speaks of: "measurement [as] an operation that locates an item (already classified as in the domain of a given theory) in a logical space (provided by the theory to represent a range of possible states or characteristics of such items)" (Van Fraassen 2013, 164). Therefore primary modeling as measurement is also an incomplete picture. It is the projection of relevant data and their "external recoding" as physical variables in the language of physics. Through representation in a specialized semiotic realm, they can be operated upon. In the next phase, physical variables become mathematical variables, state variables, internally recoded and transferred to the semiosphere of mathematics (cf. Mecke 2015, 61). In this framework, the variables can be secondarily modelled according to the "*keying*," the rules and methods of mathematics. 'External recoding' means the application of those semiotic rules that ensure the transfer from the semiotically amorphous external region into the semiotic code of experimental physics and its experimental practices. 'Internal recoding' corresponds to the semiotic transition between primary and secondary modeling; in Mecke's terminology: from measurement narrative to model narrative or from the realm of experimental physics to that of theoretical physics. It is the transfer to a second-order semiological sphere, since it concerns the distinction between and the transition from the measurement variables of physics, which are determined by specific rules, to the state variables of mathematics, which in turn have their own operational rules and symmetry structures.

The term *ratio facilis* characterizes those semiological practices that follow traditional, known, socially accepted and habitualized practices. An internal recoding according to *ratio facilis* is the transformation of physical variables into mathematical variables. In the case of the praxeology of *ratio difficilis*, the rules and practices of modeling itself come under the lens of observation. Those are problematized, classified as deficient, and changed in the course of modeling, even if this involves a break with tradition. This is the function of tertiary modeling.

In his article, Einstein chooses this way of recoding, which takes place *in actu*, in the midst of the process of modeling. He states that time can no longer be measured according to conventional practices – according to *ratio facilis*. In this respect, I will show that interformation is a modeling practice of the *ratio difficilis* kind, because the cross-over of rules, principles and modeling practices between two theories – mechanics and electrodynamics – brings forth completely new rules and practices of modeling. The interpolation of principles gives birth to the special relativity theory and is mediated by epistemic narrativity, as I have shown in my first paper. The new formal symbolic correlations open up, by a new theory, new possibilities of epistemic organization of experience, and a new view on reality.

Einstein's recoding of the measurement of time (simultaneity) and length occurs entirely *during the modeling process in a ratio difficilis* mode as the interformative narratological reading of the first paper demonstrated. The rupture with the tradition occurs in the context of a thought experiment. His recoding of the measurement narrative breaks abruptly with any conventional consensus on the measurement of time and distance that had applied before 1905. Willard V. O. Quine's selected as motto for *Word and Object* a quotation from Otto Neurath that illustrates the above mentioned process:

> We are like sailors who must rebuild their ship on the open sea, never able to dismantle it in dry-dock and to reconstruct it there out of the best materials.[29] (Neurath 1959, 201)

3 Interformation in Einstein's "On the Electrodynamics of Moving Bodies"

3.1 The constancy of the speed of light transferred to measuring practices of mechanics

In the first part of his work – in the first five sections of the kinematic part – Einstein transfers to the measurement practices of mechanics the principle that resulted from the experiments of electrodynamics: the constancy of the speed of light. He also analyses the consequences of the Michelson-Morley experiment in respect of a fundamental principle of mechanics, the theorem of addition of velocities.[30] In the theoretical frame of mechanics, it had been assumed that the speed of light emitted from a body is always dependent on the velocity of that body, i.e. from its state of motion. Einstein revises the principle of addition of velocities in §5 of his paper. Michelson and Morley (1886, 1887; Michelson 1881) provided, through interferometer-measurements, the decisive proof that the speed of light remains constant and independent of the state of motion of the

29 "Wie Schiffer sind wir, die ihr Schiff auf offener See umbauen müssen, ohne es jemals in einem Dock zerlegen und aus besten Bestandteilen neu errichten zu können" (Neurath, quoted in Quine 1960, vii; cf. also 1980, 5).

30 For a historical survey on the importance of the Michelson-Morley-Experiment cf. Swenson 1972.

body that emits it. Einstein argues that the addition-theorem of velocity, which is still fundamentally valid in mechanics, must be revised. The propagation of the speed of light depends on neither the rest nor the movement of the observer and their reference-systems. The speed of light, instead of space and time, could be explained as invariant that does not depend on any reference-system.

Einstein demonstrates that the Galilean transformations between the space and time coordinates of two inertial frames of reference had to be replaced by the spatial and temporal coordinate transformation called Lorentz transformations. The result of this is the reconfiguration of the theoretical framework of mechanics from a relativistic perspective. This concerns the primary as well as the secondary modeling practices of mechanics, i.e. the practical principles of measurement as well as the principles of theoretical modeling. There also results a reconceptualization of the concepts of time, precisely of the absolute simultaneity, and of space (as the length/extension of an object in space).

3.2 Principle of relativity is transferred to electrodynamics

In the second part of his treatise – sections 6 to 10 of the electrodynamic part – Einstein applies the principle of relativity, which stems from mechanics, to electrodynamics. The principle of relativity implies that rest and motion are not absolute physical values. An observer who must define his own state of rest or motion can do this, first, only with respect to his own system, and second, relatively to a second system. Galilei (1632; cf. also 2014, 220–222) and Newton had concluded from this that there can be no principled distinction between a stationary inertial system and one in uniform motion. The laws of physics must apply equally in both systems. Yet in the frame of electrodynamics this principle did not apply to Faraday's law of induction.

For Maxwell's equations this applied only in limited ways. Faraday's law of induction – which is a component part of the Maxwellian system of equations – was an exception. Einstein showed a definite contradiction between the laws of mechanics and those of electrodynamics. The laws of mechanics obeyed the principle of relativity fully, the laws of electrodynamics only partially. The contradiction in relation to the Faradayan law of induction was interpreted by Einstein as an asymmetry: If one observes how a magnet and a conducting medium that are adjacent to one another interact with one another electrodynamically, one notices that their interaction is not symmetrical. If one sets the magnet in motion while the conductor remains at rest, an electrical field forms around the magnet, which generates electrical current when touched by the conductor. The reverse, however, does not hold: If the magnet remains motionless and the conductor is moved nearby, no electrical field is created around the magnet. Instead, an electromotoric force arises in the conductor (Einstein 1989, 140; cf. also 1905, 891). If one assumes, however, that “the relative motion in the two cases considered is the same,” (Einstein 1989, 140)[31] then, as Einstein showed, a second-order equivalence can be established, despite the stated first-order difference (electrical field *around* the magnets or electromotoric power *in* the conductor). As Einstein puts it:

> But if the magnet is at rest and the conductor is in motion, no electric field arises in the surroundings of the magnet, while in the conductor an electromotive force will arise, to which in itself there does not correspond any energy, but which, provided that the relative motion in the two cases considered is the same, gives rise to electrical currents that have the same magnitude and the same course as those produced by the electric forces in the first-mentioned case.[32] (Einstein 1989 [1923], 140)

The electrical currents that result from both motions are manifested as quite distinct phenomena. But Einstein shows that an equivalence can be established between them: For the magnitude of electrical currents that result from the different motions is comparable. From this Einstein concludes that, measured by the observed effect – the size and course of electrical currents – only relative movements count. In sum, Einstein transfers the principle of relativity from the theory of mechanics to the theory of electrodynamics.

This is the scenario that Einstein calls up before the eyes of the reader. He presents the example of relative motion between conductor and magnet and the generation of electrical current, and thereby implicitly evokes the entire discursive formation of the unification of electricity and magnetism. This began with Hans Christian Oersted’s discovery of the deflection of magnetic poles by electrical currents (cf. Brain et al. 2007). The next step was the theoretical action-at-a-distance model provided by André-Marie Ampère (1826; Ampère and Babinet 1822) and Charles Augustine de Coulomb (1785a, 1785b, 1785–1789). Finally, Faraday (1852, 2004, 2016) discovered the law of induction,[33] the effect of moving magnets on electrical conductors. He introduced the proximity-effect theory, i.e. field theory, in

31 dass die “Gleichheit der Relativbewegung bei den beiden ins Auge gefaßten Fällen” gilt (Einstein 1905, 891).

32 “Ruht aber der Magnet und bewegt sich der Leiter, so entsteht in der Umgebung des Magneten kein elektrisches Feld, dagegen im Leiter eine elektromotorische Kraft, welcher an sich keine Energie entspricht, die aber – Gleichheit der Relativbewegung bei den beiden ins Auge gefaßten Fällen vorausgesetzt – zu elektrischen Strömen von derselben Größe und demselben Verlaufe Veranlassung gibt, wie im ersten Falle die elektrischen Kräfte” (Einstein 1905, 891).

33 Cf. Kieran Murphy’s paper “Induction after Electromagnetism: Faraday, Einstein, Bachelard, and Balzac” in this volume.

experimental ways – through primary modeling. This process of unifying electricity and magnetism ultimately culminated in the theoretical modeling of Maxwell's (1856, 1865, 1955) equations of electromagnetism. These equations provided a precise description of electrodynamic and optical phenomena that had been experimentally confirmed from 1865 – the date of their first publication – until 1905. They also gave rise to the theoretical value of the speed of light in a vacuum, which itself was confirmed by numerous measurements and experiments. Nevertheless, as already shown, not all of these laws were conform to the principle of relativity.

But both the principle of relativity and the principle of the constancy of the speed of light in vacuum were fundamental. In order to avoid a contradiction, Einstein faces the dilemma that either the principle of relativity or the constancy of the speed of light must be renounced. A considerable dilemma, because he needed both for his argumentation and for the modeling of special relativity theory. What does Einstein do? He maintains both principles, even though they contradict one another in the old framework, and takes just this contradiction as an opportunity to intersect the modeling practices of both theories, to transfer them into a new theoretical configuration of the special relativity theory and to transform them.

This new configuration of the theory of relativity served to unify the two principles that were previously contradictory. But for this purpose both previous theoretical frameworks had to be changed – that of mechanics and that of electrodynamics. Trough the cross-over of the two principles of relativity and of constancy of the speed of light in vacuum, it became necessary to represent the discrepancies between the previous theoretical frameworks of mechanics and electrodynamics and negotiate the differences between them by rule-based transformations. So one can conclude that precisely the sustained contradiction initiated a new theoretical dynamic. It turned out that neither of the two principles, neither that of relativity nor that of the constancy of the speed of light, was dispensable, because both proved to be logically *necessary*. By contrast, the concepts of space and time, which were still considered absolute in Newtonian mechanics and in Kantian philosophy, turned out to be *habits* of thought, which themselves needed reframing. The contradictions that are manifested through this intersection of principles processualize further modeling insofar as they challenge almost every traditional concept of the two older theories: for mechanics, the concepts of absolute simultaneity, absolute length, absolute mass and of the additivity of velocities; for electrodynamics, the concept of the ether. In the following, the above-mentioned modeling practices are described and the solution presented by Einstein is discussed. I will show, that it presupposes an interformative modeling process on the three modeling levels.

4 The process of interformation

For a better understanding of the praxeology of interformation in the case of special relativity theory, let us first describe step-by-step the various stages of the process of remodeling and reconceptualization shown in the following three diagrams of a double cone starting with Fig. 1.

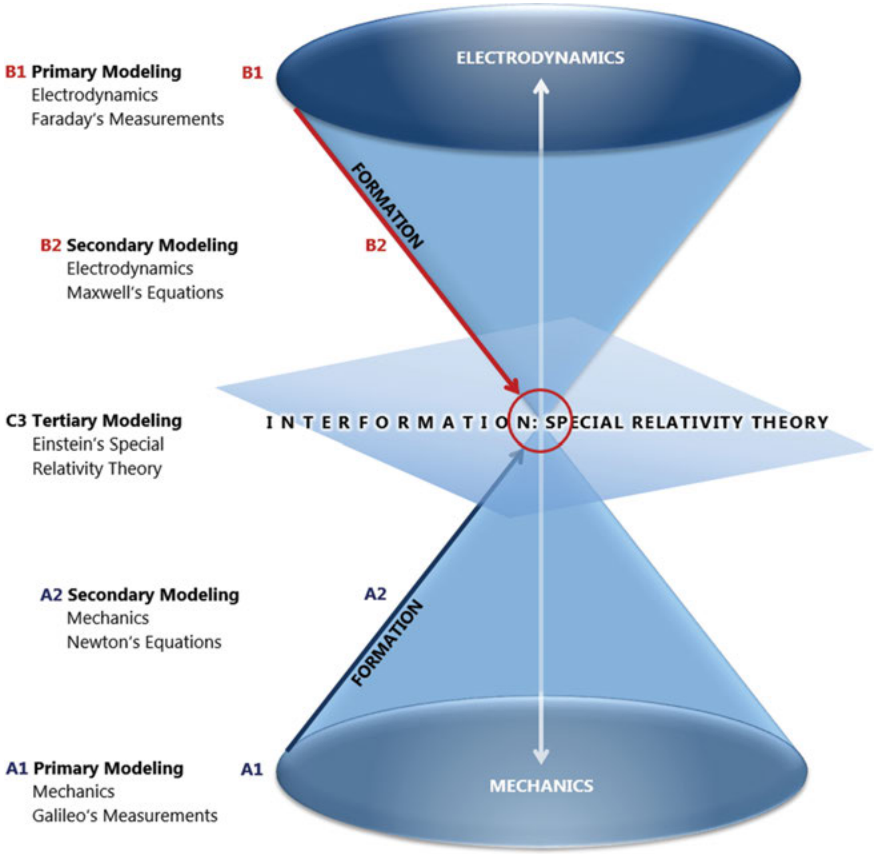

Fig. 1: The process of interformation part I: Formation © Aura Heydenreich.

4.1 Formation

Einstein proceeds from two fundamental theories of physics: mechanics and electrodynamics. I represent these two fields of "formation" along the left lateral line of the cone surface. The under-side of the double cone stands for the two modeling stages of mechanics. The upper side of the double cone stands for the two modeling stages of electrodynamics. This division is justified because the first half of Einstein's paper (the first five sections) is devoted to mechanics, and the second half (the last five sections) to electrodynamics. Additionally, for both mechanics and electrodynamics, I differentiate between the practice of primary modeling of physical measurements and experiments (A1, B1) and the practice of secondary mathematical, theoretical modeling (A2, B2). I propose to locate Einstein's modeling process of special relativity theory at the intersection of the double cone: (C3).

Mechanics was the result of the theorization of the seventeenth and eighteenth centuries by Galilei, Newton and their followers. Electrodynamics was conceptualized in the nineteenth century, mainly by Oersted, Ampère, Coulomb, Faraday and Maxwell.

For mechanics I assign point A1 to *primary modeling*, which may be exemplified by Galilei's measurements and experiments, as represented in *Dialogue Concerning the Two Chief World Systems* (1953) [*Dialogo sopra i due massimi sistemi del mondo* (1632)] and *Dialogues Concerning Two New Sciences* (1914) [*Discorsi e dimostrazioni matematiche intorno à due nuove scienze* (1638)]. Galilei introduced the principle of relativity into mechanics and showed how mass and velocity can be measured. This includes selecting relevant features of empirical bodies and representing these in a symbolic configuration framework, so that they can be related to one another. These are the beginnings of experimental physics.

Again for mechanics I assign point A2 along the left lateral line of the cone surface *secondary modeling*. Secondary modeling refers to the symbolic, mathematical modeling that uses the mathematical procedures of differential analysis as in the case of Newton's mechanics. The arrow on the cone surface line points upwards, in the direction of the intersection of the double cone, because Newton's and Galilei's modeling will be incorporated into special relativity theory, although they will be transformed by it.

A similar ordering would be assumed for electrodynamics on the upper surface-line of the double cone, yet here the arrow points in a downwards direction. At the outermost left point of the upper cone is the *primary modeling of electrodynamics*, which I designate as B1. This is what Faraday's (2016; Steinle 2004) groundbreaking measurements and experiments stand for, as documented in the numerous volumes of *Experimental Researches in Electricity*

(1831–1855). Faraday's methods were summed up by the historian of science Friedrich Steinle (2005a, 2005b, 2010) with the formula of "explorative experiments." Naturally, Oersted, Ampère and Coulomb, among others, have also contributed to the conceptualization of electrodynamics. The latter continued to base their studies on Newton's remote-action theory. Faraday chose a radical new way and proposed a field-theory on the basis of experiments, which was finally developed mathematically by Maxwell on the basis of Faraday's experiments. Faraday's law of induction from 1831, which described the generation of an electrical field by the alteration of magnetic flux-density, is mentioned in Einstein's preliminary considerations of "On the Electrodynamics of Moving Bodies." The law of induction proved problematic because it was not consistent with the principle of relativity of classical mechanics.

James Clerk Maxwell's work refers explicitly to Faraday's experiments, and advances its assumptions theoretically. In 1865 he achieved the mathematical – *secondary* – modeling of electrodynamics in "A Dynamical Theory of the Electromagnetic Field." In the diagram this point on the left surface-line of the upper cone is marked B2. Through his equations Maxwell accomplished the theoretical unification of all previously known theoretical fields of electricity and magnetism into the theory of electromagnetism: Voltaic electricity, Coulomb's law, Faraday's law of induction. Hertz then succeeded in proving, in 1888, that Maxwell's secondary modeling was empirically adequate, and that it also included electromagnetic waves, i.e. electromagnetic light-phenomena. Faraday's law of induction, the Maxwell-Hertz equations and Lorentz's contributions to electrodynamics play a crucial role in the argumentation of Einstein's article of 1905.

4.2 Intersection

In the context of the treatise "On the Electrodynamics of Moving Bodies" all previously stated primary measuring and secondary theoretical modeling practices are found superimposed in the diagram on the cross-cutting plane (C3), the level on which they are reciprocally transformed, and transferred into a new, relativistic theory. I discuss this in further detail in the next section.

The intersection of modeling practices occurs, as shown in Fig. 2, at the interformation point C3, which is at once the meeting-point of formation lines and the starting point of the transformation dynamics. The modeling practices of the two theories meet here, are intersected, and are transferred into special relativity theory. This process of transformation is symbolized by the arrows, which depart from the intersection point of interformation.

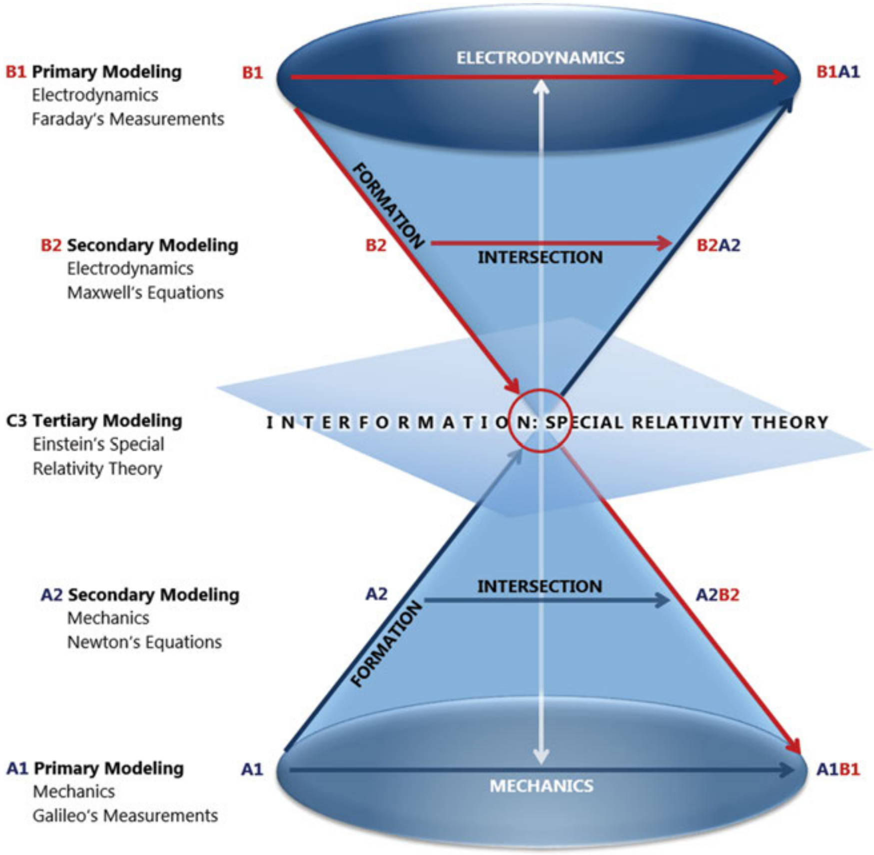

Fig. 2: The process of interformation part II: Intersection © Aura Heydenreich.

4.3 Epistemic transformation

The diagram shows the cross-cutting plane (C3): the level on which previous modeling practices are intersected and reciprocally transformed, and transferred into a new, relativistic theory. The new correlations established through intersection show that it will be necessary to revise certain assumptions of the theories of mechanics and electrodynamics. This is symbolized by the transformation arrows that depart from the point of interformation. The contrasting arrows, which lead back to the base-levels (downwards to the primary modeling of mechanics and upwards to the primary modeling of electrodynamics), show that there is a transformation of the two original primary and secondary modelings of the left side: Classical mechanics is transformed into relativistic mechanics, electrodynamics has to be re-conceptualized without the ether hypothesis. This is represented on the right side of the cone in Fig. 3.

At the end of the Einsteinian interformation process are the following results:

- A1, which stands for the primary modeling of mechanics, is transferred from left to right, and intersected with B1. B1, which stands for the primary modeling of electrodynamics, crosses through the entire interformative modeling diagram on the diagonal from top to bottom and is intersected with A1. The primary modeling, the measurement codes and practices of mechanics, A1, is transformed through the intersection with the measurement codes of electrodynamics, B1, hence with the concept of the constancy of light velocity, to A1 × B1: mechanics is thereby transformed into relativistic mechanics. Absolute space and time have to be refuted, the relativity of simultaneity and the relativity of distance-measurement result out of this.
- A2, the secondary modeling of mechanics, i.e. Newton's theory, is intersected with Maxwell's theory, which is transferred diagonally downwards from B2. Both are correlated and transformed into A2 × B2. As a result, the Galilean transformation is replaced by the Lorentz transformation.

Now I focus on the upper cone, the modeling of electrodynamics:

- B1 is transferred from left to right and meets on the right at A1. A1 is transferred from the bottom to the top and crosses through the entire interformative modeling diagram – in all three differentiated modeling stages – on the diagonal. A1 is transformed and finally intersected with B1 at the top end of the double cone. Thus the reconceptualization of electrodynamics is achieved through the intersection of B1 × A1: The measurement narratives of electrodynamics around 1900 still assumed the existence of an aether, in which electrodynamic phenomena diffused in a wave-like manner. Einstein's modeling shows that the assumption of the aether is superfluous.
- The reorganization of symbolic modeling on the secondary level (A2 × B2) is also considered: The model-narrative of electrodynamics, which Maxwell founded and Lorentz further developed, B2, remains valid. Einstein shows, however, that the principle of relativity, in the form he proposes, applies to it too: B2 × A2 are intersected. Thus Einstein demonstrated that both secondary modelings, A2 × B2 and B2 × A2, are Lorentz-covariant – and thus also equivalent with one another.

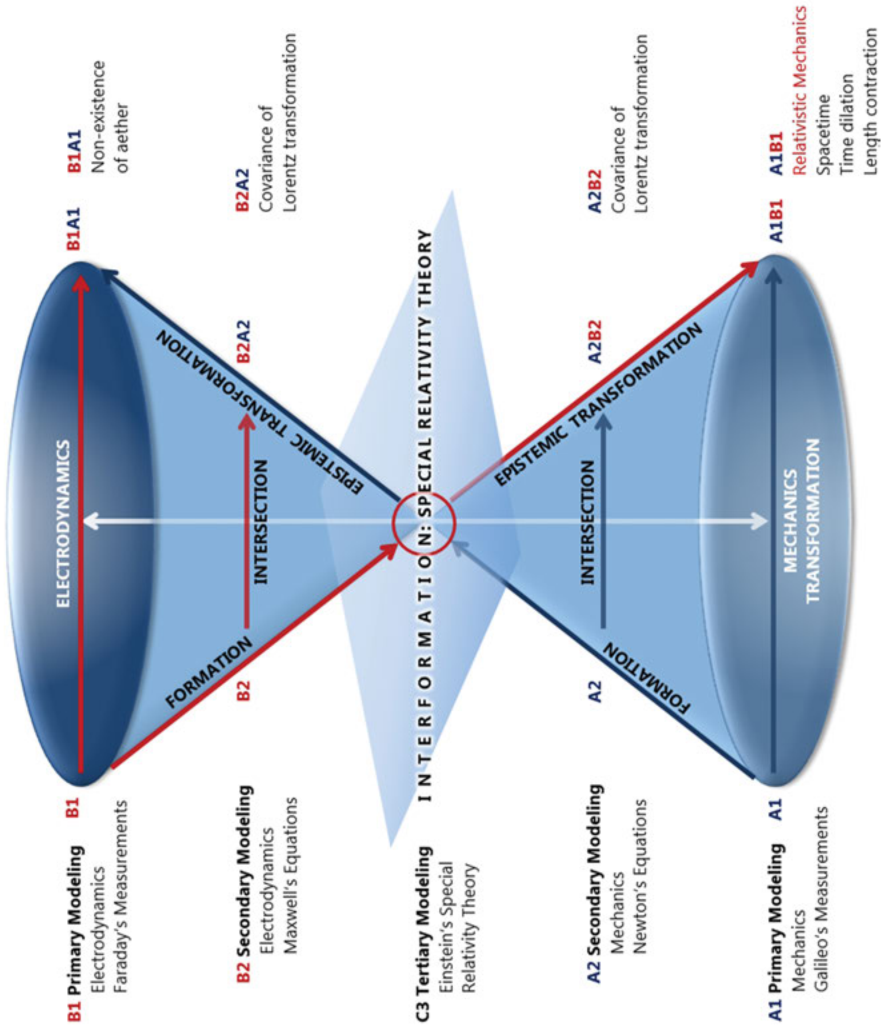

Fig. 3: The process of interformation part III: Epistemic transformation © Aura Heydenreich.

This result has of course a double price, which Einstein announces early, in the preliminary remarks of the article. If one accepts this intersection of principles of these two different knowledge-systems – mechanics and electrodynamics – and models their consequences theoretically in the course of the process of interformation, then one can no longer accept the necessity of absolute simultaneity and absolute length-measurement, as Newton had to postulate them. The necessity of accepting the ether likewise disappears.

The essential mechanism of interformation consists in starting from two distinct theories, knowledge and/or symbol systems that are in certain respects incompatible with one another and establishing correlations between them through a ternary modeling configuration. This reflects both differences on the primary semio-logical and second-order equivalences conditioned by the possibility of the mutual transformation of primary codes from the perspective of a tertiary level. What is concretely achieved is the production of second-order equivalences due to the secondary semio-logical sphere and its codes while preserving first-order differences. The latter differences indicate that the crossover of the two theory-frames in the context of an epistemic configuration requires the mutual transformation of both preceding systems. The production of second-order equivalence-relations while maintaining first-order differences requires a new, tertiary level, which makes visible mathematical symmetry-relations for the interactive transformation of the codes of the previous theories, that entered the process of interformation.

To summarize: The primary level is that of denotation, which links the ternary modeling frame with immediate reference to empirical reality, while the secondary symbolic level is the level of exemplification. Thus the reference-relation is double-coded: on the one hand to empirical reality through measurement, on the other hand to symbolic modeling through mathematics. The tertiary level offers an alternative model of the symbolic organization of reality due to an aequivalence to another quantitative relation from another frame. The tertiary level is that of transformation. What tertiary modeling proposes, then, is orientation to the symbolic coding of another domain of reality and the possibility of intersecting the two codes and their modeling principles and practices. But this does not occur without certain constraints. For this purpose the level of tertiary modeling has to institute a complex transformation relation, which fulfills a double function: to accept the differences between the primary measurement-modeling of the two domains while at the same time indicating the equivalences between the two existing mathematical configurations. If the symbolic integration succeeds in being logically convincing due to a complex symmetry-relation, then this induces a renewed feedback with the two secondary and primary modeling levels of both initial theories (mechanics and electrodynamics) – and these are thereby transformed relativistically: both the correspondance relation and the coherence relation of the primary and secondary modeling level change. Because now they are dependent on the transformation result of the tertiary modeling level – that of correlation between the two theoretical fields. This feedback-process that induces the epistemic transformation is marked on the diagram by the two arrows on the right side of the double cone. This means that the entire ternary modeling process should be read from this intersection-point of interformation: and indeed as a reciprocal transformation of both previous primary and secondary domains of modeling of mechanics and electrodynamics.

Interformation is thus a process of "creation as reconfiguration" through the intersection of modeling practices from different semio-logical fields performing that test-simulation which demonstrates that both differences and the possible equivalences conditioned by a transformation relation can be legitimated in their logical necessity. The art of *emplotment* through epistemic narrativity in the new framework consists of showing the epistemic fruitfulness of equivalence *and* difference on different levels, and assigning them to their appropriate epistemic function in the modeling architecture, so that contradictions indeed arise, but on different semio-logical levels, so that these can be taken into account as opportunities for epistemic transformations.

At this point, the process of interformation goes decisively beyond the process of metaphorical correlation. For it initiates the concrete symbolic formation of a new modeling configuration, which provides the new world-model of the special relativity theory mathematically-symbolically and also as a physical world-model, and thereby narrates it in new ways. It is thus a matter of the setting of a new framework, which draws new boundaries that cross-cut the traditional differentiations. I've showed this in detail through the analysis on the epistemic value of narrativity in Einstein's treatise of special relativity in my first paper in this book.

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Giovanni Vignale

Physics and Fiction

Abstract: Rather than describing the natural world "as it is", physical science weaves some key observations into a convincing and memorable narrative. It is not within its power to explain reality, but it can fictionalize it and thus make it understandable, sometimes even predictable. Due to the presence of internal and external constraints, physical theories are much more akin to myths – i.e., fiction created by many authors over an extended period of time – than to ordinary fiction. The mythical character of a theory does not diminish its scientific validity; quite the contrary. Convincing myths are not easily found and better observations demand better myths. The mythical content of the theory is not some extraneous content that we introduce for the sake of popularization, but an essential part of the science itself.

1. *"The truth has the structure of a fiction."* This Lacanian quotation (Lacan 1986, 12) offers a good starting point for the present chapter.[1] The assertion is provocative: truth and fiction are supposed to be mutually exclusive. But the opposition is fictitious. Truth, like fiction, is something that is constructed to be narrated: the real question is whether the narrative is valuable, **that is to say, whether it helps us to think more clearly and deeply about the subject, to discover connections between different experiences, to create new layers of meaning and imagine new possibilities.** Consider, for example, the well-known episode reported in Matthew's version of the Gospels, in which Jesus walks on water in full sight of his disciples (Matthew 14, 25–27). Is this truth or fiction? A little thought shows that it is both: the fiction of a glaring violation of physical laws, and the truth that faith can keep us afloat in a time of distress. A similar idea can be found in Mikhail Bulgakov's novel *The Master and Margarita* (Bulgakov 1996), **where violations of the physical laws are frequently used to undermine the soundness of conventional thinking**. When the Devil appears in Moscow disguised as a professor of Black Magic, the witnesses of the extraordinary event are mystified, and they give contradictory descriptions of his physical appearance. All these reports are brushed away as "worthless" by the narrator, who then with absolute confidence – the confidence of the fantastic writer – goes on to say "The truth is that …" and proceeds with his own

1 This chapter is partly based on Vignale 2011.

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description of the stranger, which closely parallels the description of Mephistopheles in Faust.[2] And indeed, *The Master and Margarita* is from beginning to end a celebration of the power (and the weakness) of the fantastic writer, who strives to recreate a reality that he cannot possibly have witnessed.

2. *Physics as mythopoesis*. Does this sound familiar? Physicists are also constantly striving to recreate a reality that admits no witnesses, being either too small, or too large, or too distant: such a reality can only be imagined. Consider, for example, the Big Bang theory. The singular foundational event in the history of the universe is by its very nature unobservable. In spite of much indirect evidence (e.g., the cosmic background radiation) it has an essentially mythical status. To make things worse, crucial parts of the event unfold on an extraordinarily short time scale: for example, the so-called inflationary phase of the expansion of the universe (a period of accelerated expansion that plays a crucial role in explaining the present state of the universe) is supposed to have lasted about 10^{-33} seconds – far shorter than the shortest time ever measured in an experiment. A mythical status can be attributed not only to events, but also to key concepts of physics. The wave function of quantum mechanics, for example, is not directly observable: its purpose is to establish a causal continuity in the evolution of the probabilities of singular events. The spin of the electron cannot possibly be described as a physical rotation of the electron, for the simple reason that a point particle (such as the electron) has no body that can rotate. Furthermore, quantum field theory tells us that point particles do not exist, or, more accurately, that they are local manifestations of a universal quantum field. In fact, the very concept of a particle disintegrates when we attempt to define it too sharply, e.g., by confining the "particle" to an extremely small region of space. **What happens is that the force field, which is supposed to pin-point the particle (think of the sharp tip of a microscope) becomes strong enough to create particles and antiparticles out of the vacuum: then the particle we were initially targeting loses its identity within a cascade of particle-antiparticle pairs.** This state of affairs is by no means unusual. It is so for almost all concepts in physics, particularly the best and most useful ones. **What makes them "mythical" is the enormous distance that exists between the levels of reality they attempt to connect: the conjectured one and the experienced one – the top of the Olympus and world of Man. These concepts disintegrate if one tries to define them too sharply, but form a recognizable pattern when viewed at the proper distance.** Their untruth is the best and only guarantee of their truth.

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2 Interestingly, Bulgakov started his career as a journalist, but later dismissed that profession as "a call without distinction" (Milne 1990).

3. *"The essential is invisible to the eye"* (Saint-Exupery 2005). In fact, for all its insistence on experiment and observation, physics could never have developed to its present heights if its practitioners had not realized the need to discard some observable information in order to grasp the essential picture. It is well known that Aristotelian physics was much closer to naive observation than present-day physics. It is true that solid objects gravitate towards the Earth as if they belonged to it, that flames and gases move away from it, as if they belonged to the sky, that earthly motions exhaust their momentum along straight lines, while celestial motions proceed eternally on closed circular paths. Galileo made a big leap of imagination when he said that a ship would keep moving forever in the direction of the initial push if nothing intervened to alter its course. He could not possibly perform that experiment. But he was not quite right, because he assumed (not unreasonably) that the ship would follow the curvature of the Earth – a last tribute to the Aristotelian way of thinking. And so he narrowly missed the exact formulation of the principle of inertia, leaving to Newton the glory of that accomplishment. Newton himself did not check the principle experimentally, but placed it correctly in the conceptual framework of an infinite universe in which no point is different from the others. This framework still endures, but might change in the future, as we become more aware of the large-scale structure of the universe. By transcending mere observation, Newton created a kind of tangential reality, a land of "asymptopia" in which the laws of his wonderful mechanics hold true.

4. *Purification: the holographic principle*. Going to the limit, as Galileo and Newton did in order to arrive at the principle of inertia, is not the only way to create a mythical reality. Another way is *purification*, which is exemplified by the holographic principle.

The basic idea is that the bulk properties of a system imprint themselves on the surface (the boundary) of that system, in such a way that by looking only at the surface we can infer the properties of the whole. If we now abstract from the bulk (this is the purification step I was alluding to), then the surface becomes the whole world, but this world owes its characteristic properties to an underlying bulk, which remains unobserved and unseen. This is, in a highly stylized form, the idea that is exploited in many contemporary string theories, in which the four dimensions of the visible world are just the observable boundary of a higher-dimensional universe (some theories predict 11 dimensions). A more concrete realization of the idea is the concept of a topological insulator in condensed matter. This system is an electrical insulator in the bulk, but its surface behaves like a two-dimensional electrical conductor characterized by a very tight correlation between the spin and the velocity of the electrons. The point is that this peculiar two-dimensional system cannot exist in two dimensions, strictly speaking. It can only exist on the surface of a three-dimensional system with suitable characteristics.

5. *Purification: broken symmetry*. Another interesting form of purification is the one that underpins our understanding of order. **The problem here is that order and rigidity in the physical world arise from laws that have no tendency in themselves to order one way or the other, i.e., the fundamental equations of physics have a much higher degree of symmetry than their observed solutions.** According to the basic laws of physics, only the perfectly symmetric solution (an infinite sphere in Pascal's metaphor, so brilliantly popularized by Jorge Luis Borges 1993, 205) would be stable: everything else is transitory. As John Donne writes, *"Whatever dies was not mixed equally"* (Donne 1983). In the real world, however, we see many "unequally mixed" things that seem to be virtually eternal, in spite of their reduced symmetry. This apparent contradiction is resolved in statistical mechanics by going to the limit in which the number of particles, N, within the system becomes infinitely large: $N \to \infty$. The limit of infinite N is actually the purification step, which distils the broken symmetry phase out of a fully symmetric ensemble of states. The tension that exists between the rigidity (low symmetry) of the world and the fluidity (high symmetry) of the laws that are supposed to govern it, is beautifully rendered by the American transcendentalist thinker Ralph Waldo Emerson, when he writes that *"Permanence is but a word of degrees"* and goes on to explain that *"Our world as seen by God is a transparent law, not a mass of facts. The law dissolves the fact and holds it fluid"* (Emerson 1983, 401–414). To translate this somewhat cryptic sentence into contemporary physics language, we should say that the point of view of God is that of eternity and infinite grandeur: from this point of view the number of particles in the system, no matter how large, is just a finite number N; on the other hand, the time scale, T, of His observation is truly unlimited: $T \to \infty$. The fluidity of the physical law, which eventually dissolves any established order, takes hold in the limit in which N is finite and $T \to \infty$. This is the point of view of God. By contrast, the point of view of Man is one of mortality and pettiness. To us N is very large, while T is pitifully small. Thus, the point of view of Man takes hold in the limit in which T is finite and $N \to \infty$. It is only in this special order of limits that states of broken symmetry – be they diamonds or institutions, appear crystalline and unchangeable.

6. *Manual of fantastic zoology*. It was Jorge Luis Borges who once remarked, in the introduction to his Manual of Fantastic Zoology (Borges 2010), that the zoology of mythical species is far more restrictive than the zoology of natural species. There is a huge number of animal species in nature, but only a few imaginary

animals (e.g., unicorns) are deemed convincing enough to become members of the fantastic zoology. Similarly, in physics there is only a small set of charismatic concepts, which are deemed sufficiently strong to serve as building blocks for theories of the real world. These concepts exert a special attraction on the human mind. Particles, fields, rays, vortices, and now strings, are all examples of such charismatic concepts. Dark matter and ether belong to the same category. Throughout the history of science these concepts have gone through varying spells of fortune, now being more fashionable, now less, but never becoming so completely extinct that they cannot resurface in new glory at the next turn. The eternal wavering between the particle and the wave descriptions of light is a well known example of this phenomenon. We are used to thinking of the universe in terms of dramatic, singular events, that are well localized in space and time – such as the Big Bang or the point particle. But we also like to think in terms of distributed entities that pervade the entire universe – such as force fields and the ether. **These concepts have an intrinsic stability, perhaps owing to the fact that they extend our natural experience in an intuitive and plausible manner**. In my book *The Beautiful Invisible* (2011) I discuss how the universally recognizable shape of the rainbow is caused by a "crowding" of light rays reflected by a water droplet at a particular angle of about 42 degrees from the direction of incidence. A similar phenomenon, which we could colorfully dub "crowding of imagination rays," is responsible for the formation of myths in our imagination.

7. *Internal and external constraints on scientific mythopoesis*. It would be a serious error to think of scientific mythopoesis as a territory of unrestrained license. In fact, even non-scientific mythopoesis is severely constrained – see the observation by Borges in the previous paragraph. In physics, the pressure of constraints grows to the highest levels. To begin with, the internal constraints, always present, become more stringent, because they are formulated in a mathematical language. These are comparable to the constraints on the form of a traditional poetic composition: only words of a certain length and sound are allowed. In addition, there is a requirement for internal consistency as well as consistency with general principles and key observed facts. Different parts of a theory cannot contradict each other. Nor can a theory predict effects that contradict what is observed. **When Einstein realized that Maxwell's equations of electromagnetism are invariant under the Lorentz group of transformations, which mix space and time, he immediately knew that he had to reformulate Newtonian mechanics in order to be consistent with the new view of time forced on us by the electromagnetic theory.** Similarly, the so-called "displacement current," which Maxwell introduced by hand in his famous field equations and which led to the theoretical discovery of electromagnetic waves is (as we can see with the benefit

of hindsight) an inescapable consequence of an internal constraint – the local conservation of charge – which is in turn a consequence of gauge symmetry. On a different note, about one hundred years ago Hermann Weyl (Weyl 1918) invented an extremely elegant gauge theory, which apparently accomplished Einstein's dream of unifying gravity and electromagnetism – yet he dutifully abandoned his brainchild after realizing that it predicted the rate of clocks to depend not only on where the clock is, but also on where it has been in the past – in sharp conflict with observations. The pressure of constraints on even the most elegant intellectual construction is indeed formidable. Nevertheless, even after satisfying all the known constraints there remains considerable freedom in the creation of a theory. I believe that high-energy physicists nowadays estimate the number of formally admissible theories to be astronomically large, even while, in practice, they are not able to produce a single one that works satisfactorily. Contrary to what one might imagine, this plethora of possibilities is a sign of crisis, as when the writer suffering from writer's block stares at the white sheet of paper on which many things can be written. It is at this juncture that one needs an influx of new powerful ideas. No theory may ever be uniquely determined, but a very good theory should indeed *look* as if it were. And new observations (experiments) are badly needed to constrain an otherwise too open field of possibilities. Our understanding of reality will always rely on myths, but there is no doubt that the quality of our myths should continue to improve. Better observations demand better myths.

8. *The sociology of myth: density functional theory and the quest for the Holy Grail.* Until now I have been talking about the epistemology of myth, that is to say about the role myth plays in shaping our understanding of the world. I would like to conclude this chapter with a short remark about the sociology of myth, i.e., about the role myth plays in shaping the way science is done in a society. I set aside the obvious observation that a well-chosen narrative can help popularize scientific ideas and thus garner public support for research. I focus instead on the way a well-chosen mythical narrative can act as a powerful motivator for cold-hearted scientists. There are many examples of this, and I choose one that is quite close to my own field of research: density functional theory. In 1964 Pierre Hohenberg and Walter Kohn (Hohenberg and Kohn 1964) proved an important theorem according to which all the physical properties of a quantum mechanical system are uniquely determined by the particle density of that system in its ground state (i.e. in the quantum state of lowest energy). The essential information for calculating the physical properties of virtually all systems of interest in chemistry and materials science was thus encoded in a universal functional, F, of the particle density. The F-functional yields the minimum

possible energy of a system of interacting electrons with the prescribed density. Although the proof of the existence of the F-functional is completely abstract, and although no one has ever come close to producing a practical method for computing it, the mere **certainty of its** existence has acted as a powerful catalyst in focusing and motivating the efforts of an army of researchers. In brief, the proof of the theorem has created a banner under which scores of researchers have joined the quest for better and better approximations of the exact F-functional. Quite fittingly, the exact F-functional is informally referred to as "the Holy Grail of density functional theory." Empirical procedures, which, under ordinary circumstances, would have been regarded as nothing more than expedients to get **approximate** answers to difficult questions, have been promptly re-assessed and found to be steps toward the ineffable mythical object that is waiting for us at the end of the quest. It is hard to overestimate the force of the impact that a commonly shared **mission** can have on a community – even when the members of this community happen to have Ph.D.s from **prestigious** universities. Paradoxically, the deeper value of the F-functional (like that of the Holy Grail) lies in the fact that it cannot be reached. Indeed, the level of theoretical knowledge and computational power required to achieve such a goal is stupendous: anyone who had such a power would probably find the whole framework of density functional theory (as opposed to wave function theory) no longer necessary. And yet, the assurance that the F-functional is out there, really, acts as a powerful motivator for those who work within the conceptual framework of density functional theory. One needs to know that there will be light at the end of the tunnel. Like any other human activity, science is largely motivated by the desire to discover that things are, after all, exactly what we want them to be (which brings us back to Lacan).

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Part II: **Concepts: Formation and Transfer**

Winfried Thielmann

Concept Formation in Physics from a Linguist's Perspective

Abstract: This chapter explores concept formation in physics from a linguist's point of view. After some preliminary reflections on conceptual structures, the chapter attempts to demonstrate that the key concept of modern physics is the body concept as introduced by Galileo. In stark contrast to the concepts we usually possess, the body concept is an operational concept, i.e. a concept the purpose of which is the levelling of ontological differences. Employing operational concepts in the natural sciences shifts the line of inquiry from how natural things are to how we can manipulate them. The answers we get to such questions are – even though they involve nature – not about nature, but about our interaction with nature. If we continue forgetting about the role of human agents in scientific inquiry, physics may, however, prevail at the very bottom of the epistemological well at which Eugene Wigner marvelled at the "the miracle of the appropriateness of the language of mathematics for the formulation of the laws of physics".

1 Introduction

There is a certain halo about the terminology of physics. Expressions such as *quantum leap*, *half-life*, and *synergy* have even made it into ordinary language – after having exhausted their use-by date as exclusivity markers of CEO-jargon, where they used to play a role similar to that of an expensive *eau de toilette*. This chapter, however, is not about terminology, but about concepts. My intention is to conduct an enquiry into the *conceptual* steps that brought about the physics of the modern era. I shall argue that physics is still, on the whole, quite ignorant of these steps – not least, because the terms naming the concepts involved are very ordinary: *body*, for instance, or *velocity*, and *force*.

After some preliminary linguistic remarks about concepts in general, I shall explore, in several steps, the conceptual transformations inherent in Galileian and Newtonian physics that, to this day, largely determine how physicists conceive of the world and their own scientific enterprise.

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2 Concepts

In everyday discourse we frequently do not bother too much about distinguishing between *word*, *name*, *term*, *notion*, *idea* or *concept*. The point I am attempting to make in this section is that there is a crucial difference between the words we utter and the ideas that are named by some of the words we utter.

Let us imagine two people taking a morning walk in the forest. They are having friends over for dinner and are talking about whether or not to bring up a second table to have enough room. Walking between trees they are able, without any effort, to discuss things not present – tables for instance. This example involves a function of language not too frequently recognized even by linguists, the *gnoseological function* (Ehlich 2007): language, as the prime human medium for knowledge retention and transfer, allows for transindividual representation of reality by making knowledge communicable. This is, of course, the very function of language that acts as a prerequisite for phenomena such as texts and, of course, literature.

The following model (Ehlich and Rehbein 1986) displays the instances of reality involved in this example. We have a speaker S, a hearer H – both represented by their mental spheres Π_S and Π_H – the section of extralinguistic reality where speaker and hearer are present, i.e. the forest, represented by P, and the speaker's utterance about an additional table to be brought up, represented by p (Fig. 1):

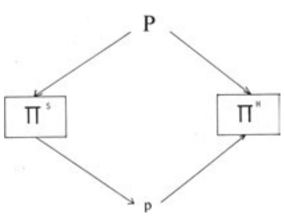

Fig. 1: Instances of reality involved in a speech situation (Ehlich and Rehbein 1986, 96).

In the case discussed here, where people speak about something not present, the current extralinguistic reality (P) of the speaker and hearer, i.e. the forest, is not relevant (Fig. 2):

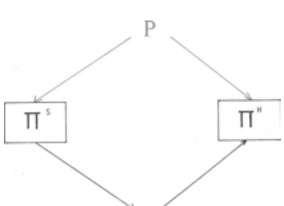

Fig. 2: Linguistic representation of things absent (modification of Ehlich and Rehbein 1986, 96).

What is required for communication about things not present? The main thing is that both speaker and hearer have a common knowledge base regarding the subject discussed, in our case tables. They do so because they are part of a societal practice that involves such artifacts.

What claims can be made about this common knowledge base? Without delving into a debate about mental representations, impressions or ideas, we can safely state that this knowledge is of a kind that allows for *linguistic* representation. Aristotle suggested a well-known method for putting this kind of knowledge into language, involving the two steps *genus proximum* and *differentia specifica*, for instance: *A table is a piece of furniture with legs and a smooth flat top*. Children have a different way of phrasing such types of knowledge: *Table is what you sit at*. A table is, and I believe we can all agree to this, made by humans to fulfil certain purposes (*sit at*) and shaped according to these purposes (*smooth flat top*). The semanticist Anna Wierzbicka has shown that natural objects – as well as people – are conceived of in a very similar fashion (1985), i.e. similar to artifacts. I call such conceptual structures *thing concepts*. Thing concepts are the most important and fundamental concepts we have: they are our link to reality, as societal beings. I have suggested that these conceptual structures – not the things or concepts themselves, but their intrinsic makeup – are universal (Thielmann 2009). Abstract concepts can always be traced back to thing concepts. *Love* is something occurring between people. So is a *contract*, as a system of action paths opened for or closed to parties ultimately consisting of people, with consequences attached to each action path.[1]

As we have seen, we are, from linguistic interaction, used to handling linguistic expressions that either name thing concepts (*table*) or that can be traced back to such knowledge structures (*love, contract*). Why have I spent so much time discussing these things when, after all, this is supposed to be a paper about concept formation in physics? This is because the conceptual side of the physics of the modern era is nothing other than a huge attack on and a transgression of thing concepts. Overcoming thing concepts is, I shall argue, the main achievement of modern physics, its main characteristic and, ultimately, the reason for the discipline's loss of reality.

1 Metaphors (for example Lakoff and Johnson 1980) play a crucial role in addressing new, previously uncharted, areas (e.g. *potential well*), allowing us to conceive of new things by applying the thing concepts we already possess.

3 Newton's second law of motion

I shall start my argument with the following well-known formula, Newton's Second Law of Motion:

$$F = ma$$

Force is the product of mass and acceleration. The formula states a relationship between force, mass, and acceleration, i.e. the change in velocity over time:

$$F = m\frac{dv}{dt}$$

The things expressed by this formula appear to be quite close to common sense: If something is subjected to a force, its velocity changes, i.e. it speeds up or it slows down. The larger the mass of the object, the stronger the force necessary to achieve the same change in velocity. However, what is the something here that is subjected to a force? A car? A bullet? A planet? And if this formula does indeed not distinguish between cars, bullets or planets, would this not imply that the differences between different things are of no importance here? Obviously, the nexus mathematically expressed by this formula concerns something that does not occur within this formula. Even though we are dealing with physics at school level here, it appears that we are confronted with conceptual structures fundamentally different from those we encounter in ordinary life. For the nexus we are looking at concerns something quite devoid of conceptual specification.

These issues regarding Newton's Second Law of Motion are by no means trivial. The formula expresses a nexus, but the very thing the nexus is about does not show up in the equation. The reason for this lies in the approach to reality that characterizes modern physics. The conceptual step that brought this physics about is the hour of birth of modern physics – and of a concept of which physics has remained largely ignorant.

4 Free fall

To understand what the physics of the modern era is about we have to cast a closer look at its founder: Galileo. As for natural philosophy, Galileo's contemporaries were still, by and large, deeply imbued by Scholasticism, i.e. a scholastic interpretation of Aristotle's physics. To them, it was perfectly natural to put their questions to canonic texts, rather than to nature. Hence, natural philosophers of Scholasticism did not direct their questions at reality, but at Aristotle's texts about reality. Galileo's interest is different, as the beginning of the *Discorsi* illustrates:

> *Sagredo*. [...] Nevertheless, what we were told a little while ago by that venerable workman is something commonly said and believed, despite which I hold it to be completely idle, as are many other things that come from the lips of persons of little learning, put forth, I believe, just to show they can say something concerning that which they don't understand.
>
> *Salviati*. You mean, perhaps, that last remark that he offered when we were trying to comprehend the reason why they make the sustaining apparatus, supports, blocks, and other strengthening devices so much larger around that huge galley that is about to be launched than around smaller vessels. He replied that this is done in order to avoid the peril of its splitting under the weight of its own vast bulk, a trouble to which smaller boats are not subject. (Galilei 1974, 11–12)

The time at which Galileo conceives of his new physics is characterized by a – diversifying – societal practice of maxim-driven production devoid of a conceptual basis. This is why Galileo does not question nature; he questions the opportunities for societal production availing itself of nature. Consequently he does not try to describe natural objects in the way they present themselves to us without our interference (this would have been Aristotle's approach). He is interested in the regularities according to which natural objects can be *manipulated*.[2] At this point, however, an important conceptual step occurs: While Aristotelian physics and the natural philosophy of Scholasticism had not only accepted that natural objects are individuals, i.e. different from one another, but in fact made this the very basis of their arguments, Galileo treats all objects the same regardless of their differences in nature. In fact, he even ceases to distinguish between natural objects and human artefacts. This important conceptual step is not obtained through experiments, but through reasoning.

Aristotle taught that all natural objects fall at their own speed determined by nature. A big, heavy rock, for instance, falls faster than a small one. Galileo reasons (1974, 66–67 and 1965, 106–107) that if this were true and one tied the smaller rock to the bigger one, the smaller one – falling less quickly – would have to slow down the bigger one. Since the composite, however, would have to move at even greater speed, being heavier than each of the single rocks, one would arrive at the absurd conclusion that the composite would fall faster and slower at the same time. The solution can only be that everything falls at the same speed.

2 Von Wright writes: "one can make a strong case for the thesis that causation in the natural sciences (better: causation in nature) is primarily and on the whole of the manipulative type" (1975, 110).

Aristotle would not have accepted this argument, since the composite, being a human artefact, differs essentially from the two natural objects, which is why – according to him – no claim could be made about it.

From this it should be clear that the question of whether or not all things fall at the same speed cannot be answered by experiment. The *Deutsches Museum* in Munich has on display an evacuated glass pipe containing a feather and a small lead ball. With both items at the bottom, you quickly turn the glass pipe upside-down and then observe that both things hit the bottom pretty much at the same time. But if you used a high quality release mechanism and detectors, you would always observe small time differences. In this case, a modern physicist would say that both release mechanism and detectors were of high quality, whilst an Aristotelian would find his view confirmed that there are ontological differences between things showing up even in an experiment of this kind. The question of whether or not all things fall at the same speed cannot be resolved, but it can be – plausibly – *decided*. This is, however, a step of *axiomatic* character, the axiom being that all things fall at the same speed.

The *decision* to accept that naturally occurring objects and artifacts, regardless of their ontological differences, fall at the same speed, leads to a new conceptual structure: the *body concept*. When viewed through the conceptual lens of the body concept, ontologically different natural things become ontologically the same: objects that differ only according to measurable dimensions (mass, volume etc.). The introduction of this concept has an important consequence: Since all objects move in the same fashion, one can *manipulate artifacts* in order to say something about nature.

The body concept is a conceptual structure of a new kind. It is an *operational concept*. Operational concepts are the key concepts of modern physics. By means of operational concepts an area of nature can be made available for quantitative exploration, which implies, at the same time, the abolishment of the structures of knowledge we have characterized above as thing concepts. With the introduction of operational concepts, physics sheds its previously hermeneutic orientation and becomes purely operational. There being no difference between natural objects and human artefacts, apparatuses can be invented to find out regularities of movement by investigating a body's path within suitably designed reference spaces of time and distance. These regularities built upon the operational concept of body and the concepts of uniform and accelerated movement are, however, not *laws of nature*, but conditions applying to a societal production availing itself of nature. The main characteristic of modern physics is the levelling and negation of the very conceptual structures we employ to make sense of our ordinary societal reality.

By the way: Galileo's radical conceptual step, without which there would be no modern physics, was by no means accompanied by terminological innovation. Galileo continued using the scholastic term *mobile*; the term *corpus* (*body*) was introduced later, by Descartes (Galilei 1974, xxxv).

Equipped with the body concept, Galileo was able to answer a question that occupied him for many years: What distances do bodies, after release, travel in equal times? Compared to the questions asked by hermeneutic Aristotelian natural philosophy, this question is purely operational. Galileo does not ask *why* something falls, but *how*.

The body concept has two facets: It determines an epistemological approach to nature and it creates the basis for the manipulation of artifacts in the place of nature. Since all bodies fall at the same speed, an *apt* body can be produced (e.g. a bronze ball) that *falls* as a representative of all bodies. From this there is a straight path to Newtonian Mechanics: Since all bodies fall at the same speed, one can look for a property that is common to all bodies and responsible for weight: *mass*. This makes it possible to conceive of accelerated motion, i.e. any change of motion, as something brought about by *force*.[3] Thus, the concept of force, i.e. Newton's Second Law of Motion, is – in a way that is not altogether obvious – built upon the operational body concept. The concept of force is a second degree operational concept.

As I have attempted to demonstrate, modern experimental physics, as established by Galileo, does not investigate nature, but the regularities to which human interaction with nature is subject. To answer the question of how things – as bodies – fall, Galileo manufactures an apparatus that simulates nature. According to the reconstructions of Stillman Drake, time and space, too, are turned into manufactured conditions for the production of physical knowledge. To answer the question of what distances are travelled by bodies in equal times, Galileo had to devise a way to produce small time intervals, as he did not have precise clocks or strobes. As Stillman Drake writes, Galileo quite possibly used his – subjective – feeling of rhythm to judge small time intervals:

> Galileo's procedure, as I reconstruct it, was this. He tied gut frets around his grooved plane, as frets are tied on the neck of a lute, so that they are snug but can be moved as needed; to set their initial positions it sufficed to sing a march tune, release the ball on one beat, and mark its approximate positions at following beats. With the frets roughly in place, the ball made a sound on striking the plane after passing over each one; they were

3 The equivalence of inert and heavy mass is a direct consequence of the body concept invested into Newtonian dynamics: Since all bodies fall at the same speed, i.e. experience the same acceleration, and weight, as a force, acts upon inert mass, weight has to be proportional to mass.

> then adjusted until each of those sounds was judged to be exactly on a beat. It remained only to measure their distances from the point at which the resting ball touched the plane. (Drake 1978, 89)

It is quite telling that this experiment by which Galileo very likely found the regularities of the movement of falling bodies was not included in the *Discorsi* – quite possibly because scholastically inclined readers would have regarded the experimental procedure as inexact. In the *Discorsi*, time is measured by a water clock – a device that, at first, sounds more convincing than a march tune and rhythmical intuition, but does not work at all, as Alexandre Koyré and others have pointed out.[4]

The manufacturing of distances was, quite possibly, conducted according to the following procedure:

> Take a short ruler divided accurately into sixty equal parts as small as you can conveniently see; mark a long rod at intervals equal to the length of your ruler, and you can quickly measure with great accuracy any distance not longer than the rod, to those units. (Drake 1978, 86–87)

Galileo's physics, in the rough sketch I have provided here,[5] is an engineer's physics: Based on the operational body concept, this physics allows for the manipulation of artifacts as representatives of natural objects. However, the true object of investigation is not nature, but the regularities of human interaction with nature. Manufacturing reference spaces of time and distance, and producing apparatuses in which processes that are seen as representative of natural processes are instigated, man creates knowledge about his own – thus measured – possibilities of interaction with nature. Viewed from this perspective, Galileo's physics is a mathematically guided anthropology that opens up for man new areas of safe and reliable action and production.[6]

4 "A bronze ball rolling in a 'smooth and polished' wooden groove! A vessel of water with a small hole through which it runs out and which one collects in a small glass in order to weigh it afterwards and thus measure the times of descent (the Roman water-clock, that of Ctebius, had been already a much better instrument): what an accumulation of sources of error and inexactitude!" (Koyré 1953, 224).

5 For a comprehensive account see Thielmann 1999, 153–205.

6 Describing Galileo's physics as an engineer's physics may seem as an affront to theoretical physicists who – especially nowadays where even pure research is judged according to *impact* and applicability – might believe that I am intent on reducing the ancestor of modern physics to the *pits* of mechanical engineering. The only thing I wish to emphasize, however, is that Galileo not only possessed the theoretical mind of a genius – a department where, for instance, the great scholastic philosopher Jean Buridan would have measured up quite well – but also had a keen interest in physical reality and application, and the hands and craftsmanship to go with such a mind, and such an interest.

The importance of Galileo's redirection of the line of enquiry from *why* to *how* cannot be over-emphasized. The natural philosophers of scholasticism wanted to find out why things are the way they are. Their line of enquiry was hermeneutic. Replacing *why* with *how*, Galileo sacrifices conceptual insight for operational success.

By the argument laid out here, I by no means wish to suggest that the line of inquiry of modern physics or its insights are flawed. The point I mean to make is that by shifting the line of inquiry from how natural things are to how we can manipulate them, the answers we get to our questions are – even though they involve nature – not about nature, but about our interactions with nature. Our interaction with nature is modern physics' real object of investigation. If we forget about our own part in this game, we are likely to mistake the regularities to which our interactions with nature are subject for laws of nature. Such reification of *laws of nature* means, however, nothing other than losing sight of the reality truly subjected to inquiry. This is the epistemological somersault occurring in Newtonian mechanics.

5 The removal of agents

Within Galileo's physics, the reference spaces of time and distance are manufactured conditions; it is a physics where human agents are still visible. Newton, however, proceeds to take man out of the equation once and for all. For he declares that time and space are not manufactured conditions, but properties of nature itself:

> Absolute, true and mathematical time, within itself and by its own nature without regard to anything external, flows equably, and by another name is called duration: [...] Absolute space, by its own nature without regard to anything external, remains always the same and immobile: [...].[7] (Newton 1972, 46)

Why is this step so important? The fundamental question *utrum tempus habeat esse extra animam* – whether time exists outside the human mind – is one of the key questions of Scholasticism (Maier 1955). By stating that time and space are properties of nature, Newton by no means settles this debate, but makes a fundamental decision about the ontological status of space and time in modern

7 Transl. by WT. "Tempus absolutum, verum, & mathematicum, in se & natura sua sine relatione ad externum quodvis, æquabiliter fluit, alioque nomine dicitur duratio: [...] Spatium absolutum, natura sua sine relatione ad externum quodvis, semper manet similare & immobile: [...]" (Newton 1972, 46).

physics. What we observe here is a step quite similar to Galileo's *decision* that there is no ontological difference between natural objects and human artifacts. In other words: The beginning of modern physics consists in *decisions* about the ontological status of natural objects, space and time. By taking man – in Galileo's physics still the manufacturer of space and distance – out of the equation, Newton achieves a physics where the regularities of human interaction with nature acquire the status of natural laws.

The price paid for this is something from which modern physics, I believe, has never quite recovered: The loss of the true object of investigation, human interaction with nature, is responsible for the conceptual crises of the physics of the twentieth century and beyond, where there is a tendency to mistake purely operational concepts for ontological concepts, i.e. concepts of an explanatory nature. The question of whether light consists of waves or particles cannot be settled within physics, because *wave* and *particle* are not explanatory concepts. On the contrary, *wave* and *particle* are both second degree operational concepts that have been successfully employed in making certain aspects of the phenomenon of light available for quantitative exploration. Interference of light beams is dealt with by applying the operational concept of *wave*, whilst the regularities of photo-electric processes can be established by applying the operational concept of *particle*. Both concepts being operational concepts, their merit does not go beyond the success of the operational procedures they make possible. The question of *what light really is* could be rephrased as *what structures of reality allow us to employ the operational concepts of wave and particle successfully?* This question, being ontological, cannot be answered within physics.[8]

With Newton, physics lost its real object of investigation, i.e. the regularities of human interaction with nature. These regularities are, instead, being

8 Heisenberg (1930, 39) conducts a thought experiment that he interprets in a way that illustrates the fallacy of reifying operational concepts: A photon, represented by a wave packet, travels through a semi-transparent mirror. The mirror decomposes the wave packet in two parts. "If an experiment yields the result that the photon is, say, in the reflected part of the packet, then the probability of finding the photon in the other part of the packet immediately becomes zero. The experiment at the position of the reflected packet thus exerts a kind of action (reduction of the wave packet) at the distant point occupied by the transmitted packet, and one sees that this action is propagated with a velocity greater than that of light. However, it is also obvious that this kind of action can never be utilized for the transmission of signals so that it is not in conflict with the postulates of the theory of relativity." As Popper points out in his *Postscript* (1982, 100 and 115), Heisenberg treats the wave packet as a natural object rather than an operational concept, a reification by which he loses sight of wave packets being the description of a superimposition of an – ideally infinite – series of experiments conducted by observers.

mistaken for laws of nature itself. In the history of the discipline, these processes are accompanied by massive abstractions (e.g. Lagrange's *Analytical Mechanics*, 1788) and the operationalization of new areas: The concept of gas in thermodynamics or the concept of wave packet in quantum mechanics are operational concepts of the same structure as the body concept they rely on. It is only when confronting the microcosm that man can no longer take himself out of the equation, but has to factor himself into operational proceedings.

It is befitting that human action is ignored in the epistemological foundation of Newtonian physics: In Kant's *Critique of Pure Reason* [*Kritik der reinen Vernunft* (1990 [1781])] time, space and causality are part of human cognitive equipment – where phenomena are, by definition, spatial, temporal and causal, any question as to their real makeup is settled in advance. Philosophy of science of the twentieth century continues to see the purpose of physics as investigating the laws of nature (Janich 1978). Theorists such as Carnap (1926), Popper (1935) and Hempel (1952, 1966) place major emphasis on the logic of induction – i.e. that the findings of physics are only supported by a finite number of experiments. This is quite ironic, since experimental proceedings – designing and building of apparatuses, waiting for and measuring results etc. – presuppose a reliability of reality without which *ex post* epistemological reasoning about the problems of induction would be quite impossible.[9]

It does not, finally, come as a surprise that methodological reflection within physics degenerates to a point where Wigner writes in his well-known essay: "The miracle of the appropriateness of the language of mathematics for the formulation of the laws of physics is a wonderful gift we neither understand nor deserve" (1960, 306). At the beginning of the 1990s, Wigner's paper experienced a renaissance (Mickens 1990). The contributors to Mickens' collection of papers quite cheerfully apply Wigner's thoughts to new areas. Hence the miracle prevails, but not the miracle of mathematics working well for modern physics or other disciplines attempting to profit from a physical approach. The prevailing miracle is that Wigner's declaration of methodological and epistemological bankruptcy has not yet thrown physics into its most fundamental conceptual crisis, the need for which it may still not understand – but which it very well deserves.

9 Theory of science also appears to be quite untroubled by the fact that the equivalence of inert and heavy mass, i.e. the *conditio sine qua non* of mechanics as we know it (see above), was put under experimental scrutiny by Eötvös (1890) and others – as if the rock upon which modern physics rests were not Galileo's axiom that all things, if considered as bodies, fall at the same speed.

6 Conclusion

In this paper I have attempted to show three things:

1. The key concepts of modern physics are operational concepts that epistemically level ontologically complex areas in a way that opens these areas up for quantitative exploration.
2. On the basis of such concepts, the regularities to which human interaction with nature is subject can be quantitatively explored.
3. It is central to the identity of physics as a discipline that the regularities of human interaction with nature are mistaken for laws of nature.

To sum up: From the beginning, the business of modern physics has been about eliminating the very conceptual structures that we as societal beings employ to make sense of reality. To make up for this, modern physics constitutes an approach to nature that puts humans at the center, as experimental agents, but, at the same time, completely removes the part we play as agents from methodological reflection as well as from theory formation. From this I conclude that modern physics is indeed neither about us nor about nature.

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Jay A. Labinger

Everything in Context

Two Episodes Relating Orbitals and Language

Abstract: The concept of atomic and molecular orbitals, which is central to both chemistry and physics, may be expressed in terms of a wide range of verbal, pictorial, and mathematical representations, and which one is most appropriate for any particular usage or situation is a highly context-dependent question. I will support this assertion by considering two (friendly) disputes in which I have been involved. The first is about the claimed need for rigorous, non-metaphoric language in talking about orbitals, while the second compares the criteria for making the *best* choice for a pictorial representation of a molecular structure to the sorts of issues that arise while performing literary translations.

1 Introduction

I came to the field of Literature and Science about 20 years ago, from a career as a practicing scientist – an inorganic chemist, to be precise – and most of my efforts to date could be said to reflect that origin, directed mainly toward interpreting literature from a scientist's viewpoint. These include analyzes of specific works with substantial scientific content, such as Richard Powers's novel *The Gold Bug Variations* (Labinger 1995) and Tom Stoppard's play *Arcadia* (Labinger 1996), as well as more general survey articles (Labinger 2002, 2010).

The complementary angle – examining scientific issues from the perspective of literary studies – is reflected in a question that has been occasionally posed to me by some of my scientific colleagues: how, if at all, does my interest in Literature and Science affect the way I think about and practice science? This essay, which is intended to address that question, was inspired by two (reasonably friendly) arguments I have engaged in within the last few years. They both center on the topic of orbitals and bonding in chemistry, which is perhaps the closest thing to a physics-related subject on which I can speak with any authority at all; and they can both be related to the role of language in scientific discourse, although in rather different ways. Hence both individually and jointly they seemed to comprise particularly appropriate subject matter for this volume on physics and literature.

Note: Portions of this article also appear in my recent book Labinger, Jay A. *Connecting Literature and Science*. New York: Routledge, 2022.

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The question of how language affects scientific thought and practice has been a common topic for Literature and Science commentators. While I haven't done any thorough survey, I think one can safely say that their dominant view is that scientists pay insufficient (or no) attention to that issue: that scientists believe, whether consciously or otherwise, that an individual's ability to grasp an idea and successfully communicate it to others does not have to be complicated by the language in which it is expressed. This is not to say that any scientist would advocate carelessness in language usage, but rather that the effort of finding appropriate language is not inherently problematic. Roald Hoffmann, a Nobel Laureate and chemist who has thought about and written on such matters extensively, sums up this attitude:

> In science, we think that words are just an expedient for describing some inner truth, one that is perhaps ideally represented by a mathematical equation. Oh, the words matter, but they are not essential for science. (Hoffmann 2012, 39)

To illustrate further, here are two brief extracts from Literature and Science commentaries. The first is from an essay by N. Katherine Hayles, a leading Literature and Science scholar, discussing a text by biologist and science popularizer Richard Dawkins:

> Dawkins, a skillful rhetorician keenly aware of the value of a good story, nevertheless espouses what might be called the giftwrap model of language. This model sees language as a wrapper that one puts around an idea to present it to someone else. I wrap an idea in language, hand it to you, you unwrap it and take out the idea […]. For example, at the critical juncture where the narrator is switching the unit of selection from the individual to the gene, we find this assertion. 'At times, gene language gets a bit tedious, and for brevity and vividness we shall lapse into metaphor. But we shall always keep a skeptical eye on our metaphors, to make sure they can be translated back into gene language if necessary.' (Hayles 2001, 147)

The second is from a book on Literature and Science by Ira Livingston, a professor of cultural studies and humanities:

> [B]oth scientists and humanists tend to overstate the independence of language from the world. Each begins by treating words and things as separate and then offers to connect them, though in rather different ways. Science, one might say, offers to nail words to things. […] Ideally, language is conceived as a space of pure, undistorted reference to (or representation of) the world, rather like the controlled conditions of a scientific experiment […]. One might even argue that an inability to see beyond the referential dimension of language is an asset for scientists, one that makes it easier to sustain belief in the scientific enterprise. (Livingston 2006, 8)

It is striking, and more than a little ironic in a reflexive sort of way, that to address scientists' practices – including the use of metaphoric language – these two commentators employ metaphors that are almost perfect opposites! Hayles's scientist thinks words are readily detached from ideas, whereas Livingston's scientist wants them to be firmly nailed in place. Nonetheless, these apparently diametric opposites actually point in the same direction. Dawkins allows that metaphoric language has its place, to liven up a story; but it is mere window dressing that can be discarded at any time, leaving behind the completely unambiguous (in Dawkins's mind) "gene language," which constitutes an example of Livingston's "pure, undistorted reference to [...] the world." Clearly both Hayles and Livingston, like many other Literature and Science scholars, are dubious (to say the least) about such a straightforward view of the role of language in science. Livingston *does* appear to allow that practicing scientists may benefit from such a limited view (much as some horses race better with blinkers on, perhaps?).

The connections between the two episodes I consider below are perhaps not immediately obvious. One shows an explicit example of a scientist's insistence on linguistic purity, while the other is more concerned with the relationship between language and pictorial representation. But I believe that both nicely illustrate, and support, what I take to be the Literature and Science position summarized above: that scientific language does not – and should not – transcend features of *ordinary* language such as ambiguity, analogy and metaphor, and that better awareness of and appreciation of that fact by scientists can be beneficial, particularly in the realm of education, by helping to focus on the goal of making scientific communication more contextually appropriate.

2 Case study 1: Can we "see" an orbital?

The starting point for this first mini-debate was an article that appeared in the prestigious British journal *Nature*, reporting on an ultra-high resolution X-ray diffractometric study of cupric oxide (Zuo et al. 1999). Since the 1910s, X-ray diffractometry has been used to determine the structure of crystalline species by locating the positions of the atoms. However, it is sometime possible to go further: since diffraction actually results from interactions of the X-rays with electrons, not nuclei, a study of sufficiently high quality can in effect *visualize* (that is, identify the location of) not just the atoms, but also the spatial distribution of regions of electron density, both those constituting the bonds between atoms and those surrounding the individual atoms themselves.

A brief reminder about atomic orbitals may be helpful. The concept, which dates back to Niels Bohr (in the 1910s, like X-ray diffraction), states that there is a set of mathematical functions that represent the spatial distribution of the electrons about an atom. Those functions can be converted into 2- or 3-dimensional pictorial representations; Fig. 1 shows such a representation for a particular set of those, the so-called *d* orbitals. The authors of the *Nature* paper reported that their diffractometric study revealed patterns of electron density, centered around the copper sites in the crystal, that very closely resemble the calculated shape of the d_{z2} orbitals:

> The correspondence between our experimental map and the classical diagrams of d_{z2} orbitals sketched in textbooks is striking. All our difference maps show strong non-spherical charge distributions around the copper atoms, with the characteristic shape of d orbitals. (Zuo et al. 1999, 51)

The editors of the journal, meanwhile, offered an even stronger claim of novelty and importance:

> The classic textbook shape of electron orbitals has now been directly observed [...]. For the first time the striking shape of some of the electron orbitals is revealed experimentally [...]. The paper by Zuo et al. is remarkable because the quality of their charge-density maps allows, for the first time, a direct experimental 'picture' to be taken of the complex shape of the d_{z2} orbital. (Humphreys 1999)

A number of equally or even more enthusiastic descriptions appeared in news sections of other journals and websites.

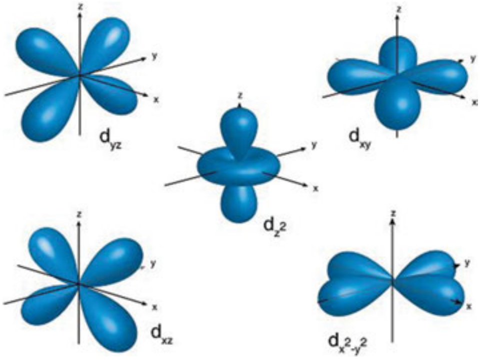


Fig. 1: Images representing the spatial orientation of the five *d* orbitals.
CK-12 Foundation. "D orbitals." https://commons.wikimedia.org/wiki/File:D_orbitals.png. *Wikimedia Commons*. 22 February 2010 (10 July 2021).

Shortly thereafter a chemist, one who is also active in the field of philosophy of chemistry, objected strongly to these claims in an essay in the *Journal of Chemical Education* (Scerri 2000), as well as in a posting on a history of chemistry website (Scerri 1999). Even though it is not particularly my area of expertise, I found myself drawn into the ensuing online discussion.

The main point the chemical philosopher/philosophical chemist made was that the term *orbitals* in no sense refers to any real physical objects. It refers only, in his view, to the mathematical wave functions calculated by quantum mechanics – and even those are strictly valid only for the hydrogen atom, not for a multielectron atom – and hence orbitals are inherently not observable:

> Let me now turn to the theoretical status and limitations of orbitals and why orbitals cannot possibly be observed. Atomic orbitals are mathematical constructs and strictly speaking are only genuine wave functions in one-electron systems such as the hydrogen atom. In many-electron atoms orbitals serve as a useful approximation […]. The orbital approximation is the basis of a great deal of the work conducted in quantum chemistry, but here it is recognized that orbitals are mathematical constructs and do not possess any independent physical status. (Scerri 2000, 1492)

I freely concede the importance of framing a discussion in terms of a very rigorous definition. But everything depends upon who is having the discussion! The meaning of *orbital* in the context of the quantum mechanical issues indicated in the above quote is unquestionably a topic of interest for philosophers of chemistry, who are concerned with the fundamental underpinnings of the science. One *might* argue further that practitioners of quantum mechanics should be aware of these issues too, although I doubt whether many of those actively engaged in computational chemistry pay much explicit attention to the strict meaning of *orbital*, or need to.

But Scerri carries his argument far beyond formal philosophical concerns to address pedagogical issues – as implied by his choice of venue, a journal devoted to chemical education. He urges educators strictly to observe his restricted usage of the word *orbitals*, even at the most basic levels:

> Orbitals are part of the lingua franca of chemistry. They represent one of chemistry's major paradigms, to use a much abused term. Surely it is essential that claims to having arrived at a new understanding of such a crucially important educational concept should be subjected to close scrutiny. It is also essential for chemical educators at all levels to take note of these developments in order to adjust their teaching accordingly if such adjustments are necessary. At the very least, educators should take some time to reflect on the meaning of such an important concept as an atomic orbital when it is claimed that, contrary to previous beliefs, they have now been observed for the first time […]. Just as the coordinate system of x, y, and z used to describe any particular experiment in classical physics is unobservable, so too atomic orbitals are completely unobservable even in principle. What can be observed, and frequently is observed in experiments, is electron density […]. My advice to chemistry educators is to avoid being seduced by the recent reports and not to revise their long-held view that atomic orbitals are just mathematical constructs. (Scerri 2000)

I completely disagree with this proclamation, whether it is meant to be taken as prescriptive or descriptive. Students, especially at elementary levels, will find

Fig. 2: Two leading inorganic chemists, Fred Basolo (left) and Ralph Pearson, manipulating three-dimensional models of *d* orbitals. © Photo courtesy of Ralph Pearson.

the visual/mental picture of how electrons are distributed in space that is commonly associated with the concept of orbitals – which determines chemical bonding and thus molecular structure – *much* more valuable than any linguistic purification. It is certainly true that one observes electron density, not some abstract outline defined by a mathematical function. But what pedagogical purpose, outside of philosophy, would be served by admonishing a student, who is perhaps trying to account for the geometry of a molecule in terms of the spatial disposition and shape of orbitals, that no, you shouldn't be talking about the orbital, but just the electron density? (If we do need a term that very precisely means the mathematical construct and nothing else, we have one: *wave function*.)

I also seriously doubt his claim that orbitals are really viewed as *just mathematical constructs* by many educators; I would wager a large sum that very few pay much if any attention to such linguistic niceties while teaching undergraduate students. (Figure 2 shows two important figures in twentieth-century inorganic chemistry who apparently see the value of allowing orbitals to be contemplated as physical objects.)

Perhaps the most extreme statement of the position Scerri is staking out appeared not in the article, but in the online discussion:

> Orbitals are mathematical constructs. In modern theory they are merely basis sets or a form of coordinate system used to express the wavefunction of any physical system. The claim that orbitals have been observed is tantamount to claiming that the x, y or z axis has been observed in any experiment in classical physics for example. What has been observed in the recent experiments is electron density. Any similarity to textbook d orbitals is either coincidental or due to somehow feeding d orbitals into the calculation which extracts the image. (Scerri 1999)

This comes across as a much stronger statement than just an argument against conflating the terms "orbital" and "electron density." As I read it, he claims that the reported observations *can't be real* – that the similarity of the observed electron density distribution and the mathematical shape of the orbitals must be coincidental and/or artifactual. Why? Simply because if they *were* real, that would contradict his restricted usage of the word *orbital*! I posted these thoughts on the website:

> [Dr. Eric Scerri's comments] seem to break into two distinct parts – the first, that observing patterns of electron density that match calculations does not mean we're actually seeing entities that we could call orbitals, and the second, that there is no significance to any such match – either it's an artifact of data processing, or a coincidence. I can see a point to the first part, but I think it's more semantic than anything else – the term orbital certainly *does* refer to a mathematical construct, but if there are in fact these regions of electron density is it wrong to use the term to refer to them as well? (Should I look up in the sky and say, 'Those aren't clouds I see, just regions of higher water vapor density?') Maybe in some ideal philosopher's world every term has one and only one exact meaning, but that isn't the world we live in. As for the second part, for all I know (nothing) about the details of the experiment the patterns *could* be artifactual, but the fact that Eric also offers an alternative (coincidence) suggests that he doesn't have any particular grounds for proposing it; and falling back on coincidence to explain away an apparent similarity between observation and prediction suggests commitment to a philosophical position that is so strong as to rule out the possibility of an experiment that might shake it. (Labinger 1999)

I got this response:

> I thank Dr. Labinger for his comments but would like to remind him that the attribution of a specific term to a particular entity is actually a form of scientific practice and not one solely confined to philosophers [...]. Could it be that Dr. Labinger's increasingly public forays into the world of "Science and Literature" have led him to be far more liberal with language than he would have been in his more scientific past? (Scerri 1999)

Note how much this sounds like Livingston: "nailing a word to a thing." My position (which, for the record, was no less liberal in my "more scientific past" before I was corrupted by "forays into the world of Science and Literature") is that trying to prevent a word such as "orbital" from referring to more than one thing – both a rigorous mathematical definition and a somewhat metaphorical but common physically real usage – is a hopeless project. Educators and students on all levels use the terms both ways and don't fret over it. Indeed, in most contexts such multiple reference is not just harmless, but productive: metaphoric usage in science encourages students and professionals alike to make useful connections between different concepts, and thus is both endemic and essential. That point was emphasized, with particular reference to atoms and orbitals, in Ted Brown's excellent discussion of metaphor in science:

> [A]ny model we might use to characterize the atom is metaphorical, whether it be that of a billiard ball [...] or a densely mathematical description based on quantum theory [...]. We don't ever 'see' atoms [...]. What we see are constructs that at their best represent reliable models of reality, with sufficient verisimilitude to serve as productive metaphors. They facilitate correlations, predictions, and interpretations of other data and stimulate the creative design of new experiments. That is all we can hope for. (Brown 2003, 99)

See also the related discussion in Nikola Kompa's paper "Insight by Metaphor – the Epistemic Role of Metaphor in Science" in this volume.

3 Case study 2: Should we draw a bond? Who's asking?

The second argument is a more recent one, into which language enters in a somewhat different way, and which (unlike the first) puts some real literature into Literature and Science. It was inspired (or provoked) by a review article that argued for a particular approach to the visual representation of certain classes of molecules. The abstract ended with the following claim:

> This bonding description also provides a simple means to rationalize the theoretical predictions of the absence of M-M bonds in molecules such as $Fe_2(CO)_9$ and $[CpFe(CO)_2]_2$, which are widely misrepresented in textbooks as possessing M-M bonds.
> (Green et al. 2012, 11481)

Again, clearly, some background is needed. Very broadly speaking, there are two approaches to the description and portrayal of chemical bonding and structure in molecules: valence bond and molecular orbital. The first tends to be used almost entirely qualitatively, although it can involve mathematical treatment, and is probably more familiar. Basically, a bond between two atoms corresponds to a shared pair of electrons, represented pictorially by a line between them, as in H_2 for example; these are usually called Lewis structures, after G. N. Lewis, who introduced them in the early twentieth century. The molecular orbital approach is much more quantitative: it involves the mathematical combination of atomic orbitals (the things we were discussing in the first case study) to obtain a set of molecular orbitals that account for the nature of the chemical bonding. Computational chemists have developed increasingly sophisticated techniques for carrying out such calculations, which in favorable cases can give highly accurate predictions of molecular structure, as well as observables such as reactivity, spectroscopy, etc. These molecular orbitals are mathematical constructs just like the atomic orbitals, and the most *correct* way to present the computational results would be as the full set of wave functions. But those may be hard to interpret for the nonspecialist, so more often we use diagrams to depict the energy levels and spatial distribution visually. Figure 3 compares valence bond and molecular orbital pictures for the simplest case, H_2.

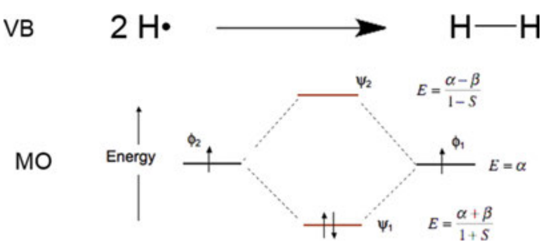


Fig. 3: Valence bond and molecular orbital representations of the H_2 molecule. Tem5psu. “H2 MO energy diagram.” https://commons.wikimedia.org/wiki/File:H2_MO_energy_diagram.png. *Wikimedia Commons*. 29 September 2013 (10 July 2021).

The molecule at issue in this argument, $[CpFe(CO)_2]_2$ (where Cp is an abbreviation for cyclopentadienyl, the C_5H_5 group), comes from a class of compounds known as metal carbonyls, containing metal atoms and carbon monoxide molecules; much of the early work that established this field of research was carried out by Walter Hieber at the Technische Hochschule München starting in the 1930s. This particular example was first prepared (at Harvard: my own PhD institution!) and structurally characterized in the 1950s, and (as the above quote indicates) has virtually universally (in research and review articles as well as textbooks) been depicted in the valence bond mode of representation as shown on the left side of Fig. 4, *with* an explicit bond drawn between the two Fe centers: a metal-metal (M-M) bond.

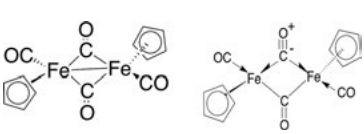


Fig. 4: Two alternate valence bond representations of the $[CpFe(CO)_2]_2$ molecule. © Jay A. Labinger.

In contrast, Jennifer Green et al. call the inclusion of an M-M bond a misrepresentation. Why? Because molecular orbital calculations do not show any significant electron density along the Fe-Fe axis, and therefore they feel the valence bond representation should not show a line there. Instead they draw the molecule as shown on the right side of Fig. 4 (cf. Green et al. 2012). (The detailed implications of their representation are complex and need not be considered here.) My objection to their position is that it, in turn, misrepresents (or fails to represent at all) many features of the molecule that are arguably at least as important as the precise localization of electrons, especially its reactivity – which after all is the main thing that chemistry is all about! In particular, drawing a line between two atoms to represent a two-electron bond implies that at least in principle the bond could be split symmetrically to generate two odd-electron fragments. Indeed, as shown in Fig. 5, under irradiation with light, $[CpFe(CO)_2]_2$ undergoes just such a fragmentation, as do other dimeric metal carbonyls. The latter clearly have a metal-metal bond: there is nothing else to hold them together! These compounds behave entirely analogously, and including the bond in the representation of $[CpFe(CO)_2]_2$ foregrounds that pattern of reactivity, while the alternate representation, without the bond, conceals it.

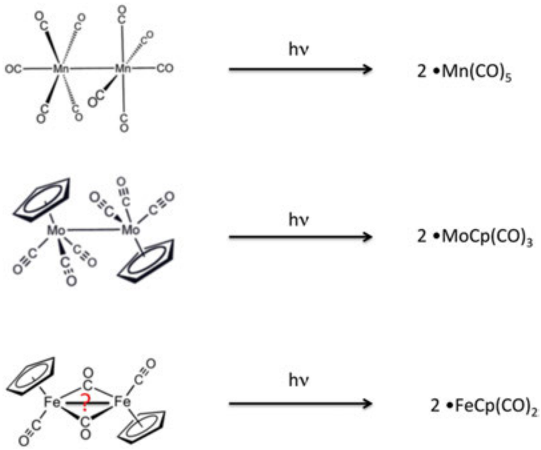
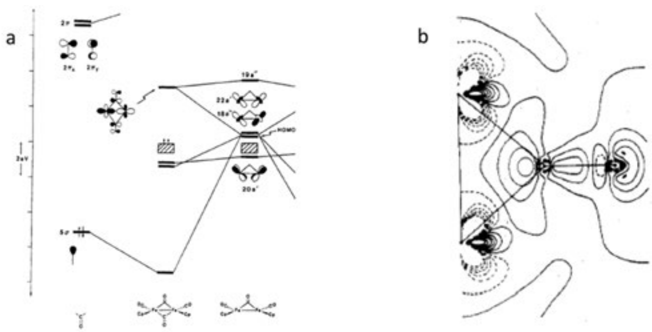


Fig. 5: Photochemical cleavage of dimeric metal carbonyl complexes. © Jay A. Labinger.

Arguments can thus be made for either of the alternative valence bond representations in Fig. 4.

Can we decide which is better? I think the answer must depend upon which aspect(s) of the molecular description are most important to us. If the distribution of electron density is of prime importance, then the no-bond version might be considered a more accurate depiction. But, as noted above, we only know that distribution by means of a molecular orbital calculation, so a molecular orbital representation would seem to be much more appropriate in that case. Several different forms of such representations are shown in Fig. 6. They are not so readily amenable to visualization, are they? Those of us who are not completely comfortable with these highly mathematical representations would prefer to convert them to a more easily grasped pictorial (valence bond) form; and as we've seen (Fig. 4), we have (at least) two different ways to do that. So the question of which representation is better becomes a question of how best to effect that conversion.



c

orbital	type	energy, eV	% on metals	% composition of metal part
b_g	π^*	−9.80	44	$41yz + 2xy + 1y$
$3a_g$	π^*	−10.04 LUMO	52	$43xz + 6z^2 + 2(x^2 - y^2) + 1s$
$2a_g$	σ	−10.90 HOMO	64	$36z^2 + 18z + 3(x^2 - y^2) + 6s$
$2b_u$	δ^*	−11.03	56	$51(x^2 - y^2) + 4z^2 + 1x$
$1b_u$	π	−11.41	68	$61xz + 4z^2 + 3z + 1s$
$1a_g$	δ	−11.45	64	$43(x^2 - y^2) + 19z^2 + 2xz + 2x$
a_u	π	−11.58	71	$58yz + 10xy + 3y$

Fig. 6: Three different MO representations of dimeric metal carbonyl complexes. Reprinted from a) Bursten and Cayton 1986, 8244; b) Benard 1979, 2785; c) Jemmis et al. 1980, 2578.

This is where literature (finally!) comes in. Galileo famously proclaimed that *the book of nature is written in the language of mathematics* (more or less: this is the most common, but not the only possible, English version of the Italian original). Not all of us are perfectly fluent in the language of mathematics! I propose that we should think about valence bond and molecular orbital representations as two different languages that we use to talk about molecular structure, and recognize that it is often necessary to *translate* from one to the other. This seems to me a highly useful analogy, because the process of converting one representation to the other raises the same sorts of issues that are common in literary translation. And literary translation is almost *never* straightforward: there are always choices to be made.

As it happens, a few years ago I was present at a panel on literary translation, at which one of the panelists – a translator from Italian – discussed several recent translations of Dante's *Divine Comedy*. Afterwards I asked him what he thought of the (much older) version I knew from my college days, and was rather taken aback when he proclaimed it *completely unacceptable*! Why? Here are the first couple of stanzas of the original Italian and the translation in question, in which the fatal deficiency is already apparent:

> Nel mezzo del cammin di nostra vita
> mi ritrovai per una selva oscura,
> ché la diritta via era smarrita.
>
> Ahi quanto a dir qual era è cosa dura
> esta selva selvaggia e aspra e forte
> che nel pensier rinova la paura!
> (Dante Alighieri 1317)
>
> Midway in our life's journey, I went astray
> from the straight road and woke to find myself
> alone in a dark wood. How shall I say
>
> What wood that was! I never saw so drear
> so rank, so arduous a wilderness!
> Its very memory gives a shape to fear.
> (Ciardi 1954, 28)

The panelist's sole objection arose from Ciardi's choice not to follow the exact rhyme scheme devised for the *Comedy*, called *terza rima*: the first and third line of each stanza rhyme with each other and the second line of the previous stanza (ABA BCB CDC ....). As can be seen, Ciardi doesn't *quite* manage that. In his translation the first and third lines of each stanza do rhyme with each other, but not with the second line of the previous stanza (ABA CDC EFE ....). For the panelist, that choice was enough to invalidate the whole translation.

There are of course many criteria one might use to assess a translation – especially of verse. They range from obvious ones such as faithful representation of meaning, rhyme, meter, etc.; down to much more subtle aspects, such as keeping content correlated with position. (Note that Ciardi doesn't do that either: the first half of the first line of the second stanza in the original is transposed to the first stanza in the translation. Should we care?) To disqualify it on the grounds of just one – any one – is to make an extremely strong value judgment about the relative importance of those criteria.

Furthermore, considering how impoverished English is in rhyming opportunities compared to Italian, it's far from clear to me that rhyming *should* be the number one criterion. In fact, according to Wikipedia there have been many more than 100 translations of the *Commedia* into English over the years, only about a quarter of which even try to employ *terza rima*. Here are a couple of examples. The first (a recent one) is in strict *terza rima*, but completely abandons Dante's regular meter; the second (a nineteenth century version by Longfellow) is entirely unrhymed, but fairly faithful to the rhythm:

> In the middle of our life's way
> I found myself in a wood so dark
> That I couldn't tell where the straight path lay.
>
> Oh how hard a thing it is to embark
> Upon the story of that savage wood,
> For the memory shudders me with fear so stark
> (Zimmerman 2003)
>
> Midway upon the journey of our life
> I found myself within a forest dark,
> For the straightforward pathway had been lost.
>
> Ah me! how hard a thing it is to say
> What was this forest savage, rough, and stern,
> Which in the very thought renews the fear.
> (Longfellow 1865)

Which should we prefer? I happen to like the second – it sounds much better to me – but I certainly wouldn't pretend to have an argument that could convince everyone to agree with me. Maybe we should abandon *both* rhyme and rhythm as top priorities in favor of a hyper-literal rendering of the meaning? That was argued by Nabokov in the preface to his translation of *Eugene Onegin*:

> In transposing *Eugene Onegin* from Pushkin's Russian into my English I have sacrificed to completeness of meaning every formal element save the iambic rhythm [...] in the few cases in which the iambic measure demanded a pinching or padding of sense, without a qualm I immolated rhythm to reason. In fact, to my ideal of literalism I sacrificed everything (elegance, euphony, clarity, good taste, modern usage, and even grammar) that the dainty mimic prizes higher than truth. (Nabokov 1964, x)

But his position, I believe, received little support from translators and readers alike.

Issues such as these seem to me closely akin to those that arise in deciding how best to portray a molecular structure. How shall I *translate* the mathematical representation of my molecule into a pictorial representation? It really depends on who is asking – that is, on what aspects I am most concerned with portraying. In Fig. 4 the with-bond version on the left tells us about reactivity, while the no-bond version may more accurately locate electron density. Different people can quite legitimately have different preferences, as they care for translations. What is to be avoided, in my opinion, is dogmatism: one should *not* proclaim one or the other a *misrepresentation*, just as one should not proclaim a translation unacceptable because of a choice that doesn't happen to agree with one's needs or preferences.

4 Conclusion

I believe that these two case studies, highly specialized and limited in scope though they may be, are quite relevant to much more general considerations of the role of language in science. I would emphasize three points: 1) The polysemous, metaphor-laden nature of language is productive in science just as in all realms of communication; it is by no means something that we should try to purify out of scientific discourse. 2) The problematics of translation between languages apply to science just as they do to literature. 3) Most importantly, keeping those considerations from literature somewhere near the forefront of one's mind can have a significant and beneficial impact on scientific practice, even in such a *hard* scientific area as physical chemistry. As two thoughtful commentators have expressed it:

> [T]here is no single correct analysis of the complex entities of chemistry expressed in a single adequate language, as various reductionist scripts require; and yet the multiplicity and multivocality of the sciences [...] do not preclude but in many ways enhance their reasonableness and success [...]. We understand the reality whose independence we honor as requiring scientific methods which are not univocal and reductionist precisely because reality is multifarious, surprizing, and infinitely rich. (Grosholz and Hoffmann 2012, 223)

Surely, in such a reality, literature and science should not be separate pursuits; indeed, they have great potential for being mutually supportive.

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Kieran Murphy

Induction after Electromagnetism

Faraday, Einstein, Bachelard, and Balzac

Abstract: Faraday's discovery of electromagnetic induction transformed the world by providing the blueprint for the mass production of electricity and a new type of motor that replaced the steam engine as the main driving force of the global economy. Electromagnetic induction presented a new set of physical problems whose solutions undermined the theoretical framework of Newtonian physics and redefined the nature of inductive reasoning. As the main logical inference characterizing the natural sciences, induction has been the subject of numerous philosophical debates about its definition and scientific value. In this paper, I trace a lesser-known contribution to these debates that developed in the wake of the epistemological changes instigated by the phenomenon of electromagnetic induction and that, through Einstein's and Bachelard's achievements, changed the modern conceptions of science, discovery, and history. I also argue that these achievements are inscribed in a tradition that should include Balzac's pioneering use of electromagnetic induction to convey the elusive nature of scientific discovery.

1 Transformational motors and interdisciplinary practices

Michel Serres has shown how the steam engine marked the advent of *transformational motors* and impacted modern thought by redefining the origin of movement (1977, 1975, Ch. 2).[1] From Aristotle's *unmoved mover* to the neoclassical period, the ultimate cause of all movement in the universe remained metaphysical. Ancient motors such as a spring or a water mill relayed the motive force provided by human, animal, or natural actions, which themselves worked as the relays of the primordial motor. The steam engine did not simply transport and transmit movement; it appeared to generate its own motive force by transforming heat into mechanical work. This remarkable motor turned the age-old

1 This essay is an early version of some of the ideas and arguments that I explore in greater details in my book *Electromagnetism and the Metonymic Imagination* (Penn State University Press, 2020).

https://doi.org/10.1515/9783110481112-008

metaphysical inquiries concerning the origin of movement into a physical problem. In 1824, the founder of thermodynamics, Sadi Carnot, began to provide the scientific explanation to this problem when he demonstrated that the motive force of the steam engine depended on a temperature difference between hot and cold sources. According to Carnot, a temperature difference displaces the metaphysical motor as the source of movement.

Beyond mines, factories, and locomotives, the steam engine embodied a shift from the metaphysical to the secular generation of movement transpiring concurrently in the sciences, arts, and humanities. Serres has traced how influential figures such as Hegel, Turner, Darwin, Marx, Zola, Nietzsche and Freud attempt to seize the means of production of their respective subject matters by displacing metaphysical intervention with the generative power of difference. Their wide-ranging works not only rely on analogies inspired by the steam engine; they themselves function as transformational motors.

In his interdisciplinary study of the rise of technological and conceptual transformational motors, Serres brings the steam engine to the fore due to the central role it played in the development of thermodynamics, and pays little attention to the electromagnetic motor, the other great catalyst of the Industrial Revolution. The discoveries of electromagnetism and electromagnetic induction unveiled a new kind of relation and difference between electricity and magnetism that became another source of movement and inventions. From Michael Faraday to Albert Einstein, the electromagnetic difference contributed to the groundbreaking development of physical concepts such as energy, field theory, and relativity. Beyond physics, however, the legacy of the electromagnetic difference has not attracted much scholarly attention, especially its early impact on literature, cognition, history, and language. As Serres has demonstrated in the case of the steam engine, all cultural formations – artistic, scientific, or otherwise – partook in the exploration of the conceptual shift embodied by transformational motors. The study of the transformative energies manifested throughout nineteenth-century cultural formations cannot then be limited to the stronghold of a single academic discipline without committing an usurpation of power. The main challenge in understanding the emergence of a new type of difference – in our case, the electromagnetic difference – consists therefore of recovering the interdisciplinary bridges where it initially spread and where it continues to thrive. This paper contributes to this vast undertaking by showing how the electromagnetic difference is at work in Balzac, Poe, Einstein, and Bachelard, and, in turn, how it provides a critical connection between disciplines such as literature, physics, and the philosophy of science and history.

2 Electromagnetic interaction and induction

When Hans Christian Ørsted (1777–1851) discovered the existence of a connection between electricity and magnetism in 1820, it took the English and French speaking scientific community by surprise because, following Benjamin Franklin and Laplacian physics, it believed that these two forces were completely unrelated. Ørsted stumbled upon the proof of this affinity when he noticed that a current-carrying wire deflected a nearby compass needle. He also realized that the needle would point in the opposite direction whether it was above or below the wire. This strange behavior greatly intrigued the scientific community because it indicated the existence of a different kind of attraction and repulsion that did not simply follow a straight line, as in Newton's law of universal gravitation, but that operated through a kind of circular action. Ørsted argued that the electric current generated a magnetic effect in its vicinity spiraling along the length of the wire. He coined the adjective *electromagnetic* to characterize the new type of circular influence manifested by the interaction of the current-carrying wire and the compass needle (1998; Caneva 2005, 176–183). Ørsted's experimental proof of the connection between electricity and magnetism gave birth to a new field of research, electromagnetism, prompted by the necessity of studying the two forces together.

In 1821, Michael Faraday (1791–1867) provided an empirical validation of Ørsted's idea of circular action spiraling along the current-carrying wire by inventing a new type of transformational motor. Faraday used mercury, a liquid conductor, to design a flexible electrical circuit, and succeeded in making a current-carrying wire rotate about a magnet, and vice-versa. In addition to clearly illustrating the circular nature of the newly found electromagnetic attraction, Faraday's experiment displayed the first electromagnetic motor by showing that the interaction of an electric current and a magnet could produce a steady movement.

The steady movement resulting from the interaction of an electric current and magnetism suggested that the reverse effect was also possible and, throughout the 1820s, researchers looked for a way to convert movement and magnetism into an electric current. Following a series of experiments that showed various aspects of this conversion, Faraday finally announced in 1831 that a conductor generated an electric current by simply moving a magnet near it. Now known as electromagnetic induction, he initially called this new phenomenon “*magneto-electric* or *magnelectric* induction.”[2] Through the progressive mastery of the conversion of heat into useful work, the steam engine powered the first cycle of the Industrial Revolution. Faraday’s discovery of electromagnetic induction proved that electricity, magnetism, and movement were interconvertible, and provided the blueprint for the next generation of transformational motors that, through electric motors powered by power plant dynamos, would eventually displace the steam engine as the main driving force of the global economy.

The link between the electric current and magnetism quickly led to new theories concerning the nature of these two forces. Soon after Ørsted’s discovery, André-Marie Ampère (1775–1836) began to consider magnetism only in terms of an effect generated by loops of electric current. The reduction of magnetism to an electric current led him to devise an effective approach to quantify the relation between the two forces. To distinguish his theory from Ørsted’s, Ampère rejected the term *electromagnetic* and introduced his own term, *electrodynamic action* (as opposed to electro*static* action) because he was confident that he could explain all magnetic effects in terms of an electric current.

At the time Ampère laid the foundation of electrodynamics, others such as Johann Joseph Prechtl (1778–1854) and Jöns Jacob Berzelius (1779–1848) took the opposite approach as they attempted to explain the electric current in terms of magnetism (Caneva 2005, 184–188). Although their failed and forgotten theories lacked the mathematical clarity of Ampère’s, they serve as a historical reminder that, despite its achievements, electrodynamics remains a convention. As discussed below, Einstein’s theory of special relativity will re-legitimize the use of the term *electromagnetism* by arguing that, in the phenomenon of electromagnetic induction, electric current and magnetism are manifestations of the same fundamental entity, the electromagnetic field, and that they appear different due to the frame of reference of the observer.

3 A new motor for analogical exploration

In the nineteenth century, due to the pioneering works of Ørsted, Ampère, and Faraday, electromagnetism also emerged as a new empirical model to explore

2 Faraday’s italics. Faraday initially adopted this terminology to differentiate “magneto-electric” from “Volta-electric induction,” or the induction of a current by another current. He soon realized that they were just variations of the same electromagnetic effect, and stopped using the latter term (Faraday 1839a, 16).

other elusive, puzzling, or highly speculative connections and interactions. Honoré de Balzac was the first canonical literary author to exploit electromagnetic induction as a conceptual engine. Less than two years after Faraday's discovery, Balzac already sensed its epistemological importance when, in his philosophical novel *Louis Lambert*, he replaced a Newtonian image with an unprecedented electromagnetic image to describe how great discoveries come from involuntary intuition. In the 1832 edition of *Louis Lambert*, Balzac invokes the Newtonian model of gravity to express how an unexpected event can lead to such an *eureka* moment: "as the fall of a pear became the primary cause of Newton's discoveries" (Balzac 1832, 333).[3] A year later, in the 1833 edition of *Louis Lambert*, Balzac replaces this Newtonian image with the new electromagnetic model: "as the electric sensation always felt by Mesmer at the approach of a particular servant was the starting-point of his discoveries in magnetism" (Balzac 1833, 111).[4]

Balzac was a staunch supporter of the proto-hypnotic psychotherapy invented by Franz Anton Mesmer and known back then as *animal magnetism*. According to this last citation, Mesmer discovered a kind of *magnetism* connecting his body to his servant's by feeling an *electric sensation*. For Balzac, there is then something akin to an electromagnetic induction occurring between Mesmer and his servant. The approaching servant recalls a moving magnet that induces electricity in a nearby conductor represented by Mesmer's body.

Sporadically in other novels, Balzac relies on electromagnetic phenomena to convey the invisible workings of cognitive and vital forces, and the way they can exert an influence on other bodies through space. Balzac was particularly attuned to the implications of Faraday's discovery because he believed in the same Romantic idea that had guided Ørsted on the path to his discovery of a connection between electricity and magnetism, namely, the unity of natural forces (Balzac 1976a, 16–17). Balzac was also a friend of André-Marie Ampère's son, Jean-Jacques Ampère. Jean-Jacques Ampère had an illustrious career as a literature professor, and reportedly joked that his two greatest achievements came down to having met Balzac when he was unknown and skinny (Balzac 1906, 366).

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3 Transl. by KM. "comme la chute de la poire devint la cause première des découvertes de Newton" (Balzac 1832, 333).

4 Transl. by KM. "comme la sensation électrique toujours ressentie par Mesmer à l'approche d'un valet fut l'origine de ses découvertes en magnétisme" (Balzac 1833, 111).

Another contemporary of Balzac, Edgar Allan Poe was also among the first major literary figures to create electromagnetic images. In the introduction of the little-known 1844 humorous tale, *The Spectacles*, Poe coins the term "magnetœsthetics" and defines it in terms of an electromagnetic interaction:

> Modern discoveries, indeed, in what may be termed ethical magnetism or magnetœsthetics, render it probable that the most natural, and, consequently, the truest and most intense of the human affections are those which arise in the heart as if by electric sympathy [...]. (Poe 2000, 886–887)

As in Balzac, such passages should be considered as unconventional for this era, the norm being images relying solely on magnetism *or* electricity to describe romantic attraction (i.e. love as magnetic attraction, etc.). What makes the above passages from Balzac and Poe remarkable and cutting-edge, is how they use magnetism and electricity together, to convey the workings of invisible interaction behind scientific inspiration and "human affections." The discovery of electromagnetic induction provided then a new analogical model, based on a new type of difference and relation, particularly suited for the exploration of other elusive and puzzling relations at work in phenomena such as involuntary cognition.

4 The term *induction* in electrical science

The electromagnetic difference also became a motor for exploration and discovery in physics. The various conceptual transformations undergone by the term *induction* from its initial meaning in electrostatics to Faraday's redefinition provide an effective starting point for investigating the impact of this unprecedented motor in physics. Faraday begins the series of papers on his discovery of electromagnetic induction by defining the meaning of *induction*. The term comes from phenomena attributed to "electricity of tension," or what we now call electrostatics:

> The power which electricity of tension possesses of causing an opposite electrical state in its vicinity has been expressed by the general term Induction; which, as it has been received into scientific language, may also, with propriety, be used in the same general sense to express the power which electrical currents may possess of inducing any particular state upon matter in their immediate neighbourhood, otherwise indifferent. It is with this meaning that I purpose using it in the present paper. (Faraday 1839a, 1)

Unlike conduction, or charging by contact, induction refers to how a negatively charged object causes a positive electrical state in another object, or vice-versa, without apparent contact. Although they relied on different terminologies, historians credit Benjamin Franklin (1706–1790), John Canton (1718–1772), Johan Carl Wilcke (1732–1796), and Franz Aepinus (1724–1802) with the first formulation of the concept of electrostatic induction (Heilbron 1979).

From the second half of the eighteenth to the beginning of the nineteenth centuries, the term induction progressively made its way into the official terminology of electrical science. In 1777, Tiberius Cavallo (1749–1809) stated in his treatise on electricity, "The action of these plates depends upon the principle long ago discovered, *viz.* the power that an excited electric has to induce a contrary Electricity in a body brought within its sphere of action" (Cavallo 1777, 382).[5] Cavallo does not explain his choice of the verb "to induce" for this electrical effect. He follows the verb's typical eighteenth-century dictionary definition of producing or bringing into view by influence or exterior cause (Johnson 1785).[6] The same meaning of the verb appears elsewhere in the treatise in the more familiar non-electrical contexts. At times, Cavallo also relies on "to induce" to refer to the logical inference characteristic of the scientific method associated with Francis Bacon (1561–1626), and consisting of generalizing observations into a law.

The introduction of the term *induction* in electrical science did not happen without controversy. In his often-cited 1814 treatise on electricity, George John Singer (1786–1817) writes on the subject of electrostatic induction: "Such phenomena are classed under the general term electrical influence; and positive and negative states so produced are called the electricities of position, or approximation, and by some writers induced electricity" (Singer 1814, 130). The main writer that Singer has in mind when he reluctantly mentions the term "induced electricity" is Humphry Davy (1778–1829), the great pioneer in electrochemistry, and Faraday's old boss at the Royal Institution.

In 1812, Davy had advocated the use of the terms "induced electricity" and "induction" in his descriptions of electrical effects (Davy 1812, 74).[7] In an article predating his treatise, Singer had criticized Davy's indiscriminate use of the term *induction* for electrical effects that he thought were actually different and stated that "in its literal interpretation [induction] expresses nothing analogous

5 I could not find an eighteenth-century example that clearly signals the shift from old electrical terminologies to the verb "to induce."

6 The Latin etymology of the verb "to induce" means to lead.

7 As noted by Singer, in Davy's published works the apparition of the term "induction" for various electrical effects dates back at least to 1807 (Singer 1812, 219).

to any known electrical effect."[8] Singer also had his critics. For instance, a reviewer of Davy's work aware of Singer's terminological objection, stated, "As to the term induction, which is more familiar to metaphysical than physical language, it seems as convenient and applicable as any other" ("Notices Respecting New Books" 1812, 435). Although the debate on the value of the term *induction* in electrical science would go on throughout the nineteenth century,[9] Davy's usage quickly became the norm.

5 Thinking with magnetic curves: Faraday's law of induction

Whether its "literal interpretation" fails to convey the nature of electrical effects or is as good "as any other," the early controversy surrounding Davy's choice of "induction" manifests a more profound epistemological issue linked at the time to the Newtonian framework of electrostatics. As Newton's classical mechanics rose to prominence in the eighteenth century, it became the paramount physical elucidation of the universe. In 1785, Charles-Augustin de Coulomb (1736–1806) published the law uncovering the mathematical relation between electrostatic force and the interaction of electrically charged particles. Coulomb's law ($F = kqq'/r^2$) looks structurally the same as the law of universal gravitation ($F = Gmm'/r^2$), suggesting that the fundamental principles of Newtonian physics were at work in all natural forces. However, as in Newton's law, Coulomb's law implied a type of action at a distance that occurs without delay or mediation. The actual way electricity produced an action through space remained a mystery (Balibar 1992). The debate as to whether Davy's "induction" provided the most accurate term for a kind of electrostatic influence sidestepped the critical issue since, regardless of what word was used, it could only refer to a vague action at a distance.

During the first half of the nineteenth century, Coulomb's achievement prompted other natural philosophers to apply Newtonian physics to magnetic and electromagnetic phenomena without conclusive success. As Faraday struggled

8 For Singer, Davy conflated two fundamentally different types of electrical effects, namely, the redistribution and the communication of charges that an electrically charged object could provoke in a nearby conductor (Singer 1812, 217–219).

9 "Amid such varying adaptations of the word *induction* there is much to gain in allotting to the electrostatic induction of charges by charges the distinguishing name of *influence*, as suggested by Priestley" (Thompson 1898, 153).

to formulate a simple rule to account for the electromagnetic effects he had identified through systematic experimenting and subsumed under the electrostatic term *induction*, he reached the first conceptual breakthrough that would eventually lead to the rejection of the theoretical framework informing Newtonian physics. Following an initial failed attempt to account for the interaction of magnetism, motion, and the induced electrical current in terms of Ampère's electrodynamics, he began to consider and develop a new concept based on the "magnetic curves" drawn by iron filings around a magnet (Steinle 1996, 152–153). He realized that he could consistently predict the electromagnetic effects of induction by focusing on the way a conductor in relative motion to a source of magnetism "cuts" its "magnetic curves" (Faraday 1839a, 32; 1839b, 66–67). By shifting the attention to the previously ignored "magnetic curves," this first formulation of what textbooks now call Faraday's law of induction was a theoretical leap whose far-reaching epistemological impact would only much later concretize (Steinle 1996).

Historians have differed widely on the main methodological factors that led Faraday to his revolutionary discoveries. Some have portrayed him as a "Baconian empiricist," others as "driven solely by theoretical and metaphysical speculations" (Steinle 1996, 144). More recently, Friedrich Steinle has described his approach in terms of "exploratory experimentation."[10] The unorthodox and puzzling nature of electromagnetic induction prompted Faraday's exploratory experimentation, where, instead of designing experiments to test a pre-established idea or theory, he systematically varied experimental parameters in order to reduce the inductive effects to their essential features. Once this empirical reduction was achieved, Faraday realized that these features did not comply

10 "Far from being a mindless playing around with an apparatus, exploratory experimentation may well be characterized by definite guidelines and epistemic goals. The most prominent characteristic of the experimental procedure is the systematic variation of experimental parameters. The first aim here is to find out which of them are essential. Closely connected, there is the central goal of formulating empirical regularities about these dependencies and correlations. Typically they have the form of 'if – then' propositions, where both the if- and the then-clauses refer to the empirical level. In many cases, however, the attempt to reformulate regularities requires the revision of existing concepts and categories, and the formation of new ones, which allow a stable and general formulation of the experimental results. It is here, in the realm of concept-formation, where exploratory experimentation has its most unique power and importance. There is, finally, often the attempt to develop experimental arrangements that involve only the necessary conditions for the effect in question and thus represent the general regularity or law in a most obvious way. Those experiments are attributed a particular status in that they serve as core effects to which all other phenomena of the field can be 'reduced'" (Steinle 2002, 419).

with existing concepts and categories, and proceeded to revise them by putting forth a radically new theoretical framework based on the idea of "magnetic curves." Faraday's exploratory experimentation highlights the effectiveness of a methodological approach that depends much more on process than theory. Although the variation of experimental parameters is systematic, its main purpose does not consist in confirming theoretical expectation. The outcome of this process remains then more open-ended and, in turn, more attuned to the need for conceptual change.

Steinle's description of exploratory experimentation downplays other factors that constitute an integral part of the process of discovery. As discussed above, Balzac saw early on in electromagnetic induction a new type of difference and relation that helped him convey the complex nature of the eureka moment. Balzac's initial Newtonian image conveys a straightforward experience where the detached scientist discovers universal gravity by witnessing the fall of a fruit. By replacing gravity with electromagnetic induction, Balzac creates an image that conveys a much more complex experience. Mesmer's discovery of *animal magnetism* proceeds indirectly via the *electric sensation* he feels as his servant is approaching. Furthermore, Mesmer's personal experience is not detached from the event that led to his discovery. He intimately partakes in it through an involuntary cognitive action described as the sensation of an "electric" effect. For Balzac, then, and in contradistinction to Steinle's account of exploratory experimentation, the process of discovery cannot exclude involuntary actions, which, in the case of Faraday, might be termed intuition. This latter term is notoriously vague and usually associated with poetics. However, as an open-ended process, exploratory experimentation must involve crucial decision making and theoretical leaps based on both voluntary and involuntary influences. Balzac considered intuition central to understanding the process of discovery, and perceived early on in electromagnetic induction a new and more accurate way to convey its elusive nature.

Balzac's image also provides a hint that the singular nature of the electromagnetic interaction Ørsted and Faraday had uncovered influenced the latter's experimental approach. Ørsted's compass and conductor apparatus and Faraday's invention of the first electromagnetic motor displayed a circular attraction that did not fit with the straight-line model of Newtonian action at a distance. This indirect or, more precisely, roundabout electromagnetic action provided empirical justification for practicing open-ended methods such as exploratory experimentation that do not simply depend of the straightforward application of theory. This circular motion must also have inspired Faraday in his groundbreaking choice of *magnetic curves* as an effective means to visualize and in turn formulate the law of induction.

6 Electromagnetic induction as a motor for scientific discovery

The discovery of electromagnetism and its circular action came with a new set of difficulties concerning the nature of the universe that would lead to the reconceptualization of its spatiotemporal fabric. This profound epistemological shift stemmed from Faraday's struggle to find an effective rule to explain electromagnetic induction, which prompted him to elaborate a new physical framework based on the *magnetic curves* drawn by iron filings around a magnet. In later works, Faraday renamed "*magnetic curves*" to "*lines of force*," and used them as an alternative to the seemingly unmediated influence implied by the Newtonian model of action at a distance.[11] James Clerk Maxwell perceived the physico-mathematical value of Faraday's lines of force, and relied on them to derive the classical laws of electromagnetism. Faraday's and Maxwell's work on electromagnetic induction and lines of force provided conceptual tools that brought about *field theory*, revolutionized the understanding of radiations, and enabled the exploration of the atom. It also played a central role in 1905, when Albert Einstein published a series of epoch-making articles that would displace the theoretical framework of Newtonian physics (Balibar 1992). In what follows, I will focus on Einstein's description of the thought process behind the article most closely associated with the conceptual breakthroughs of electromagnetic induction, "On the Electrodynamics of Moving Bodies," where he first postulated the special theory of relativity.[12]

In this article, Einstein, similarly to Balzac before him, would exploit the electromagnetic difference to elaborate new theories. Einstein's article starts with

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11 Faraday criticized such action at a distance with a thought experiment: "The notion of the gravitating force is, with those who admit Newton's law, but go with him no further, that matter attracts matter with a strength which is inversely as the square of the distance. Consider, then, a mass of matter (or a particle), for which present purpose the sun will serve, and consider a globe like one of the planets, as our earth, either created or taken from distant space and placed near the sun as our earth is; – the attraction of gravity is then exerted, and we say that the sun attracts the earth, and also that the earth attracts the sun. But if the sun attracts the earth, that force of attraction must either arise *because* of the presence of the earth near the sun; or it must have *pre-existed* in the sun when the earth was not there. If we consider the first case, I think it will be exceedingly difficult to conceive that the sudden presence of the earth, 95 millions of miles from the sun, and having no previous physical connexion with it, nor any physical connexion caused by the mere circumstance of juxtaposition, should be able to raise up in the sun a power having no previous existence" (Faraday 1855, 571–572).

12 Cf. Aura Heydenreich's paper "Albert Einstein's 'Physics and Reality' and 'The Electrodynamic of Moving Bodies'" in this volume.

a description of electromagnetic induction where, as Faraday had shown, the induced current depends on the interaction of a magnet and a conductor:

> It is well known that Maxwell's electrodynamics – as usually understood at present – when applied to moving bodies, leads to asymmetries that do not seem to attach to the phenomena. Let us recall, for example, the electrodynamic interaction between a magnet and a conductor. The observable phenomenon depends here only on the relative motion of conductor and magnet, while according to the customary conception the two cases, in which, respectively, either the one or the other of the two bodies is the one in motion, are to be strictly differentiated from each other. (1989 [1905], 140)

Einstein notes that the mathematical laws James Clerk Maxwell devised to quantify electromagnetic interaction distinguish between whether it is the conductor or the magnet that moves. However, for Einstein this distinction must be artificial because the induced electrical current only depends on the relative motion of the conductor and the magnet. In later writings, Einstein provides a more detailed account of the thought experiment that prompted him to apply the principle of Galilean relativity to electromagnetic induction:

> The difference between [the electric and magnetic fields] could not be a real difference, but rather, in my conviction, could only be a difference in the choice of reference point. Judged from the magnet there certainly were no electric fields; judged from the conducting circuit there certainly was one. The existence of an electric field was therefore a relative one, depending on the state of motion of the coordinate system being used, and a kind of objective reality could be granted only to the electric and magnetic field together, quite apart from the state of relative motion of the observer or the coordinate system. The phenomenon of the electromagnetic induction forced me to postulate the (special) relativity principle.[13] (1972, 32)

Einstein found in electromagnetic induction the clues that paved the way for the theory of special relativity. The application of Galilean relativity to electromagnetic induction "forced" him to recast the foundation of physics on new relativist grounds that attributed a special status to the electromagnetic field. This application yielded new concepts such as *time dilation* and *length contraction* that would undermine the notions of absolute space and time that informed the theoretical framework of Newtonian physics (Balibar 1992).

13 This excerpt is from an unpublished essay entitled *The Fundamental Idea of General Relativity in its Original Form*, written about 1919 (Einstein 1972).

In 1907, two years after publishing his special theory of relativity, Einstein had “the happiest thought of [his] life” when he made an analogy between the gravitational field and his relativist interpretation of electromagnetic induction:

> Just as in the case where an electric field is produced by electromagnetic induction, the gravitational field similarly has only a relative existence. Thus, for an observer in free fall from the roof of a house there exists, during his fall, no gravitational field – at least not in his immediate vicinity. If the observer releases any objects, they will remain, relative to him, in a state of rest [...]. (1972, 32)

As with the electric and magnetic fields, the gravitational field is relative. Einstein’s “happiest thought” marked the beginning of years of work that culminated in 1916 with the inclusion of gravity in the theory of relativity, or *the general theory of relativity*.

7 Bachelard’s electromagnetic epistemology

Einstein’s supersession of Newtonian physics would profoundly influence the intellectual climate of the twentieth century by providing an exemplary case study for reevaluating the process of scientific discovery. Bachelard was one of the first epistemologists to develop a new philosophy of science and history that drew extensively on Einstein’s example. Along with Einstein’s theory of relativity, he refers to Faraday’s electromagnetic science as “epistemological breaks [ruptures]” (1952, 15 and 25–26). The bachelardian idea of an *epistemological break* greatly contributed to the development of *historical epistemologies* during the twentieth century (Rheinberger 2010). It particularly influenced the historical approaches of thinkers such as Louis Althusser and Michel Foucault, who adapted it for their own purposes. It also paved the way for Thomas Kuhn’s *paradigm shift* theory. Like Einstein, Bachelard, who knew about the instrumental role electromagnetic induction had played in the discovery of the theory of relativity (1934, 125), implemented the electromagnetic difference to elaborate his critical ideas on the nature of discovery and history.

Bachelard considers the conceptual breakthroughs instigated by the discoveries of electromagnetism and Einstein’s theory of relativity as scientific revolutions that not only transformed our conception of the universe but also signaled a “new scientific spirit” (1938). According to Bachelard, before Einstein came to the fore, scientific practices derived mainly from empirical evidence and common sense. However, what the theory of relativity revealed about the nature of the universe had very little to do with everyday experience. The counter-intuitive outcomes of the theory of relativity could not have been derived from the accepted empirical framework of its day. For instance, before being tested and confirmed, Einstein's prediction of the phenomena of *length contraction* and *time dilation* stood in sharp opposition to the notion of absolute space and time that had informed physics since Newton. For Bachelard, Einstein constructed a new and more accurate physical reality through bold reasoning and rigorous mathematical exploration that only later turned to empirical validation. Electromagnetic science and Einstein's theory of relativity proved that scientific revolutions do not occur through the continuous accumulation of knowledge, but abruptly, through epistemological breaks triggered by unheralded theories that stood fundamentally at odds with the accepted scientific framework of their time (1934, 42 and 146–147).

As it did in Balzac's description of the *eureka* moment and in Einstein's thought experiment, the model of electromagnetic induction plays a central role in Bachelard's historical epistemology. Charles Alunni (1999) has shown the emergence in Bachelard's work of a new concept of cognitive *induction* informed by the phenomenon of electromagnetic induction and the formative role it played in Einstein's discoveries.[14] Alunni has also demonstrated how, in Bachelard, this new type of induction becomes a model to conceive a cognitive manifestation common to scientific, philosophical, and literary inventions. Bachelard called such cognitive induction, "dynamic intuitions" (1951, 214), and thought that electromagnetic induction best describes its elusive mode of operation.

Alunni's work on the new electromagnetic meaning of induction in Bachelard's philosophy of science also helps clarify the latter's early formulation of *epistemological break*. Bachelard actually uses the expression *epistemological break* on rare occasions. Following Althusser's and Foucault's reformulations, the expression has endured as a way to refer to Bachelard's contribution to epistemology and the philosophy of history, and as the name of one of the most influential ideas of the twentieth century. Through its canonization and subsequent reinterpretations, the term *epistemological break* lost track of the electromagnetic model Bachelard implemented to conceptualize the discontinuities that marked the evolution of science. The idea of *epistemological break* in Bachelard's philosophy of science hinged initially on a new interpretation of cognitive *induction* that took into account Faraday's and Einstein's discoveries. Bachelard writes:

14 See also Bontems 2010, 22–24 and 124–126.

> There is no transition from the system of Newton to the system of Einstein. One does not proceed from the first to the second by amassing data, perfecting measurements, and making slight adjustments to first principles. What is needed is some totally new ingredient. It is a 'transcendental induction' and not an 'amplifying induction' that leads the way from classical to relativistic physics.[15] (1984, 44)

"Ampliative induction" or, more broadly, inductive reasoning refers to the Baconian scientific method. It stands as the quintessential empiricist's logical inference of generalizing observations into a law. Inductive reasoning has been particularly at home in the natural sciences, but it depends too much on observable facts to trigger an *epistemological break*. Einstein transcended the empirical constraint imposed by the physics of his time through a different type of *induction*. As Einstein makes known, a thought experiment that consisted of applying the principle of Galilean relativity to electromagnetic induction is at the source of his *transcendental induction*.

8 Conclusion

The interaction of electricity, magnetism and movement did not just induce the electric current that transformed the world at the turn of the twentieth century; it also *induced* a new scientific spirit. In physics, Einstein became one of the most outstanding manifestations of this new type of thought when he drew an analogy between electromagnetic induction and the laws of mechanics in order to move the physics of his time beyond its own limits. In philosophy, Bachelard also relied on the electromagnetic difference and relation and the historical significance of its discovery in order to conceptualize the non-linear evolution of science. By identifying a new type of cognitive induction rendered manifest by the occurrence of *epistemological breaks*, he showed that epistemology itself was subject to change and, in turn, paved the way for the subsequent historical epistemologies that would shape the intellectual landscape of the second half of the twentieth century.

Bachelard's attraction to the multipurpose term *induction* to describe the *dynamic intuitions* at work in discovery echoes Faraday's aforementioned series

15 "Il n'y a donc pas de transition entre le système de Newton et le système d'Einstein. On ne va pas du premier au second en amassant des connaissances, en redoublant de soins dans les mesures, en rectifiant légèrement des principes. Il faut au contraire un effort de nouveauté totale. On suit donc une induction transcendante et non pas une induction amplifiante en allant de la pensée classique à la pensée relativiste" (Bachelard 1934, 42).

of papers on his discovery of electromagnetic induction. In addition to defining the new electromagnetic meaning of *induction*, Faraday also relies in these texts on the verb "to induce" in the Baconian sense.[16] In retrospect, Faraday's undiscriminating and wide-ranging applications of induction begin to resonate with each other but, unlike Bachelard, he does not make an explicit link between the new physical phenomenon and the logical inference.[17] As discussed above, it is a contemporary of Faraday, Balzac, who pioneered that link when in his description of the eureka moment he substituted the traditional Newtonian image of the falling fruit for the new electromagnetic model. Balzac's unprecedented image conveys a much more roundabout experience of discovery where a cognitive reaction akin to intuition is set in motion by the interaction of Mesmer's *electric sensation* and his servant's *magnetism*. Balzac therefore prefigures Bachelard's electromagnetic model of Faraday's and Einstein's *dynamic intuitions* and *epistemological breaks* by a century.[18]

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16 "[…] but later investigations […] of the laws governing these phenomena, induce me to think that […]" (Faraday 1839a, 16). "Thus the reasons which induce me to suppose a particular state in wire (60.) have disappeared […]" (Faraday 1839b, 69). As discussed above, similar wide-range uses of "to induce" appeared in Cavallo's early treatise on electrostatics.

17 A similar implicit resonance occurs when the proper interpretation of the discovery of electromagnetic induction becomes a point of contention between William Whewell, who frequently collaborated with Faraday on the creation of new scientific terms, and John Stuart Mill in their debate on the nature of the inductive sciences. Cf. Whewell 1849, 48–51.

18 Bachelard himself lends support to this last claim in the preface he wrote for Balzac's *Séraphita*. In this novel, where some of the earliest instances of electromagnetic images appear (Balzac 1976b, 737 and 823), Bachelard describes the power that Balzac's literary images can have on the reader in terms of "dynamic induction" (Bachelard 1970, 128).

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The Paradoxical Interplay of Exactitude and Indefiniteness

Reality, Temporality, and Probability, from Hölderlin to Heisenberg to Musil

Abstract: The aim of this paper is to explore the radically new relationships among reality, temporality, and probability, and the corresponding revision of these concepts themselves, that emerged in the wake of the introduction of quantum mechanics in 1925–1926. I argue, however, that an analogous understanding of these concepts and their relationships had begun to emerge in literature, as a response to Kant's philosophy, with the Romantics, such as Kleist and Hölderlin in Germany and Shelley and Keats in England, and has gradually developed throughout the history of literature and later on in philosophy. This understanding became especially pronounced in modernist literature, under the direct impact of quantum theory. Musil's *The Man Without Qualities* serves as the main modernist example of this understanding in this paper.

1 Introduction

Introduced in 1925, quantum mechanics, at least in certain interpretations of it, "in the spirit of Copenhagen [*Kopenhagener Geist der Quantenheorie*]," as Werner Heisenberg called it, radically changed our understanding of the concepts of reality, temporality, and probability, and their relationships, as against classical physics or relativity (Heisenberg 1930, iv).[1] Whether or not Georg W. F. Hegel's concept of *Geist*, which redefined this confrontation through his concept of concept [*Begriff*], was on his mind, Heisenberg must also have been thinking of the confrontation between nature and human spirit. This confrontation took a new form with quantum theory and its new concepts, as a confrontation between the nature of quantum reality and the spirit of Copenhagen. The spirit of Copenhagen may be defined

1 "The spirit of Copenhagen" is preferable to the more common rubric of the Copenhagen interpretation, because it is not possible to speak of a single Copenhagen interpretation, even in Niels Bohr's case. While always following the spirit of Copenhagen, which he initiated, Bohr changed his interpretation a few times. Here, I shall primarily refer to Bohr's ultimate interpretation developed in the 1930s. For the development of Bohr's views, see Plotnitsky 2012a.

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by the questioning of the possibility of realism in quantum theory, from quantum mechanics to quantum field theory, ultimately defining its concept of reality, specifically that of quantum objects and processes (viewed as defining the ultimate constitution of nature), as *reality without realism*, and, as a consequence, without causality. The absence of causality makes recourse to probability unavoidable in principle (rather than only in practice, as when classical statistical physics uses probability), and correlatively, gives a special character to temporality in quantum physics. Quantum mechanics only concerns future events and says nothing about the past, which is only defined by information obtained in actual, already performed, measurements (independent of the theory).

This article will argue, however, that a fundamentally analogous reconceptualization of reality, temporality, and probability emerged over a century earlier with the Romantics, such as Friedrich Hölderlin, the main Romantic author I shall consider, and Heinrich von Kleist in Germany, and Percy Bysshe Shelley and John Keats in England.[2] This reconceptualization was in part a response to David Hume's and Immanuel Kant's philosophy, especially their critical exploration of causality. The contemporary development of mathematical probability theory was another key factor shaping this reconceptualization, mostly indirectly, except with Kleist.[3] I shall call this rethinking *nonclassical*, as well as *Romantic*, the first being a more conceptual designation (applicable beyond Romanticism) and the second a more historical one. This rethinking developed gradually throughout the nineteenth century, beginning in philosophy with Friedrich Nietzsche, and in science, leading to quantum theory (introduced in 1900) via the kinetic theory of gases and thermodynamics. Although not a probabilistic theory, electromagnetism was another key development in the history of quantum theory. Darwin's evolutionary theory was shaped by similar thinking, and as such influenced both Ludwig Boltzmann's and James C. Maxwell's work in thermodynamics. Nonclassical thinking then entered modernist literature and art in the works of, among others, Wassily Kandinsky, Paul Klee, Arnold Schönberg, Franz Kafka, James Joyce, Virginia Woolf, and Robert Musil, who is the main modernist author I shall consider.

2 For the discussion of Shelley from this perspective, see Plotnitsky 2015.

3 While questions of reality and causality (or chance) have been extensively discussed in the humanities, probability is a marginal subject there, especially in literary studies. There are not many books on the philosophy of probability and little on it in Eighteenth-Century and Romantic studies. Rüdiger Campe's *The Game of Probability: Literature and Calculation from Pascal to Kleist* (2012) is one significant exception. However, historically and conceptually, this article takes off where Campe's book leaves the subject, as Campe does not enter into the more radical aspects of Romantic thinking (even in the case of Kleist) explored here.

Throughout this history, however, an alternative, *classical* understanding of reality and probability and their relationships, firmly established by the nineteenth century – as represented in particular by Pierre-Simon Laplace's vision of the world – has continued to persist and to remain dominant. *Classical* works both as a conceptual and a historical designation, the first vis-à-vis *nonclassical* and the second vis-à-vis *Romantic*. The dominance of this view in our own time is exemplified by Albert Einstein's famous discontent with quantum mechanics, in particular in his life-long debate with Bohr on quantum foundations, a discontent most widely known by his repeated pronouncements to the effect that "God doesn't play dice" (e.g., Born 2005, 88).[4] This discontent, however, had more to do with reality or ontology than it did with randomness and causality as such, although Einstein ultimately preferred to have causality as well. Whether nature or our interactions with it would allow for a classical view is another matter. Einstein's thought that it should, while Bohr argued that it *might not*, which is not the same as claiming that it *never will*. As we haven't yet heard nature's last word on this – that is to say, nature's next word (the only last word it ever gives us) – the debate continues with undiminished intensity.

This is not surprising, because the philosophical stakes are immense and they extend well beyond physics. These stakes arise from the confrontation between two fundamentally different views of the world, or two ontological hypotheses, classical and nonclassical or Romantic. While it may be intriguing that physics, in the form of quantum theory, has presented us with these two possibilities, the situation would not be different philosophically even if quantum theory had proven to be classical-like, as it was initially expected to be after its discovery by Max Planck in 1900, and, again, as it might yet be proven to be. I would surmise that our thought's confrontation with human life is unlikely ever to resolve this situation one way or the other, even assuming that physics would. Let me briefly sketch this situation by way of a prolog.

Suppose something, anything, has happened: let us call it an *event*. How did it come about? Something must have caused it, or so it would appear and so it is generally assumed, especially if the event belongs to an ordered configuration or arises according to some law. Kant calls this assumption the principle of causality. He defines that which causes an event as the cause of this event, which is an effect of this cause (Kant 1997, 305 and 308). Causality proceeds from causes to effects, while the principle of causality proceeds, by inference, from effects to causes. The principle of causality implies that reality has a causal character, if one can establish it – conceive of it, define it, describe it,

4 For Bohr's account of this debate, see Bohr 1987, vol. 2, 32–66.

and so forth. This is a major difficulty, known as the problem of causality, which Hume understood especially astutely. It is, Hume contended, beyond our reach ever to ascertain actual causal connections between events, even if such connections exist; we can at most surmise probable connections between events, although in certain cases such connections are sufficiently determinable and even nearly certain. Nevertheless, one might still reason as follows. While such ultimate causal connections between events and the architecture of the underlying reality (responsible for these connections) may be *unknowable* for us, they may, in principle, be *thinkable*, conceivable for us, even if without certainty as to whether such conceptions are correct (Kant 1997, 115). This is the most general form of the view of the world or ontological hypothesis that I call *classical*. Assuming this architecture to be in principle knowable, rather than merely thinkable, is a less stringent version of this view. Kant appears to have allowed this access with a greater (even full) certainty to what he called reason [*Vernunft*], a higher faculty than understanding [*Verstand*], which latter only concerned phenomena or representations. There is some debate concerning Hume's position in this regard.

The *nonclassical* or *Romantic* ontological hypothesis, while it assumes that the world exists, is *real*, rejects the applicability of the principle of causality and, even more fundamentally, the assumption that one could assign or even conceive of the ultimate constitution of reality. Such concepts as things, world, causality, architecture, constitution, or any other possible concept could only apply within certain limits, and within certain limits they must apply, although it is difficult and arguably impossible ever to know these limits completely, as Heisenberg observed in commenting on Kant (Heisenberg 1962, 92). At the ultimate level, however, these and any other concepts cannot apply. In philosophy, this view or hypothesis was arguably first advanced by Nietzsche, in part, again, by way of a critique of causality, as, to give one example, in the famous chapter "How the 'True World' Finally Became a Fable" of *Twilight of the Idols* (Nietzsche 1977, 485–486). As I argue here, however, this view had previously been adopted by several Romantic authors, some of whom might have influenced Nietzsche, especially given that in both cases confrontations with Kant are at stake. The same type of view then emerged in Bohr's and other interpretations of quantum phenomena and quantum mechanics in the spirit of Copenhagen. The situation becomes especially enigmatic, even mysterious, when the effects in question exhibit certain forms of order, along with randomness, as they do in quantum physics (where this order is that of statistical correlations). Where does this order come from? The underlying classical-like order would be a natural answer, were it compatible with these statistical correlations, which it is not, the incompatibility being reflected in the so-called Bell and Kochen-Specker theorems. The nonclassical or Romantic answer is that we do not or, more radically, cannot know or even conceive of how this order, or this randomness, comes about. They are effects of that which is neither ordered nor random, any more than anything else. There is no story to be told and no concept to be formed concerning the processes that lead to this order or this randomness. Fortunately for us, quantum theory predicts, it follows, probabilistically or statistically, these effects, in accordance with what is experimentally observed. However, we can and even must form concepts and tell stories concerning how such experiments are performed.

2 The key concepts of nonclassical theory

This section is designed to explain my key concepts. Given that I consider concepts operative beyond Romanticism, I shall for the sake of economy primarily speak of nonclassical concepts, while indicating their role or genealogy in Romantic thought whenever necessary. I begin with *ontology*, by which I understand what is claimed to be possible to say or represent or, in the first place, to *think* concerning the ultimate constitution of things in a given domain. Thus, ontology is not only a claim concerning the *existence* of something, say, material bodies in physics or thoughts in philosophy or psychology, but also and primarily a claim concerning the *character* of this existence. Realist theories are essentially ontological theories. This terminological difference is in part due to the relative prominence given to the language of ontology in post-Heideggerian continental philosophy and the language of realism in the philosophy of science, although the term ontology is found in the philosophy of science as well. These terms also reflect the difference between Greek ontology and Latin realism (and translations from one to another), which difference elicited some reflections by Heidegger, in part defined his preference for ontology, but that subject is beyond my scope.

The limits of ontological or realist theories are defined by the fundamental assumptions of Kant's philosophy. As already indicated, Kant's epistemology places the ultimate, noumenal, reality beyond our knowledge, or understanding based on this knowledge, both of which are associated strictly with phenomena or appearance to our minds. However, while *beyond knowledge*, Kant's noumena are not *beyond thought*. They are, according to Kant, thinkable, insofar as this thinking is logical (Kant 1997, 115). As mentioned, Kant associates this type of thinking with reason [*Vernunft*], a higher faculty that can reach the ultimate nature of things, whereas understanding [*Verstand*] applies to phenomena only. Kant recognized that our thinking concerning the character of noumena or things-in-themselves might be wrong, even if it works in practice. However, his view of the situation still logically implies that this thinking may also be correct, even though it may not be possible to verify its correctness. Indeed, Kant argues that some claims of reason are in fact determinately correct. As Kant also argues, under this assumption that the truth of our conception of ultimate reality is only possible rather than determinate, this conception need not be justified in theoretical terms: a practical justification, defined by the workability of such a conception, may suffice (Kant 1997, 115). However, because such a conception might still be true (it is, again, determinately true in the case of reason), this view implies at least the possibility of a representation of reality, albeit one that is never guaranteed to be correct (or verifiable). At the very least, then, realist theories assume that the concept of structure can in principle apply to this constitution, no matter how far off the mark may be anything we can come up with in conceiving of this constitution. The hope is that our theories can capture, even if approximately, something of this architecture.

Romantic thinking or quantum-theoretical thinking in the spirit of Copenhagen not only avoids making any of these assumptions; it actually disallows them. This thinking does assume that certain entities, material or mental, which define the ultimate constitution of physical nature considered in quantum physics, or the ultimate nature of things in life in Romantic thinking, *exist*, are *real*. However, the character of this existence is such that it prevents us from describing, or even from forming a conception of, these entities and their behavior. There may thus be a *reality without realism*, insofar as no conception of this reality, or in Jacques Lacan's terms, the Real, is possible, keeping in mind that reality, too, remains a provisional name (Lacan 1998). One could still speak of ontology in this case, which justifies my use of nonclassical or Romantic *ontology*. Ontological considerations are applicable to actual phenomena or events, which are effects of that reality which is beyond the reach of thought and hence of realism or ontology. There may be, and there must be, ontological or realist representations of events, but there are no representations or conceptions of how these events ultimately come about.

The lack of causality is an automatic consequence. As Erwin Schrödinger observed, with some disparagement, by this point seeing quantum mechanics, which he helped to create, as "the doctrine born of distress:" "if a classical state does not exist at any moment, it can hardly change causally" (Schrödinger 1935, 152 and 154). I understand *causality* as an *ontological* category (part of reality) that pertains to objects or systems whose behavior is defined by the fact that the state of such an object or system is, at least in principle, determined at all times by its state at a particular moment of time, indeed any given moment of time. Classical, Newtonian mechanics, which offers an idealized mathematical model of the behavior of classical objects, is a paradigmatic example of causal and realist or ontological theory in science. (All modern, post-Galilean physics, quantum theory included, deals only with such models.) Classical mechanics has also been one of the primary inspirations for modern philosophy, and its paradigmatic model of causal thinking, from John Locke on, including Kant.

I understand *determinism* as an epistemological category (part of our knowledge of reality) that denotes our ability to predict, again at least in principle, the state of an object exactly, rather than only probabilistically, at any moment of time, once we know its state at a given moment of time. The term *determinism* is sometimes used, as it was by Laplace, in the sense of, or interchangeably with, *causality* as defined here. However, a system may be causal without allowing us to predict its behavior (ideally) exactly. The models of classical statistical physics and those in chaos and complexity theories are of this type – causal but not deterministic.

By *randomness* or *chance* I refer to a manifestation of the unpredictable. Randomness and chance are not the same, but I shall put the difference between them aside, given that my main argument applies to both. A random or chance event is an unpredictable event. It may not be possible to estimate when such an event will occur or to anticipate it as an event. Such an event may or may not hide some underlying causal dynamics that lead to it. The first case defines classical randomness or chance, essentially an appearance of randomness or chance concealing some hidden causality. This has been the dominant form of classical – ontological or realist – thinking throughout the history of Western thought, from the pre-Socratics on, although, as will be seen below, classical or realist ontology may be defined, as in Lucretius, by randomness and chance, or the interplay of randomness and causality. Thus, as already noted, Kant and an even more skeptical Hume appear to have seen the ultimate ontology of the world as causal. What they denied was that the human mind could have access to this causality and, as a result, establish definitive *causal* connections between events, rather than surmise *probable* connections between them. The concept of randomness or chance that suspends the possibility of underlying causality emerges, I argue here, with Romantic thinking and, with some intermediate developments mentioned above, becomes central to quantum theory. As explained, by precluding any representation or even conception of ultimate reality in principle, this ontology automatically suspends causality. By the same token, randomness and chance become unavoidable in principle, for fundamental reasons, even in dealing with individual (undecomposable) processes and events, rather than only for practical reasons, as when classical physics deals with systems of great mechanical complexity. These systems are assumed to be decomposable into individual components that behave and interact causally and are represented as such, thus assuring the underlying, even if not in practice accessible, causality of the aggregate systems. This assumption is incompatible with the probabilistic or statistical data of quantum physics, as Einstein was the first to establish (Einstein 1906). However, in quantum physics or elsewhere where nonclassical ontology applies, the ultimate level of reality could not be seen as random or as the interplay of randomness and causality, any more than as causal.

It is important to distinguish between randomness or chance and probability. Probability or statistics deal with estimates of the occurrences of certain individual or collective events, which defy deterministic handling (whether or not there is a hidden underlying causality determining these events), in physics or science generally, usually in accordance with mathematical probability theories. The terms *probabilistic* and *statistical* are generally used differently. *Probabilistic* refers to our estimates of the probabilities of either individual or collective events, such as that of a coin toss or of finding a quantum object in a given region of space. *Statistical* refers to our estimates concerning the outcomes of identical or similar experiments, such as that of multiple coin-tosses or repeated identically prepared experiments with quantum objects; or to the average behavior of identical objects, or objects treated as identical. Definitions of probability may reflect this difference, as in the case of (so-called) Bayesian vs. frequentist understandings of it. Bayesian theories define probability as a degree of belief concerning the occurrence of possible individual events on the basis of the relevant information we possess, thus making probabilistic estimates generally subjective, although there may be agreement (possibly among a large number of individuals) concerning such estimates. Frequentist theories, sometimes also referred to as *frequentist statistics*, define probability in terms of sample data by an emphasis on the frequency or proportion of these data, which is often seen as more objective. The Bayesian approach allows one to make estimates concerning individual or even unique events, say, betting on the outcome of a basketball game or, as in Pascal's wager, on the existence of God and the salvation of the soul, rather than on frequently repeated events, such as repeated coin tosses, where our estimates are defined by previous experience of the same or closely similar events. Technically, no two coin tosses are strictly the same, a point used by Bayesian theorists against frequentists. In the frequentist view they are sufficiently similar to be treated as statistically identical.

This brief summary sidesteps some of the deeper aspects of probability, but it suffices for my purposes.[5] I conclude by stressing two points that are central to this article's argument. First, probability has a temporal structure by virtue of its (correlated) irreducibly futural and irreducibly discrete character, because one can only estimate future discrete events. In the case of quantum events only probabilistic or statistical predictions are possible, even in dealing with primitive individual events. Secondly, probability introduces an element of *order* into situations defined by *randomness and chance*, and allows us to handle such situations better, even in the absence of an ultimate causality (ontologically) underlying such situations, an absence found in quantum mechanics. Probability or statistics is, thus, about the interplay of randomness and order. This aspect of probability takes on a special significance in quantum physics because of the presence of statistically ordered correlations not found in classical physics. These correlations are correctly predicted by the formalism of quantum mechanics. As we will see, a similar situation is found in Romantic ontology, which, like quantum physics, is also more about order and rhythm, than about randomness or chance.

3 Rhythm, caesura, and the unthinkable in Hölderlin

Romantic thinking, I argue, introduced a new concept of ontology and, with it, a new ontological hypothesis. Although sometimes associated by the Romantics, including Hölderlin, with ancient Greek thinking, which is to say, their *interpretation* of this thinking, this ontology does not appear to have been developed before the Romantics, such as Kleist and Hölderlin in Germany, or Shelley and Keats in England. It emerged, I argue, in part in response to Hume's and Kant's philosophy, by taking their thinking to the limit that Hume and Kant had not envisioned or had been reluctant to accept. This is why I call this ontology Romantic ontology, while keeping nonclassical ontology as a more general conceptual designation. This ontology is juxtaposed to classical ontology (or, again, the corresponding ontological hypothesis), which allows for an ontology offering a conception and a representation of the ultimate nature of reality, usually, but not always, assumed to be causal.

5 See Háyek 2014 and further references there.

A paradigmatic example of classical causal ontology is Sophocles's *Oedipus the King*, where the apparently random or chance events are ultimately (pre)determined by the inescapable causal necessity of fate, no matter how one tries to circumvent fate. Or such is the case if one interprets the ultimate ontology of the events in the play in this way, an interpretation that Hölderlin's reading of the play questions, also insofar as this (classical) ontology might be presumed by Oedipus or other characters. In Hölderlin's reading, tragic fate is determined otherwise. Rather than a form of causal necessity, fate is a form of necessity without causality or, again, any ontological attributes. As will be seen, Musil suggests that *destiny* (a concept related to fate) may be given *a statistical meaning* (Musil 1996, vol. 2, 783). The nature of fate is captured, as that which is beyond capture, by the structure of tragic representation, as the interplay of a rhythm (a form of order or pattern) and a caesura (a break in this rhythm). The characters' ontological calculations and decisions or bets, such as Oedipus's decision, against Tiresias's advice, to pursue his investigation of the murder of Laios (revealed to be Oedipus' father), are measured against this noncausal concept of fate and in relation to this structure. Caesurae reflect the fact that tragic fate will defeat these bets and plunge the characters into chaos, without return. This is how the structure of tragedy appears in Sophocles, *in Hölderlin's reading*. This structure is defined by a precise *calculable law*, which relates the calculable to that which is unthinkable and, hence, incalculable (Hölderlin 2009, 317). This law, it follows, implies the absence of causality, and yet also the impossibility of seeing the workings of fate as random. The situation is not unlike the way quantum mechanics calculates the probabilities of quantum events, in this case in precise numerical terms, which it must do in order to be an exact science.

The ancient Greeks did contemplate a reversal of the classical causal ontology – an ontology defined by the rule or misrule of chance, which makes all causal order an appearance or illusion. This ontology may be called the Jocasta ontology, because it was expressly stated by Jocasta, Oedipus' mother and wife, in *Oedipus the King*: "Fear? | What should a man fear? It's all chance, | chance rules our lives. Not a man on earth | can see a day ahead, groping through the dark. | Better to live at random, best we can" (Sophocles, *Oedipus the King*, ll. 1068–1072). No appeal to probability is possible under these conditions. Next to nothing can be estimated with any degree of belief; and there is no order, rhythm, or a meaningful temporality either, only a sequence of random discrete events. Jocasta's view is proven to be illusory in the play, because the lives of the characters are ruled by fate, defined either by a causal ontology or, if one adopts Hölderlin's reading, by necessity without causality. The effects of this fate are ultimately discrete and have randomness to them, but some of them are also rhythmic in their collective temporal structure, in accord, *at the level of effects*, with another ontology contemplated by the ancient

Greeks, that of the interplay of chance and necessity. The emphasized qualification is crucial when the ontology of this interplay is nonclassical, as in this case. First, however, I shall briefly consider a classical (representational) ontology of this interplay.

This ontology was introduced, as the atomist ontology of nature, by Democritus and developed by Epicurus and Lucretius, whose *De Rerum Natura* is based on it. Certain individual events, such as Lucretius's famous clinamen, a random swerve of an atom from a causal trajectory, are not given causality, are random, just as are those of the Jocasta ontology (in this case, all events). Lucretius' account of this random swerving is not accompanied by a nonclassical account of its efficacy. This makes this ontology representational and hence classical, insofar as it is assumed to be the ultimate ontology, even though it is not strictly causal.

Lucretius does not explain how such swerves happen, but rather presents them as random events "at quite uncertain times / And uncertain places," without an assumption, at least a stated assumption, of causality behind them (Lucretius, *On the Nature of the Universe*, book 2, ll. 218–219). This type of randomness was also initially a problem in quantum theory, and remains one unless a causal interpretation of quantum processes is in place. This is not surprising because, according to Wittgenstein, we might not be able to conceive of a process that is not causal (Wittgenstein 1924, 175). Nonclassical ontology of quantum phenomena resolves or avoids this problem by assuming that quantum objects and processes responsible for quantum phenomena (observed in measuring instruments) are inconceivable altogether. The interplay of randomness and order, or statistical regularities, although not causality, is present, as quantum events are not only random. But this interplay occurs at the level of effects, while the efficacy of these effects – that is, the reality that is responsible for them (in the absence of causality) – is beyond representation or the reach of thought altogether, and hence is neither causal nor random, and nor is it any combination of randomness and causality. According to Bohr: "we are not dealing with an arbitrary renunciation of a more detailed analysis of atomic phenomena, but with a recognition that such an analysis is *in principle no emphasis on excluded*" (Bohr 1987, vol. 2, 62). Some among these ontological *effects*, effects that we can perceive, know, describe, and so forth, compel us to infer this unthinkable, because these effects cannot be accounted for otherwise. That is, the unthinkable is a rigorous inference from these effects and not merely an imaginative conception, an imaginative conception of the unimaginable. The concept of necessity or fate in Hölderlin, too, refers to this type of noncausal efficacy. It follows, of course, that "efficacy" is a provisional name and is ultimately inapplicable, which compels Hölderlin to appeal to the unthinkable, [*das Undenkbare*], although this unthinkable is ultimately unthinkable even as unthinkable.

Not all Romantic authors subscribed to nonclassical ontology, although most Romantics appear to have confronted this ontology as a *possibility*. Some Romantics found this possibility troubling or undesirable, or, as Kant did earlier and Einstein later, rejected it and adopted more classical-like ontological hypotheses. I would argue that Blake, Coleridge, and Wordsworth had adopted positions similar to that of Kant, or in the case of Coleridge, that of (early) Schelling. Even Hölderlin, Kleist, Shelley, and Keats were hesitant and oscillated between nonclassical ontology and less radical alternatives. Their different works reflect these oscillations. Thus, its appeal to highly improbable events notwithstanding, Kleist's *Improbable Veracities* [*Unwahrscheinliche Wahrhaftigkeiten*] appears to be based in classical-like ontology, which allows for such events. Such situations, as noted earlier, defined the structure of ancient Greek tragedy, in which, in Aristotle's famous words in the *Poetics*, "it is probable that some improbable things occur" (Aristotle 2013, 53). Campe reads Kleist's novella on these classical lines, and he sees the Romantics as defined merely by mixtures of harmony and conflict in relating to truth within classical-like thinking. This may be cogent in the case of this particular work, but is inadequate to the radical nature of Romantic thinking, as understood here, including those among Kleist's works, such as *Penthesilea* and *On the Marionette Theater*, that are defined by this thinking. It is not merely a question of the probable and the improbable. It is a question of what kind of reality is assumed behind improbable events or ordered patterns of collective events – classical, which is also causal, or Romantic, which is not and is in the first place a reality without realism. This reality only allows for randomness or order at the level of effects of this reality. While each event is singular and not subject to a causal law or even a probabilistic law (one cannot assign a probability to it) in all circumstances, collective events may, in certain circumstances, exhibit correlational patterns in the absence of causality, with which these patterns are indeed incompatible. This may appear contradictory, and it would be under classical assumptions. If, however, one assumes the noncausal efficacy of these events, this is possible without contradiction.

Such a pattern of events is akin to a poetic line, in which words and even letters form a complex pattern but in a way that makes their causality difficult and even impossible to establish (although in the case of poetry this causality may, in principle, exist). Hölderlin would have spoken of a *rhythm* of events, a rhythm, however, possibly involving counter-rhythm and caesura, and the architecture of rhythm in Hölderlin contains all three. While the confluence of rhythm, caesura, and time is manifested more immediately in poetry, because these concepts originate in the structure of the poetic line, it is also found elsewhere – in mathematics, physics, philosophy, history, ethics, and politics. "*Everything is rhythm*," Hölderlin is reported (by Bettina von Arnim) to have said, "*the entire destiny is a single celestial rhythm, just as the work of art has a unique rhythm*" (von Arnim 1983, 294). Whether Hölderlin said exactly this or not, he indeed appears to have thought that rhythm is found everywhere – in poetry, philosophy, politics, mathematics and science. As I argue here, Hölderlin's concepts of rhythm, caesura, and time are subject to nonclassical or Romantic ontology, according to which the ultimate workings of matter or thought that give rise to rhythm are inconceivable, un-thinkable, ultimately unthinkable even as unthinkable. The word *das Undenkbare* is used by Hölderlin in defining human understanding of things as *wandering beneath the unthinkable*, which, ultimately, defines one's fate, governs it, from above (Hölderlin 2009, 327; translation modified). He also speaks of *das Unförmliche* (e.g., Hölderlin 2009, 263).

What, then, is the architecture of Hölderlin's ontology that led him to, or emerged from, his reading of tragedy? I shall first outline this architecture (in the present interpretation) in more general terms, and then consider his reading of tragedy, as governed by this architecture. The most immediately manifested effects are those of the *rhythmic* successions of events or *representations* [*Vorstellungen*], such as those developed through the tragic hero, successions interrupted and altered by caesurae, which also represents the tragic *agon*. This type of organization becomes the governing principle of the structure of tragedy, a principle that is found elsewhere, for example, in modernist novels, or actual history (Hölderlin 2009, 317 and 325; Lacoue-Labarthe 1997, 41). However, in the present reading, there is a further architecture of discreteness underlying this structure in tragedy or history, as Hölderlin's law of tragedy is also the law of historicity. This architecture is as follows.

At the ultimate *ontologically available* limit, all individual events (which could also be events of thought), including those composing each rhythmic succession, are always *singular* and *discrete* relative to each other, without any causal or otherwise lawful relationships between any *two events*, while the ultimate efficacy of all events is, again, *not available* to thought, is *das Undenkbare*. This is the case even when such events occur in a temporal sequence, to the degree that the concept of sequence can apply, and within its limits, because their temporal succession may only be apparent and not assured. In other words, at this ultimate available level of the constitution of events, all events are always separated from one another, and any *two of them* are generally unrelated to each other, and this underlying manifold of events can be random overall. Each event can have its own probability of occurrence, or possibly have no probability assignable to it. However – and this is a defining aspect of this ontological architecture, also found in quantum theory – in certain circumstances (but not all), some collectivities of such underlying events can have an order or rhythm to them. In the case of tragedy, this order or rhythm reflects the nature of fate as a form of necessity without causality. In these situations, the overall structure of such collectivities is not random, even though *any two events* may not be connected by any law. I shall return to this apparently (but only apparently) paradoxical situation below, merely noting here that the paradox is avoided if it is assumed, nonclassically, that it is impossible to conceive how this situation comes about.

If considered more coarsely, a given manifold of events may include intervals or trajectories of continuity and continuous temporality (or what appears to be so), or intervals that have discrete rhythmic structures, even if the underlying, more coarsely grained manifold of events does not. The presence of such continuous intervals and discontinuous rhythmic sequences, along with the counter-rhythms and caesurae that interrupt them, are central for Hölderlin's concepts of rhythm and caesura. As I said, however, at the ultimate available level of resolution any such interval would always resolve into a discrete multiplicity, either random or rhythmic, of discrete events that might, but need not, have occurred in close temporal proximity to each other. It is this proximity, whether temporally defined or not, that prevents one from perceiving their discreteness. On the other hand, it is this discreteness that gives rise to any caesura and its counter-rhythmic effects, which interrupt a given rhythmic sequence, continuous or discontinuous. An interruption may, and generally does, occur at an intersection between two rhythmic sequences, but even then each of these sequences is still ultimately discrete. It is, I argue, the corresponding broken and nonsequential – "caesuraed" – temporality that is at stake in Hölderlin, who finds it in the structure of tragedy. Placed beyond the reach of thought, as *das Undenkbare*, the efficacy of all events and sequences considered (rhythmic or broken by a caesura) cannot be assumed to be either continuous or discontinuous, or as forming a mixture of both, just as it cannot be assumed to be either causal or random, or any combination of causality and randomness. Nor can it be seen as temporal, unless one defines this efficacy as time, which one might be reluctant to do because one would then *name* this efficacy "time." Lacan intriguingly spoke in this connection of "logical" (vs. "ontological") temporality (Lacan 1998, 27–28). It is true that "efficacy" is also a name. However, it is a provisional name that has strategic neutrality, which is difficult to have in the case of time. Hölderlin, too, uses *das Undenkbare* or *das Unförmliche*, and not *Zeit*, in (un)naming the efficacy of fate or time itself.

The architecture just outlined defines Hölderlin's reading of *Antigone* and *Oedipus the King*, or is extracted or constructed from these works by this reading. In Sophocles' plays, counter-rhythmic caesurae, marked by the intervention of Tiresias in the end (ancient tragedy) of the first and the beginning (modern tragedy) of the second play, introduce a disjunction between two sets of events (Hölderlin 2009, 324). Consider the case of *Oedipus the King*. Although Thebes is in crisis from the outset, the course of the events is initially normal, as concerns Oedipus' action aimed at solving the crime by finding the murderer of Laius. Tiresias's announcement, however, to the effect that it is Oedipus himself who committed the murder, and not merely a murder but a patricide, radically transforms the course and rhythm of events. Indeed it defines a new course of events, disconnected from the preceding ones. It is a caesura, which makes the plot no longer a single rhythmic sequence but a balance or equilibrium of two rhythmic sequences. The expectations concerning what is probable (also as concerns past events) radically change as well, because of this new (in our terms) *information*, which Oedipus initially dismisses as false in view of its unlikely veracity from where he stands at the moment. According to Hölderlin: "Hence, in the ensuing dialog with Tiresias, the wonderful angry curiosity; because knowledge, when it has broken through its limits, as if intoxicated in its own magnificent and harmonious form, which can yet remain, at first, provokes itself to know more that it can bear or grasp" (Hölderlin 2009, 319–320). A caesura, then, breaks a possible rhythmic or causal connection (causality is replaced by fate, as a form of necessity without causality) between two rhythmic tragic representations, and relates them not in terms of succession but in terms of a kind of equilibrium, as the structure of representation as such. According to Hölderlin:

> [the] rhythmic succession of representations [*Vorstellungen*], wherein the *transport* [in French in the original] represents itself, demands a counter-rhythmic interruption, a pure word, *that which in meter is called a caesura*, in order to counteract the turbulent [successive] alternation of ideas at its climax, so that that it is not the alternation of representations that now appears but a representation as such [...].
>
> (Hölderlin 2009, 317; translation modified)

This interruption has, thus, a meta-dimension because it also reveals *a representation as such*, the structure of tragic representation within a given tragedy, even demanded by the genre of ancient Greek tragedy as tragedy. In a caesura, this structure reveals the efficacy of all tragic events, including caesurae themselves, but is itself "the most unbounded of all," and hence, unlike these events, is beyond representation (Hölderlin 2009, 317). In other words, the structure of tragedy is defined by those events which appear as caesurae. What appears (at a meta-level) between representations, representing rhythmic sequences of events, at a point of caesura is the nature of tragic representation as such, a structure that relates to discontinuous events, without representing their connections to other events and, hence, the ultimate efficacy of these events. More representational sequences are part of this structure but they do not represent the processes responsible for the event of a caesura, or ultimately for these sequences, although there may be local causal relations within these sequences. This *formalism* reflects the fact that the rhythm of life can be radically altered by a caesura at any point, revealing the underlying *caesured* discontinuity, rarely completely random, but not always manifesting a tragic fate either. The structure of tragic representation *relates* to each caesura without representing the process that gives rise to it or to rhythmic parts of tragedy, or assuming that it is representable.

It follows that, thus understood, the unthinkable cannot be divine. The divine, the God, is still thinkable, thinkable as God, even if, as in negative or mystical theology, none of God's actual attributes are thinkable. In this respect the situation is parallel to that of causality, and more than parallel, because God is also causality. It was Nietzsche's radical critique of causality that led him to nonclassical ontology and to his concept of the death of God. It is unthinkable (and hence, again, noncausal and un-divine) efficacy that ultimately creates "the conditions of [pure or empty forms] of time and space," forms exposed, unlike the unthinkable itself (which cannot be exposed), at the moment of a caesura (Hölderlin 2009, 323). This move toward the unthinkable, even if not quite a nonclassical staging of the unthinkable itself, appears to be characteristic of Sophocles. Unlike other Greek tragic writers, Sophocles knows how to portray human understanding [*Verstand*] as "wandering beneath the Unthinkable" [*unter Undenkbarem wandelnd*] (Hölderlin 2009, 326; translation modified), the abyss or (this word is no longer applicable either) the un-abyss, the beyond-abyss of the unthinkable beneath or, as the case might be, "above" the divine.[6] If this is the God's withdrawal, as claimed by Hölderlin, one could read it as a tragic representation of the workings of the unthinkable, and also as the un-divine efficacy of the divine, thus announcing the death of God or at least a figure of the death of God.

To recapitulate, in the Hölderlinian architecture of tragedy, any actual individual event – at least, again, in the finest possible resolution of the flow or, thus, un-flow of events – is irreducibly singular and, in general, cannot be comprehended by a law that would position it in a calculable relation to any other event that precedes or follows it. In some cases, but not always, one could assign a probability to such an event, on Bayesian lines, on the basis of various kinds of information we have; for example, concerning similar events that have happened previously. However, in literature or in life, manifesting a tragic fate

6 The phrase "the abyss above" occurs (in a different set of contexts) in the title of Silke Weineck's book (2002), which offers an important analysis of Hölderlin.

as necessity without causality, in some, but only some, circumstances, certain collectivities of events (which may appear as continuous because of the close proximity of the events involved), exhibit ordered, rhythmic patterns, which may or may not be interrupted or counter-rhythmically hinged by caesurae. The events involved are collectively organized, yet every single event is nevertheless random: that is, the law and the rhythm of this organization does not allow us to put any single event in a determined or determinable relation to any other single event preceding or following it. This situation may, again, appear paradoxical, and it is paradoxical, if considered classically: there is no conceivable logic that could explain how this is possible. The paradox is resolved if one adopts a Romantic or nonclassical ontology: this organization is possible and actually occurs, but how it comes about is inaccessible to thought. As I said, there could be no story to be told about it, or any conception to be formed about how it comes about, but both are possible and necessary at the level of effects.

The structure of tragedy and its law, thus emerging, are *calculable*, which is one of Hölderlin's starting points. One must, however, establish "how the content is different from this law, and by what means; how the particular content relates to the general calculation within a continuum, which, though unbounded, is nevertheless determined throughout; and how the developments and the intended statement, the living sense of which cannot be calculated, may be related to the calculable law" (Hölderlin 2009, 317; emphasis by AP). The calculable *formal* law of tragedy or history only relates (and then still without fully governing them) to the temporal effects of the unthinkable, which is beyond all calculations, including the type of approximation found in calculus in mathematics (likely on Hölderlin's mind), the approximation of the continuous by the discrete. This is because, in the present reading of Hölderlin, the ultimately reachable architecture of effects is always discrete, if sometimes organized, rhythmic, with any continuity appearing only at a coarse resolution as a second-order effect. It is this underlying manifold that gives rise to any given caesura that interrupts continuity or discontinuous rhythms. It is difficult to properly elaborate on the connections between Hölderlin's thought and differential calculus within my limits. But it would be equally difficult to bypass them, in part because it gives this paper a more rigorous historical trajectory, from calculus to Hölderlin to quantum theory to Musil.

Hölderlin is clearly concerned with the relationships between continuity and discontinuity, and the difficulty of rigorously defining the constitution of a *continuous* manifoldness (to use the technical term [*Mannigfaltigkeit*] introduced by Bernhard Riemann), say, a straight line, as comprised of *discrete* individual points, corresponding to real numbers, a difficulty perhaps ultimately insurmountable, as was revealed by Georg Cantor's set theory later on. In the case of Hölderlin's concept of rhythm, this difficulty is, as just explained, resolved by suspending continuity altogether at the level of the ultimate available *resolution* of events, and suspending both continuity and discontinuity at the level of the ultimate efficacy of events. One of the major developments of eighteenth and then nineteenth-century mathematics was a radical rethinking of the nature of continuity, in conjunction with establishing, around the time of Hölderlin's work, the mathematical foundations of calculus, which until that time, while extraordinarily effective practically, lacked rigorous mathematical definitions of its key concepts.[7] This rethinking allowed one to more properly address, even if not ultimately resolve, the difficulties and paradoxes plaguing the subject in mathematics, physics, and philosophy. Cantor's set theory is part of this history. It was of course developed well after the time of Hölderlin and is unlikely to have had connections to him. The theory, however, confronted problems analogous to those to which Hölderlin's thinking also responded, admittedly as philosophical rather than mathematical problems. But then, these problems were also philosophical as well as mathematical for Cantor and other mathematicians who addressed them.

The textual evidence for the connections between Hölderlin's thinking and calculus is indirect, but is apparent in Hölderlin's appeal in his discussion of rhythm and time to *calculus* and its avatars (*calcul*, *Rechnung*, *Berechnung*), as in considering the *calculability* of the law of tragedy by virtue of the rhythmic and counter-rhythmic order that defines it, as considered above. Hölderlin appears to have questioned the model of continuity analogous to that defining and defined by calculus (and the theory of continuous functions), at least as applicable to temporality, ultimately defined by continuity in Kant, to whose thought Hölderlin has direct connections. In approaching temporality, Hölderlin appears to envision a very different relation between continuity and discontinuity, and a different form of *calculus* of the temporal, as considered above. As explained, at stake in his analysis of the structure of tragedy and, by the same token, historicity, is *the calculable law*. One must, however, establish

> how the content differs from this law, and by what means; how the particular content relates to the general calculation within a *continuum* which, though endless, is nevertheless

7 A proper understanding of the difference between continuity and differentiability was part of this history. Although Bernhard Riemann provided some earlier insights, Karl Weierstrass was the first to construct an example of a function that, while continuous at every point, does not allow for a derivative and hence is not differential at any point. This means roughly that, if one thinks of it as a curve, one cannot define a tangent to this curve at any point.

> determined throughout; and how the developments and the intended statement, the living sense of which cannot be calculated, may be related to the calculable law.
> (Hölderlin 2009, 317; translation modified, emphasis by AP)

It is possible to read this elaboration and hence Hölderlin's ontology on the model of calculus, for example, as used by Richard Dedekind to define real numbers, some of which, specifically irrational or transcendental, are incalculable, as represented by the discrete, and thus *calculable*, sequences of rational numbers (speaking very roughly). This definition was introduced in the 1870s, again, long after Hölderlin's death, but the role of series in differential calculus, which is similar and which in fact was Dedekind's model, might have been familiar to Hölderlin. In this reading, the calculable law of tragedy, technically applied to the discrete, could be related to the infinite of a continuum, which would be, thus, determined without being strictly computed, and then the calculable law of tragic representation would be related to the incalculable *living sense* of this representation. This reading is possible, but it would be much more difficult to relate to *das Undenkbare* than the present reading. The calculable formal law of tragedy or (this is the same *formal* law) of history only relates to (yet does not fully govern) the temporal effects of the unthinkable, which is beyond all calculations, including the type of approximation found in calculus, of the continuous by the discrete. This is because in this interpretation of Hölderlin, the ultimately reachable or ascertainable architecture of effects is always *discrete*, if sometimes organized, rhythmic, with any continuity appearing only at a low resolution, as a second-level effect. It is this underlying manifold that gives rise to any given caesura that interrupts continuity or rhythmic discontinuities. Crucially, it is not a matter of reversing the ontological order of the continuous and the discontinuous, although this reversal takes place (the discontinuous underlies the continuous). It is a matter of seeing both as effects of the unthinkable, which is itself neither continuous nor discontinuous.

The conceptions of temporality available at Hölderlin's time could not accommodate this view because they all had assumed an underlying efficacious architecture of such effects as either continuous or discontinuous, as in atomism, which was beginning to enjoy new prominence at the time. Models and calculus (which allows us to work with the effects involved, even if never with their efficacies) analogous to that of Hölderlin are, however, conceivable in modern physics, specifically in quantum theory, and in post-Cantorian mathematical logic. These mathematical models would conceptualize the line as irreducibly inaccessible, beyond the reach of thought, which would also prevent us from assuming that the ultimate constitution of the line is in any way linear, is a line in any sense we can give to this term. Temporality and rhythm need not require rigorous mathematical models, unless one deals with physics, where temporality must at least be connected to mathematics. On the other hand, philosophical conceptions of both can suggest the corresponding mathematical models. These models could be made rigorous in the way they are in quantum mechanics, which could, I argue, be connected to Hölderlin's thinking of temporality developed through his concepts of rhythm and caesura.

4 The rhythms and caesurae of the quantum: Temporality, complementarity, and the spirit of experimentation

Quantum physics, discovered in 1900 by Max Planck, gradually revealed the nonclassical character of quantum phenomena or events, defined by the fact that Planck's constant *h* (which has a very small magnitude) cannot be neglected in considering them. That quantum phenomena and the quantum mechanics that predicts them have proven to be open to or even to require nonclassical interpretations may have been unexpected given the preceding history of physics (ontologically classical until then), but it should not perhaps have been entirely surprising, given the microscopic scale of quantum objects responsible for these phenomena. According to Heisenberg:

> It is not surprising that our language should be incapable of describing the processes occurring within the atoms, for [...] it was invented to describe the experiences of daily life, and these consist only of processes involving exceedingly large numbers of atoms. Furthermore, it is very difficult to modify our language so that it will be able to describe these atomic processes, for words [when they describe things] can only describe things of which we can form mental pictures, and this ability, too, is a result of daily experience. Fortunately, mathematics is not subject to this limitation, and it has been possible to invent a mathematical scheme – the quantum theory – which seems entirely adequate for the treatment of atomic processes [in terms of predicting the outcomes of quantum experiments]; for visualizations, however, we must content ourselves with [...] incomplete analogies [such as] the wave picture and the corpuscular picture. (Heisenberg 1930, 11)

Heisenberg, modestly, does not mention his own pioneering role in the invention of this "mathematical scheme," which is, however, hardly a secret. That Heisenberg found a mathematical scheme that could predict the data in question was as fortunate as that mathematics is free of this limitation of visualizability, for the latter is also the case in classical physics and in relativity. Ultimately, although heuristically useful, all visualizations are not only incomplete but are also provisional, for no representation of any kind, visualizable or not, of quantum objects and processes is possible, at least in the interpretations in the spirit of Copenhagen, to which Heisenberg refers here (Heisenberg 1930, 10–11). Unlike classical mechanics or relativity, which ideally and, at least up to a point, visualizably represent the behavior of individual classical systems and give exact predictions concerning them on the basis of such representations, quantum mechanics, thus interpreted, does not represent the behavior of even elemental quantum objects. It only provides probabilistic or statistical predictions concerning the outcome of quantum experiments manifested in measuring instruments, outcomes that define quantum phenomena, in contradistinction to quantum objects. Although this is in accord with what is actually observed in quantum experiments, contrary to Heisenberg's sentiment expressed here, the adequacy of quantum mechanics, especially in this interpretation, has been questioned, again with Einstein leading the way. This adequacy remains under debate, notwithstanding the enormous successes of the theory and its extensions, such as quantum field theory. These extensions thus far remain probabilistically or statistically predictive, rather than realist, theories; at least interpreting them as realistically descriptive poses major difficulties, although there has been no shortage of attempts to do so. In nonclassical interpretations, no two experimentally observed quantum phenomena can ever be continuously or causally connected physically, specifically in terms of the movement of quantum objects, such as electrons, photons, or other elementary particles, or their composites. In Heisenberg's words: "There is no description of what happens to the [quantum] system [itself] between the initial observation and the next measurement" (Heisenberg 1962, 47). Nobody has ever observed a moving quantum object as such, and nonclassical interpretations place quantum objects and processes beyond the reach of human thought altogether. The fact that the probabilistic predictions of quantum mechanics or higher-level quantum theories are correct is enigmatic, given that they do not appear to have a physical justification of the type found in classical physics or relativity.

The *affinities*, thus transpiring, between Hölderlin's thinking (or that of other Romantics) and quantum theory may appear artificial or forced. I do not think that either is the case. As I noted from the outset, nature, as manifested in physics, might have remained classical, and it might yet prove to be. However, the fact that nature and physics, as a science, were complicit in creating this situation is important for the affinities in question, not least because physics is never only physics, mathematical or not, but is also philosophy and culture. Both play their roles in shaping an interpretation of physical phenomena and a given theory such as those in the spirit of Copenhagen in the case of quantum phenomena and quantum mechanics. Hume's and Kant's philosophies are part of the philosophical genealogy of both Romantic thinking and that which shaped quantum theory. The influence, direct and mediated, of Romantic literature and thinking on the founders of quantum mechanics, including Bohr and, especially, Heisenberg, could be surmised from their writings, although these connections are rarely considered (Plotnitsky 2004). It is true that there is no direct evidence concerning the impact of Hölderlin or the other Romantic figures mentioned here. This does not, however, prove that their thought did not play a role, even if only indirect or mediated by other sources (for which there is evidence), in the rise of quantum theory. More significant, however, is that the Romantics were confronting problems concerning reality, temporality, chance and probability analogous to those encountered in quantum physics. Accordingly, it is not surprising that both Romantics and physicists responded to these problems by means of similar concepts. As Bohr said:

> [...] we are not dealing here with more or less vague analogies, but with an investigation of the conditions for the proper use of our conceptual means shared by different fields. Such considerations not only aim at making us familiar with the novel situation in physical science, but might [...] be helpful in clarifying the conditions of logical relations which, in different contexts, are met with in wider fields [...].
>
> (Bohr 1987, vol. 2, 2; Bohr 1987, vol. 3, 7)

As I said, the philosophical concepts discussed above in connection with Hölderlin do not require and, in their proper domains, may not allow for mathematical models. On the other hand, such philosophical concepts, possibly supplied by literature, can lead to mathematical models in science. Conversely, quantum theory, on its own or in combination with related trajectories of thought, including Romantic thought, can provide a rich source for philosophical and literary thinking, as happened in the case of modernism.

Thus, the unavoidable *caesura* between quantum phenomena introduces a kind of Romantic, Hölderlinean temporality or, in Lacan's terms, *logical temporality*, which results from a different synthesis of time, as Kant would have said, into quantum physics. This temporality is no longer linked to motion as it is in classical mechanics or relativity – insofar as we can only predict the state of certain possible measuring arrangements at a future time on the basis of the state of certain measuring arrangements and measurements performed at a given earlier time.[8] This aspect of quantum ontology has important physical and philosophical implications, which I shall now discuss via the uncertainty relations discovered by Heisenberg in 1927, and Bohr's concept of complementarity, introduced in 1927 as well, in part under the impact of Heisenberg's

8 Clocks and their (classical) motions are of course used in quantum experiments, which use is part of the disciplinary nature of quantum physics as a mathematical-experimental science. But one could only relate the data (physical time) observed in clocks, which are measuring instruments themselves, to what occurs, as a set of discrete phenomena, in other measuring instruments, and not to the motion of quantum objects.

introduction of the uncertainty relations. I begin with complementarity, because it helps to better understand the uncertainty relations. Complementarity is defined by:

(a) a mutual exclusivity of certain phenomena, entities, or conceptions; and yet
(b) the possibility of applying each one of them separately at any given point; and
(c) the necessity of using all of them at different moments for a comprehensive account of the totality of phenomena that we must consider.

This definition is very general and allows for different instantiations of the concept in the case of quantum phenomena, and for its applications beyond physics. Parts (b) and (c) are as important as part (a), and to miss them, as is often done, is to miss much of the import of Bohr's concept.[9]

The wave-particle complementarity, with which the concept of complementarity is most associated, played little if any role in Bohr's thinking. Bohr's solution to the dilemma of whether quantum objects are particles or waves – or his *escape* from the paradoxical necessity of seeing them as both – is that they are neither. Each feature is seen by Bohr as an *effect* or set of *effects*, particle-*like* (which may be individual or collective) or wave-*like* (which are always collective), of the interactions between quantum objects and measuring instruments, where these effects are manifested, while their efficacy is beyond representation or even conception. The most significant among the complementarities considered by Bohr are those of position and momentum measurements, and of space-time coordination and the application of momentum or energy conservation laws. These complementarities are also those between different experimental arrangements, in which the corresponding measurements and applications of physical concepts occur. This view enables Bohr to give an interpretation of Heisenberg's uncertainty relations.

Technically, the uncertainty relations, $\Delta q \Delta p \cong h$ (where q is the coordinate, p is the momentum in the corresponding direction, Δ is the standard deviation, and h is Planck's constant, the signature of the quantum), only prohibit the simultaneous *exact* measurement of both variables. The physical meaning of the uncertainty relations is a complex subject, which cannot be considered here, beyond what is pertinent to Bohr's interpretation of them. First of all, the

9 Bohr and a few others inspired by him, such as W. Pauli, C. G. Jung, and M. Delbrück, proposed instantiations of the concept in philosophy, psychology, and biology. Attempts to do so continue. I shall not, however, be concerned with these extensions here.

uncertainty relations are not a manifestation of the limited accuracy of measuring instruments, because they would still obtain even if we had perfect measuring instruments. In Bohr's interpretation, the uncertainty relations make each type of measurement complementary to the other. Indeed, in Bohr's interpretation, not only can one not (exactly) measure both variables simultaneously, one also cannot define them simultaneously. This is always possible, at least ideally and in principle, in classical physics, and it is this possibility that allows one to maintain causality there. The reason for this situation in quantum physics is the irreducible role of measuring instruments in the constitution of quantum phenomena (as opposed to classical physics where this role could be disregarded, at least in principle), which circumstance, like the uncertainty relations, is correlative to the probabilistic or statistical nature of quantum predictions. This situation results from the fact that what will happen is determined by the questions we ask and the particular experiments we *stage* (a relevant metaphor, as will be seen). It is not merely a matter of our capacity, as in classical physics or relativity, to track what happens in nature independently of our intervention. As Bohr was fond of saying, "the new situation in physics reminded us of the old truth that we are both onlookers and actors in the great drama of existence" (Bohr 1987, vol. 1, 119; vol. 2, 20 and 63).

Quantum mechanics and subsequent higher-level quantum theories continue classical physics and relativity insofar as they continue the experimental-mathematical science of nature. However, these theories, again at least in nonclassical interpretations, break with both classical physics and relativity by establishing radically new relationships between mathematics and physics, or mathematics and nature. Taking advantage of and bringing together both main meanings of the word *experiment*, I would argue that quantum mechanics was the first physical theory that was both, and jointly, truly experimental and truly mathematical. It is truly experimental because it is not, as in classical physics, tracking the independent behavior of the systems considered (which is not possible in quantum physics), but what kinds of experiments we perform, how we *experiment* with nature, that defines what happens.[10] If one makes one measurement, one thing happens; if one makes another measurement, another thing happens, in some cases, such as those in which complementarity applies, incompatible with the first (although this difference can, in general, only be established statistically). It also follows that the data obtained in one measurement is "erased" by a subsequent measurement and thus is no longer useful for the purposes of our predictions concerning the outcomes of later experiments.

10 I am indebted to G. Mauro D'Ariano on this point.

Accordingly, we can no longer use successive observations and measurement in the way we do in classical physics to improve the accuracy of our predictions. As will be seen, this aspect of the situation is intriguingly paralleled by Musil. Of course we experiment, with great ingenuity, in classical physics as well, but there our experiments stage, in a laboratory or some equivalent setting, processes that, once staged, could be considered as in principle independently mathematically representable, apart from the interactions between classical objects and measuring instruments.

By the same token, quantum mechanics is truly mathematical because the mathematical formalism of the theory is not in the service of such a tracking, by way of auxiliary description of what would have happened anyhow, but is in the service of predictions defined by our experiments. This makes mathematics more important than ever because there is nothing else to help us in our predictions. It also follows that we experiment with mathematics, more so than in classical physics, because we invent mathematical schemes unrelated to any reality, rather than using them to refine our phenomenal perceptions or representations, which constrain us in classical physics. Heisenberg's discovery of quantum mechanics was a remarkable product of this type of mathematical experimentation. One might say that mathematically, quantum mechanics is compositional. It is a compositional mathematical abstraction that in the absence of a physical description of quantum objects and processes, nevertheless, enables correct statistical predictions of the outcomes of quantum experiments, which, again, may be as much as nature allows us to have. It is, I think, fitting to borrow the term composition from music or abstract painting. Both modernist music, with Schönberg and Stravinsky, and abstract painting, with Kandinsky, Mondrian, and Klee, were dramatic examples of modernist art, in some ways parallel to abstract mathematics and quantum mechanics, especially in their purely compositional aspects. Modernist literature, or Romantic literature, may be seen in this way too. Composition, Deleuze and Guattari say, is "the sole definition of art," and no true art was ever merely representational (Deleuze and Guattari 1994, 191). Not all art is quantum-like in that it is composed of effects of the unthinkable; that of Kandinsky, however, refers to the "internal silence" of the unthinkable, and that of Klee refers to the "nonconceptual concept" of the unthinkable (Deleuze and Guattari 1994, 218).

5 Experimental life and experimental literature in Musil's *The Man Without Qualities*

While one might be surprised that nonclassical thinking had appeared in literature or philosophy before quantum physics, its appearance there after the rise of quantum physics in 1900 and especially after the discovery of quantum mechanics in 1925 could hardly be unexpected. Numerous links to quantum theory, manifest or hidden, are found throughout the history of literary modernism and then postmodernism, from Franz Kafka, Virginia Woolf, James Joyce and Samuel Beckett to Tom Stoppard, Thomas Pynchon, and Don DeLillo, to name only a few major figures.[11] Here, I would like to consider Robert Musil's *The Man Without Qualities* [*Der Mann ohne Eigenschaften*] because of its affinities with certain specific features of quantum theory and of Hölderlin's thinking as considered in this essay. These features are less prominent elsewhere. In addition, as in the structure of tragedy in Hölderlin's readings, these affinities between Musil's novel and quantum physics are found not only at the level of content, but also at the level of form. I can only offer a sketch for a possible reading of these aspects of the novel, which contains many passages offering deep explorations of these ideas and their implications. It would be difficult to do more here.

The main protagonist, Ulrich, *the man without qualities*, which, I would argue could also be read, *without properties [proper attributes]* is a mathematician, who was previously in the military and then studied engineering. This gives the novel autobiographical dimensions: Musil attended an engineering school, where his father taught, and was well versed in science. It may be noted that Ulrich's last name, one of the defining *proper* attributes of our world, is not given, out of respect for his famous father, a jurist, a man with qualities, and who, unlike *the man without qualities*, is introduced right away. Even Ulrich's first name is not introduced until Chapter 5. That Ulrich is a man without qualities or properties may be seen as a negative (even as a kind of lack of *propriety*) by some, even most, other characters in the novel – not least, I would argue, because of their view of life, defined by causal realism, which only Ulrich and his sister Agatha appear to reject. For Ulrich, however, his lack of qualities/properties is a reflection of his affinities with life, which, as regards the efficacy of its events, is, at the ultimate level of its workings, without proper attributes, and as such, requires the corresponding hypothetical or experimental, and hence probabilistic way of conducting one's actual life. It is true that, given that

11 See Plotnitsky 2012b for a discussion of these connections and further references.

Ulrich's primary mathematical area of specialization is the study of turbulence, one could see Ulrich's or Musil's view of life in terms of a more complex form of causality, such as that found in fluid dynamics. This picture of life does play its role in the novel. I would argue, however, that ultimately Musil's thinking and Ulrich's view of life is quantum-mechanical.

Musil introduces this thread of the novel from the outset. The first chapter, "which, remarkably enough, does not get anyone anywhere" (the chapter's title), begins with a picture of global weather patterns, manifestly probabilistic and described as such. Much of the chapter, quite short and essay-like, as many of the novel's chapters are, invokes probabilistic themes. It closes with a couple, a man and women, unidentified and apparently with no further connection to the novel's events, encountering a car accident in Vienna, although Musil says (making another statistical point): "Let us not place any particular value on the city's name" (Musil 1996, vol. 1, 4):

> 'According to American statistics,' the gentleman observed, 'one hundred ninety thousand people are killed there every year by cars and four hundred fifty thousand are injured.'
>
> 'Do you think he's dead?' his companion asked, still on the unjustified assumption that she had experienced something unusual.
>
> 'I *expect* he's alive,' he answered, 'judging by the way they lifted him into the ambulance.' (Musil 1996, vol. 1, 5; emphasis by AP)

The defining maxim of this trajectory of the novel appears as the title of Chapter 4, *If there is a sense of reality, there must also be a sense of possibility*, a chapter which is an essay on reality and possibility, and thus probability. As the chapter proceeds, Musil deprives this reality of realism. He closes as follows: "And since the possession of qualities assumes a certain pleasure in their reality, we can see how a man who cannot summon up a sense of reality even in relation to himself may suddenly, one day, come see himself as a man without qualities" (Musil 1996, vol. 1, 13). This announces the novel's major theme of reality and probability, ultimately reality without realism (which would still allow one to "summon a sense of reality") and probability without causality – quantum-like reality and probability, although this quantum-like character of both will take a few more twists to establish. The fact that this reality without realism is still reality remains as crucial as the fact that it is without realism: "It is reality that awakes possibilities, and nothing would be more perverse than to deny it" (Musil 1996, vol. 1, 12). Also, in effect defining the program of Ulrich's life and of the novel's structure: "A possible experience or truth is not the same as an actual experience or truth minus its 'reality value' but has – according to its partisans, at least – something quite divine about it, a fire, a soaring, a readiness to build and a conscious utopianism that does not shrink from reality but sees it as a project, something yet to be invented" (Musil 1996, vol. 1, 11). This is parallel, conceptually, to the point made above, that in quantum physics our experiments define, *invent*, the course of reality rather than, as in classical physics, follow it. A bit earlier, Musil confirms this:

> Whoever has it [a sense of possibility] does not say, for instance: Here this or that has happened, will happen, must happen; but he invents: Here this and that might, could, or ought to happen. If he is told that something is the way it is, he will think: Well, it could probably just as well be otherwise. (Musil 1996, vol. 1, 11)

"It was," Musil says,

> [Ulrich's] opinion that in this century, together with everything human, one was on an expedition, which required as a matter of pride that one cut off all useless questions with a 'not yet,' and that life be conducted on a provisional basis, but with awareness of the goal to be reached by those who will come after. (Musil 1996, vol. 1, 43)

This (reflecting Ulrich's earlier view) is still too Moses-like, dying in the wilderness, with "the hope," supported by science, "that a distant day will come when a race of intellectual conquerors will descend into the valley of spiritual fruitfulness." "But," Musil counters with his characteristic comic touch, "this works only so long as the eye is not forced to abandon visionary distance for present nearness, or made to read a statement that in the meantime a racehorse has become a genius" (Musil 1996, vol. 1, 43). This is both a much more local and a more experimental, more probabilistic, more quantum-mechanical, view of reality and possibility. Later, Ulrich is "comparing the world to a laboratory," in which one lives one's life as an experimental life (Musil 1996, vol. 1, 160). But what kind of experiments or what kind of experimental situations or phenomena would one encounter? And what would be a theory, if any, by which one could relate to these experiments, and how? There is always one theory or another, unless one conducts one's life along the line of the Jocasta ontology of absolute randomness and chance. I don't think that this is what Musil or Ulrich has in mind, and one could hardly think of experimenting under the conditions of the Jocasta ontology. The conception of experimental life at stake here is, again, much more like quantum physics. As discussed earlier, the latter makes science experimental by defining what is (at least more likely) to occur by our decisions concerning what kinds of experiments we perform, a situation that corresponds to nonclassical ontology. I would argue that two conjoined utopias of the novel, the utopia of precision and the utopia of essayism, amount to this type of situation as well:

> Utopias are much the same as possibilities; that a possibility is not a reality means nothing more than that the circumstances in which it is for the moment entangled prevent it from being realized – otherwise it would only be an impossibility. If this possibility is disentangled from its restraints and is allowed to develop, a utopia arises. It is like what happens when a scientist observes the change of an element within a compound and draws his conclusions. Utopia is the experience in which the possible change of an element may be observed, along with the effects of such a change on the compound phenomenon we call life. If the element under observation is precision itself, one isolates it and allows it to develop, considering it as an intellectual habit and way of life, allowed to exert its exemplary influence on everything it touches. The logical outcome of this should be a human being full of the paradoxical interplay of exactitude and indefiniteness. [...]
>
> Such is the utopia of precision. One doesn't know how such a man will spend the day, since he cannot continuously be poised in the act of creation and will have sacrificed the domestic hearth fire of limited sensations to some imaginary conflagration.
>
> (Musil 1996, vol. 1, 265–266)

The phrase "the paradoxical interplay of exactitude and indefiniteness," which I adopted as this article's title, is a pretty good description of quantum mechanics in general and the uncertainty relations in particular, and it would be difficult to assume that Musil was unaware of this parallel. As concerns what can happen, at most only a probability can be assigned to a possible event, and moreover, only sometimes. Ulrich's decisions (not to be confused with choices, especially *free* choices) concerning what he does from one point to another exemplify this situation. They are unexpected from the outside and sometimes even from the inside of his thought, and yet there is a strange precision to these decisions. His existence in the novel has a rhythm and is multi-rhythmic, but these rhythms are only those between caesurae, each of which also moves him to a new rhythm, as with modernist music, from Arnold Schönberg to Pierre Boulez and beyond, which is defined by its disjointed, quantum-like architecture, disrupting rhythms and harmonies, and yet creating new ones. It may seem, in listening to such a composition, that one moves from a yet unfinished development to a new one by merely breaking from the former. But this is not the case. Rather one rebalances the actual and the potential of a given development with a new one, with a Hölderlinean caesura between them, just as a caesura works in a poetic line. Similarly, the structure of events of Ulrich's life and, as will be seen presently, the structure of the novel itself, combine rhythmic sequences and breaks. Some of Ulrich's trajectories and some chapters (sometimes in parallel) are extended and are given more continuity, while others are very short; some are linked and others are disjoined. The ultimate underlying architecture of all events, including those of thought is, again, discrete, and the ultimate efficacy of these events is neither discrete nor continuous, any more than it has any other properties. This efficacy is *without properties* [*ohne Eigenschaften*]. Musil says:

> Precision, as a human attitude, also demands precise action and precise being. It makes maximal demands on the doer and on life. But here a distinction must be made.
>
> In reality, as we all know, there is not only an imaginary precision (not yet present in reality at all) but also a pedantic kind, the difference being that the imaginary kind sticks to the facts and the pedantic kind to imaginary constructs. The precision, for instance, with which Moosbrugger's peculiar mentality was fitted into a two-thousand-year-old system of legal concepts resembled a madman's pedantic insistence on trying to spear a free flying bird with a pin; this precision was concerned not at all with the facts, but only with the imaginary concept of cumulative law. But with respect to the big question of whether Moosbrugger could be legally condemned to death, the psychiatrists were absolutely precise: they did not dare to say more than that Moosbrugger's clinical picture did not exactly correspond to any hitherto observed syndrome, and left any further conclusions entirely to the jurists. (Musil 1996, vol. 1, 267)

Thus, one can and sometimes must be precise about indefiniteness, as is the case in Heisenberg's very precise concept of the uncertainty relations. In living hypothetically, Ulrich is unlike Oedipus, who sees his fate as causal necessity, and is perhaps more like Hamlet, in that he proceeds, lives, under the assumption of experimental life, which is only subject to fate insofar as the latter is necessity without causality, which enables one to take bets and shape the future by these bets. As Ulrich says at the outset of (the posthumously published) Volume 2: "In times to come, when more is known, the word 'destiny' will probably have acquired a statistical meaning," which is, it is worth noting, itself a probabilistic estimate on Ulrich's part (Musil 1996, vol. 2, 783). There is a difference, insofar as Hamlet's fate is ultimately determined as tragic, while that of Ulrich remains undetermined, even as the shadows of the tragedy of World War I loom over Musil's comic novel, just as over (his main precursor) Joyce's *Ulysses*. Ulrich and his Vienna are not that far from Leopold Bloom and his Dublin. Bloom, too, lives hypothetically, finding his rhythms between caesurae on his one-day/life-long journey through Dublin. Musil describes the utopia of essayism as follows:

> Later, when Ulrich's intellectual capacity was more highly developed, this became an idea no longer connected with the vague word "hypothesis" but with a concept he oddly termed, for certain reasons, "essay." It was more or less in the way an essay, in the sequence of its paragraphs, explores a thing from many sides without wholly encompassing it – for a thing wholly encompassed suddenly loses its scope and melts down into a concept – that he believed he could most rightly survey and handle the world and his own life. [...]

> The accepted translation of "essay" as "attempt" contains only vaguely the essential allusion to the literary model, for an essay is not a provisional or incidental expression of a conviction capable of being elevated to a truth under more favourable circumstances or of being exposed as an error (the only ones of that kind are those articles or treatises, chips from the scholar workbench, with which the learned entertain their special public); an essay is rather the unique and unalterable form assumed by a man's inner life in a decisive thought. Nothing is more foreign to it than the irresponsible and half-baked quality of thought known as subjectivism. Terms like true and false, wise and unwise, are equally inapplicable, and yet the essay is subject to laws that are no less strict for appearing to be delicate and ineffable. There have been more than a few such essayists, masters of the inner hovering life, but there would be no point of naming them. Their domain lies between religion and knowledge, between example and doctrine, between *amor intellectualis* and poetry; they are saints with and without religion, and sometimes they are also simply men on an adventure who have gone astray. (Musil 1996, vol. 1, 270 and 273)

Not unlike our mathematical betting in quantum physics, the success of *essayism* in life is never assured, and it may be a product of "men who have gone out on an adventure and lost their way." In quantum mechanics, we succeed in betting on the statistics of repeated experiments, and not so much in betting on any given experiment, while life rarely gives us a chance to repeat experiments. Musil seems to suggest that *essayism* or something akin to it is the best or even the only creative approach that can succeed where it counts most, in dealing with the ultimate questions. For the moment, I would like to emphasize the structure – the quantum-like betting on the uncertain future, from one singular, discrete event to another, even though smooth, classical-like trajectories or streams of events, or what appears or is experienced as such, or rhythmic discrete trajectories are sometimes possible, before a new caesura enters. While we cannot avoid the structural, irreducible incompleteness, insofar as how things ultimately happen is beyond knowledge and thought itself, essayism is as complete as our world allows us to be, as quantum mechanics is as complete as nature allows a theory of quantum phenomena to be.

Essayism in life is akin to *amor fati*, invoked by Nietzsche, a love of fate, but a *fate* defined by uncertainty without underlying necessity, unless in Hölderlin's sense, a love for the uncertainty of the future, but also and crucially a probability of the future (Nietzsche 1989, 258). Nietzsche is an important figure in the novel. ("A Nietzsche year," is proposed by one of the characters, Clarissa, instead of "the year of Austria," at one point – admittedly, in one of the novel's numerous comic touches [Musil 1996, vol. 1, 240].) This process is, again, complex, insofar as it cannot be seen as an accumulation of knowledge, because each event, at least each key event, tends to erase the preceding history as useful for our next bet on the future. Out bets, are, however, firm decisions, products of "an essay [as] […] the unique and unalterable form assumed by a man's inner life in a decisive thought" (Musil 1996, vol. 1, 273), amidst the unthinkable efficacy of what happens.

Most centrally, for therein lies the novel's great literary innovation, the nonclassical architecture of essayism is not only described by the novel, but also defines its structure, especially in the second, unfinished, volume. Each essay-like section, into which the novel ultimately dissolves or rather crystallizes, is like a quantum experiment, which radically redefines a future history to be portrayed from this point on, never quite certain, a product of a bet, under the condition of the ultimately unthinkable efficacy. As explained, the data obtained in one quantum measurement is *erased* by the next measurement and is no longer useful for the purposes of our predictions concerning future experiments. Every new experiment redefines the future. This makes the novel itself "the unique and unalterable form assumed by a man's inner life in a decisive thought" (Musil 1996, vol. 1, 273), now Musil's own inner life as an artist in a decisive artistic thought, shaping and redefining itself with each event, each event of the novel's composition. This is similar to Nietzsche's philosophical style (undoubtedly on Musil's mind, given his persistent appearance in the novel, and manifest similarities between many chapters of Volume 2 and chapters in Nietzsche's works), making each of his works or his life a sequence of essays. In both cases, however, these essays are part of a larger essay structure, in Musil's case of a huge, interminable, multi-essay novel, which is left unfinished or is finished as unfinished. It is as if, and in this regard it goes beyond both of its great modernist precursors, Proust's *In Search of Lost Time* and Joyce's *Ulysses*, and is closer to *Finnegans Wake*, *The Man Without Qualities* had to continue to leave itself a possibility for yet another bet. This is, however, a way of life, an experimental life, like that of Ulrich, which the novel wants to portray, but it may well be the novel's own experimental life as literature that gives us the best sense, rather than only a portrayal, of such a life – its rhythms and caesurae, events and expectations, realities and possibilities.

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Stephan Mühr

The Horizon of the Horizon

On the Physical History of Gadamer's Fusion of Horizons

Abstract: In this paper, I trace how and why physical concepts of telescopy from the sixteenth century begin to travel through different disciplines and, in so doing, change their meaning to become hermeneutic metaphors. It can be proven that Gadamer's concept of the fusion of horizons [*Horizontverschmelzung*] is itself a derivative of such conceptual history originating in physics but that it becomes a fuzzy construct for an anti-methodological or anti-scientific conception of truth or reality. By tracing these travelling dynamics, one can observe that such a travelling or metaphorizing concept influences the target as well as the source field or discipline, as well as changing its own semantic shape. This paper thus also contributes to the understanding of the dynamic relation between terminology and subject conceptualizations, an issue equally relevant to the natural sciences and the humanities.

1 Introduction

Since the twentieth century,[1] physics and (the study of) literature share a recognition of the epistemological inadequacy of structuralist notions of language, in other words, a growing understanding that one signifier (or one empirical datum) does not represent one concept of truth or signified reality (cf. Foucault 1970). Strictly speaking, this commonality consists in the fact that both disciplines have overcome a mechanistic world view. Admittedly, this paradigm shift has not yet been completed in the wider public domain. This means that we are faced with a tangle of non-simultaneities and mutual transferences between theory cultures.[2] In particular, the extremely popular and broad fields of communication and media are still dominated by a structuralist understanding

1 In the twentieth century, this insight was achieved in physics long before the corresponding insights in the so-called humanities (cf. Mühr 2002).

2 Cf. Vol. 28 (2002) of the *Jahrbuch Deutsch als Fremdsprache* that focuses on the transfers between disciplines and theory cultures. See also Koschorke (2012) for the social and cultural sciences, describing transfer processes from synchronic to diachronic, from static to dynamic, and from closed or known to open and unknown paradigms or scientific models of reality, language or semiosis.

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of language, which is limited to an information-theoretical level and essentially relies on a stable code, and on a clear relation between the object and its name, signified and signifier, as its point of departure.

By contrast, we can regard Gadamer's hermeneutics largely as an attempt to overcome what he calls the forgetfulness of language [*Sprachvergessenheit*] of modernity, in analogy with Heidegger's forgetfulness of being [*Seinsvergessenheit*], anamnetically.[3] If we read *Truth and Method* in this fashion, it can be said to argue for the specific epistemological reach of the validity [*Wahrheit*] of the arts and humanities. *Truth and Method* is an answer of sorts to the excommunication of the arts from the sciences which, according to Gadamer, began with Kant and was completed by Dilthey (cf. Grondin 2000, 40). Nevertheless, the work still contains an undercurrent of partially mechanistic ideas and perceptions from physics itself, because the metaphors emerging from these perceptions are deeply woven, as a paradigm, into the fabric of the European culture of science, as a narrative claiming to guarantee truth and reality. The focus of this chapter is a reconstruction of Gadamer's understanding of the construct of the horizon, and of fusions of horizons [*Horizontverschmelzung*], as a result of a longstanding tradition of adopting and adapting optical metaphors that have become commonplace in scientific expression since Galileo, and can be traced as epistemic narratives or figures of thought right up to *Heisenberg's Uncertainty Principle*, which in German is commonly known as a theory of *Unschärfe*. Aside from aspects of a culture of science and the transitions between theory cultures, I am interested in the baggage of the underlying epistemological issue, namely the question of the representative character of concepts and terms. What Edward Said (1983, 226–247) calls *travelling theory* and Albrecht Koschorke (2012, 166–169) describes as the migration of concepts is *in nuce* the process of "metaphorising" or transferring, which is indeed a poetic-rhetorical process, because it does not obey the laws of logic and displays an aesthetic playfulness.

The research in this chapter forms part of a larger project on cultural scientific formations of infinity. Thinking the infinite overtaxes our imaginative faculties: we can think it, and yet we cannot imagine *it*. Modern mathematics can work with infinities (by working around them), but it is exactly those workarounds that have transformed the incommensurability of a *representation* and imagining of infinity into a practice of neglected and neglecting non-knowledge [*Nichtwissen*]. How has this incommensurability been dealt with in European history? Which epistemological integrative achievements have the individual

3 See the anecdote about Gadamer in Grondin 1994, xiii–xiv.

explanations of infinity brought about? And which interactions with other epistemic and semiotic fields have emerged from this? This chapter alludes to the dynamics of such transfers of figures of thought, or metaphors, in order to show how they transmit the baggage of meanings and how they influence the meaning-making in the target context. In order to study these dynamics, it is helpful to use a historical approach which I call "transformation history."

2 On the transformation history of optical figures of thought from Galileo to Gadamer

2.1 Prolegomena

Optical metaphorics is a heuristically obvious interface between physics and hermeneutics. In the process of the first secularizing trends in the attempt to interpret texts (including profane texts) correctly in the eighteenth century, an entire visual vocabulary (clear/unclear [*deutlich/eindeutig*][4]) and concrete optical terms, such as *Skopos*, point of view, vantage point [*Sehepunkt*], be clear [*einleuchten*], and horizon were adopted in the early hermeneutics of the eighteenth century. The reason for this expansion of the range of optical metaphors for aspects of understanding lies not only in the emergence of a new paradigm of empirical science (which implies an epistemic revaluation of the senses), but also, simultaneously, in the achievement of an abstraction *away from the senses*, which began with, and can be typified by, Galileo and his use of the telescope. Equating what is seen through the telescope with reality is not an empirical observation at all, but is itself a highly abstracting, *medializing* transmission process that could only find a foothold as scientific truth with the help of various supporting rhetorical conceptions.[5] One might even argue that optics (as applied geometry) only entered the discipline of physics through the Copernican Revolution,[6] before it could come to serve as a template for other processes of understanding, such as textual interpretation, because of its far-reaching

4 Cf. Mühr 2001, 425–432.

5 This becomes clearest through the subsequent assumption that we live on a globe, which contradicted all *common sense* of that time. Cf. Blumenberg 1975, I, 147–299.

6 One could argue that this optics is not a physics discipline at all, since neither a point nor a line is an object of physics; optics is rather applied geometry. Optics is only physical inasmuch as it examines the reality of the quality of light itself.

changes to our world *view*.[7] But in this transmission, there were also some counter-reactions: so, conversely, many unanswered questions in physics, about space and movement, or about the continuum, long remained unresolvable, according to Kvasz's (2008) theory, or "submerged" (Michel 1986)[8] because of the canonization[9] of this visualization paradigm. Even Newton's law of gravity is more of a proposition than an explanation, since Newton was unable to explain what gravitational force *actually* is, and why it "holds the world together from the inside," as Goethe was to argue, quite rightly, some 100 years after Newton.[10]

These interactions in the process of the transmission of optical figures between the cultures of knowledge can be identified – as undercurrents – in Gadamer's work. Optical metaphors are embedded in the rhetoric of his work as epistemically active paradigms. To analyse the function of Gadamer's concept of a horizon, it is therefore important to recapitulate the history of its origin and transformation.

2.2 Galileo's rhetoric of the telescope

Visuality is an ancient, multidimensional transferred field of knowledge that has always shifted between optical, perception-psychological and epistemological facets; in this regard, we need only consider Plato's *Allegory of the Cave*. The issue of deception of the senses stands in a critical relation to knowledge which can be abstracted from pure empiricism. Ladislav Kvasz (2008, 11–86) has demonstrated a surprisingly regular oscillation in the history of mathematics from

7 It is for precisely this reason that Heidegger (1975) writes about "Weltbild" – a concept that derives from the technological scientific paradigm.

8 I am very grateful to Idette Noome for her support in all translations. Only quotes from Gadamer's *Wahrheit und Methode* are taken from *Truth and Method* in the second revised translation by Joel Weinsheimer and Donald G. Marshall (cf. Gadamer 1998). The German original quotations are given as footnotes, with the original page numbers. For quotations from Gadamer, the German quotations show page numbers for the German text, the English quotations show the page numbers and year of the English edition.

9 Cf. Witthaus 2005, 53–88.

10 This optical *phase* in the history of science, which one can trace, with Kvasz (2008), from Galileo to Leibniz, is particularly obvious in the development of infinitesimal calculus, where more must be achieved than abstraction: it must overcome visual evidence and solve the understanding of instantaneous velocity, but it also must perform the metaphysical task of cybernetics of origin (emergence), and of unity (or wholeness of the universe).

antiquity to the present between symbolic (arithmetic) and iconic (geometric, or in this context, visual) languages, which can only be explained by mutually concealing problem areas. However, as Hans Belting shows in his work *Florence and Baghdad: An Occidental-Oriental History of Seeing* [*Florenz und Bagdad: Eine westöstliche Geschichte des Blicks* (2008)], the shift from a free seeing (view) to an organized representation of that which is seen (image) is a paradigmatic shift toward modernity from a theory of seeing to an image theory of knowledge [*Erkenntnis*]. This can be traced quite concretely in the history of the telescope. In this argument, I draw on the dissertation by Witthaus (2005), who demonstrates in Galileo's work the "implementation of the telescope and microscope as optical instruments in the rhetorical repertoire of the scientific prose of the seventeenth century" (Witthaus 2005, 14).[11] This occurs particularly by means of figures of speech relating to visualization, a "holding up to the viewer," which Aristotle had already described as "a bringing to life" or "making current" (*energeia*) and later as the figure of speech he called *evidentia* as a "form of detailed description of impressions of that which is seen" (Witthaus 2005, 15)[12] and is "somewhat similar to *ekphrasis*, the description of an image" (Witthaus 2005, 15).[13] Creating *evidentia* is precisely what a telescope as a knowledge-generating instrument does, and thereby the telescope itself becomes a reified rhetorical *instrument*.

The originally purely rhetorical *evidentia* itself becomes an independent empirical scientific paradigm – there is a certain irony in this, as this new *evidentia* opposes the pure rhetoric of Ancient philosophy, or criticises its excessive reliance on the senses (Witthaus 2005, 67).[14] But the irony goes deeper, because, if rhetoric is regarded as "a technology designed to provide certainty" (Witthaus 2005, 22),[15] the production of evidence is a medium of that which is immediable [*Mittel des Unmittelbaren*] (Witthaus 2005, 22). And here the problem of representation crops up again, as "the optical instruments of early modernity put not only their objects, but also the process of seeing itself, in the eye of the beholder" (Witthaus 2005, 27).[16]

11 Transl. by IN. "Implementierung der optischen Instrumente Tele- and Mikroskop in den rhetorischen Haushalt der Wissenschaftsprosa des 17. Jahrhunderts" (Witthaus 2005, 14).

12 Transl. by IN. "[...] Form detaillierter Deskription von Seheindrücken" (Witthaus 2005, 15).

13 Transl. by IN. "[...] in gewisser Nähe zur Bildbeschreibung (*ekphrasis*)" (Witthaus 2005, 15).

14 In this way, in the emergence of the empirical sciences, there remains an undertow of Platonic figures of thought.

15 Transl. by IN. "Technologie zur Schaffung von Gewissheit" (Witthaus 2005, 22).

16 Transl. by IN. "Die Sehapparate der frühen Neuzeit stellen nicht nur ihre Objekte, sondern den Vorgang des Sehens selbst vor Augen" (Witthaus 2005, 27). Aside from the actual "message from the stars," the telescope communicates its own entry into scientific

Witthaus's approach to Galileo's application of the telescope is influenced by Heidegger's critique of technology,[17] which became foundational for his student Gadamer, but was also well received by the Frankfurt School, and centers on Heidegger's description of framing [*das Ge-stell*] as instrumental reason [*instrumentelle Vernunft*].[18] According to Heidegger, the modern "turning to the world [...] happens in a mode of a fixating positioning" (Witthaus 2005, 23),[19] from which a scientific- or civilization-critical conceptualization of a "reified" world (Lukács) or "second nature" (Adorno) emerges. Linguistically, the "*Ge-stell*" is merely a construct(ion) – in the word "*feststellen*" we can still trace the fusion (cf. Gadamer) of a mechanistic activity with its methodological-scientific claim to knowledge. The corresponding discourse of power and subjugation has frequently been analyzed in critical theory by authors like Adorno, Foucault, Horkheimer and Feyerabend.

Nevertheless, there are complex interactions between the development of the *Ge-stell* as a scientific instrument – in other words, one that is aimed at finding evidence, in the sense of truth – and the artistry of rhetoric, as the rhetorical term *evidentia* shows. Indeed, Witthaus claims that optical instruments were born out of the written word (2005, 53),[20] citing as proof the instrumentalizing of optics ranging from the reading stones used before the invention of spectacles and glasses to the fact that even today, when we visit an optician, we are asked to decipher ever smaller letters (Witthaus 2005, 53). According to Witthaus (2005, 54), the coupling of these two domains – reading as rhetorical imagination of a content that should be regarded as *true* at least fictionally, and optics itself as the scientifically transformed rhetoric of *evidentia* – requires three postulates, which I interpret in the context of transpositions (metaphorics) as *tertia comperationes*:

a) Sequentiality and concentration (Witthaus 2005, 55): the simultaneity and shared spatiality [*Gleichräumigkeit*] in the act of reading and seeing/observing is broken up into view points [*Blickpunkte*] or suspended images – a highly abstracting process, which Gadamer refers to as heuristic horizons.

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communication ["Das Teleskop kommuniziert neben der eigentlichen 'Sternenbotschaft' seinen eigenen Eintritt in die wissenschaftliche Kommunikation"] (Witthaus 2005, 64). So, the medium *is* the message of the stars. See also Gailei 1987.

17 Cf. Heidegger 1975.

18 Max Horkheimer (1967), *Kritik der instrumentellen Vernunft*. It is the German translation of his book *Eclipse of Reason* (1947).

19 Transl. by IN. "[...] Hinwendung zur Welt [...] im Modus des festsetzenden Stellens" (Witthaus 2005, 23).

20 Transl. by IN. "Die Geburt optischer Instrumente aus dem Geist der Schrift" (Witthaus 2005, 53).

b) The reading of the familiar [*Lektüre des Altbekannten*] (Witthaus 2005, 55), which is seen better or more clearly only with the assistance of instruments.
c) A problem of storage/retention [*Problem der Speicherung*] (Witthaus 2005, 55), which results in follow-up discourses [*Folgediskurse*], for example, further reproductions – in Galileo's case, an entire network of illustrations, ekphrastic descriptions, publications and advertising campaigns, which Witthaus describes as a media event [*Medienereignis*] (Witthaus 2005, 53–63).

Witthaus's "establishment of wonderment as a guiding impulse of a scientific reception attitude" (Witthaus 2005, 70–73)[21] is not convincing. Admittedly, it is clear, that, with *evidentia*, Quintilian addresses the emotions of the listener/viewer "by placing him/her in the role of an eye-witness" (Witthaus 2005, 70),[22] and that Pseudo-Longinus takes this further in the distinction between the clarity of the picture, which is seen increasingly soberly in the sense of *perspicuitas*, versus the rhetoric of shocking [*hekplexis*] elicited by poetry. But this distinction can only be made from the current vantage point, since we now think of literature and the (natural) sciences as separate concepts. But this distinction does not apply to Galileo's astronomical treatise *Sidereus Nuncius* – which is an adept reapplication of the Christian rhetoric of Revelation, which it indeed used with the intention of shocking and leading to boundless admiration and wonderment. With Galileo, we look in vain for an "objective tone" (Witthaus 2005, 68; cf. Mühr 2001, 113–119). I have previously described the reapplication of the idea of divine unity to nature (Mühr 2001, 113), which calls for participation, in line with the rhetoric of *evidentia*, and, at the same time, has missionary-religious overtones (Mühr 2001, 114) and is meant to result in unbounded admiration – not least for God, who, after all, created this world (and the moon). One could therefore argue that this is where instrumental reason entered the scientific vocabulary; equally there is a rhetorical elevation of *evidentia* to an absolute, if not the sublime, hypertrophy of enthusiasm, which phenomenologically stabilizes the *enormity* of the new.[23] It is here that the counter-discourse to rationality begins, a discourse which led, via the Cambridge Platonists and English Sensualism, to pietist

21 Transl. by IN. "Etablierung des Staunens als Leitaffekt wissenschaftlicher Rezeptionshaltung" (Witthaus 2005, 70–73).
22 Transl. by IN. "indem sie ihn in die Rolle eines Augenzeugen versetzt" (Witthaus 2005, 70).
23 Here, I am referring to Waldenfels (2006), who describes the perception of "the other" phenomenologically, in particular to the perception of the cosmos (Waldenfels 2006, 16–19) and to his notion of pathic response (Waldenfels 2006, 38–46).

Empfindsamkeit, and which represents the psychological or reception aesthetics counterfoil to empiricism.[24]

From this, according to Witthaus (2005), we can deduce that it is with Galileo that we find the beginnings of a re-functioning in scientific rhetoric which elevates the instrument (the *Ge-Stell*) to an immanent *ingredient* of empirical research. In this genealogy of the rise of optical instruments in physics, we can also see the transposition and expansion of telescopy and optics and its language into the understanding of general issues, which for a long time were also metaphysical issues, precisely because Galileo's *Sidereus Nuncius* is also a "message/messenger" (according to its title), a "transmission."[25] After all, with its rhetorical *evidentia*, the rhetoric of the telescope carries with it the power of religious persuasion as (Hebrew) *Kabod* or as Christian *Gloria*.[26] Being deeply embedded in the Christian faith, early physicists up to Newton himself believed they could see (in a literal sense) or reveal (in a religious sense) the glory and greatness of God's creation better with the support of their new instruments. It is precisely the emotional, *aesthetic* aspects of this evidentiary technology that provided the impetus for the migration of the terminology, the wonderment and amazement, the aesthetic aspects of seeing [*Anschauung*], which are always also interpretations.

This shift in the paradigm of the history of science is therefore based on a dialectic: *because* of the *fixating of the position* of the object of research by the instrument, it is inevitably medialized, which in turn, rhetorically, as a fixing of the subject, leads to a *liquefaction* or *making fluid*." The reality (actuality) of an immediate perception of an object (i.e. which is not fixed or made lasting by any medium) is completely momentary and unique. It is free from human *beholding*. A physicist of such phenomena may write about what the reader should do in order to repeat a similar/the same perception/observation (e.g. Goethe's *Farbenlehre* contains descriptions of color by explaining what to do and how to hold objects against light etc.). A mediated perception that has been literally *captured* on a picture that claims evidential truth, can now travel to other people and even into other media, because the medium now *is* the

24 A third aspect is a concomitant anthropocentrism, which can be traced back to Descartes's *cogito ergo sum*. Cf. Blumenberg 1975, I, 80–98 and 200–246; Belting 2008, 229–281; Waldenfels 2006, 20.

25 The telescope itself then becomes *book-like*, something in which we can *read*. If one considers that Galileo sometimes sent telescopes with copies of his book (Witthaus 2005), the title "message/messenger from the stars" becomes ambiguous: it refers to that which is contained in the book and to the telescope itself.

26 In this regard, cf. Mühr 2001, 215–216. and Hoeps 1989.

message/messenger. In the case of the telescope, at least, it forms part of the message. I claim that this development is the reason why the optical terms, as a third step of *mobilization*, started also to become fluid and travel to other areas and become metaphors (which means *carriers*) for *other* truths.

In Albrecht Koschorke's work *History of the Horizon* [*Geschichte des Horizonts* (1990)], we find a similar argument regarding the dialectical dynamics of development, even though the work focuses on discourses relating to literary depictions of landscapes. Koschorke, like Witthaus (2005), maintains that in the period of the Copernican Revolution, "from the aporetic of the thought of fixed boundaries arises the general conception of a progressive and infinite shift of the horizon" (Koschorke 1990, 9).[27] In his second chapter, "The opening of the horizon" (Koschorke 1990, 49–75),[28] he describes the same dialectic of suspension and liquefaction for the development of central perspective in the history of art as Witthaus claims for Galileo's rhetoric of science. So central perspective suspends "the mobility of the viewer" (Koschorke 1990, 49)[29] and "[coerces] the eye to [look at] an absolute momentary presence" (Koschorke 1990, 63).[30]

On the one hand, the vanishing point and horizon as prerequisites for the construction of a "perspectivally correct picture" (Koschorke 1990, 49)[31] continue the ancient discourse of thought on the One and the Whole (cf. Horstmann 1993). On the other, they bring about the "discovery of the horizon as the liminal figure of immanence […] via the centering of the subject" (Koschorke 1990, 49):[32] "every image corresponding to the entity of the perspectival field of view [is], as it were, framed by a silent margin of the unlimited multiplicity of possible images" (Koschorke 1990, 50)[33] which can only be epistemically organized by the viewer. Mathematically speaking, the vanishing point refers simply to what was, according to Euclid's fifth theorem, incommensurable then: the point at infinity where parallel lines meet.

27 Transl. by IN. "[…] treibt die Aporetik des Denkens fester Grenzen die Generalanschauung einer progressiven und unendlichen Horizontbewegung aus sich hervor […]"(Koschorke 1990, 9).

28 Transl. by IN. "Die Öffnung des Horizonts" (Koschorke 1990, 49–75).

29 Transl. by IN. "Motilität des Betrachters" (Koschorke 1990, 49).

30 Transl. by IN. "[…] [verpflichtet] das Auge auf eine absolute momentane Präsenz" (Koschorke 1990, 63).

31 Transl. by IN. "[…] perspektivisch richtigen Bildes" (Koschorke 1990, 49).

32 Transl. by IN. "Entdeckung des Horizonts als Limesfigur der Immanenz […] auf dem Weg der Subjektzentrierung" (Koschorke 1990, 49).

33 Transl. by IN. "[j]edes auf die Entität des perspektivischen Blickfeldes abgestimmten Bildes [ist] gleichsam von einem Schweigerand der unbegrenzten Vielzahl möglicher Bilder umrahmt" (Koschorke 1990, 50).

So, if the concept of a boundary in the sense of unitary enclosure [*Einheitsstiftung*] is taken further in the direction of dialectically implying its opposite, in other words, the transgression of boundaries, then the term *boundary* as an edge, as a limit, becomes the term *horizon*. Ontologically and metaphysically, it is then only a small step to Leibniz's "best of all possible worlds" because if once the limits of perceiving truth or "the world" has opened up to infinitely possible worlds, human perception and intellect in their godly origin must exactly perceive that.

In his third chapter "Semantics of the infinite landscape" (Koschorke 1990, 76–172),[34] Koschorke shows how, at the end of the Middle Ages, infinity, as a theological predicate of God, first becomes conceptualized in a spatial sense, which then leads to the extinction [*Auslöschung*] of the above concept of the boundary as the principle of an edge or limit, and shifts toward the temporalization, toward a shifting boundary [*wandernde Grenze*] (Koschorke 1990, 76), and finally toward the bourgeois notion of progress (Koschorke 1990, 78) and the "awakening of a historical sense of possibility" (Koschorke, 1990, 77):[35] "A horizon of history that is open to the future – and that means: one enabling human creative freedom – corresponds to the opened horizon of a spatial experience" (Koschorke 1990, 78).[36]

But we always need to remember the semantic baggage of a secularized rhetoric of revelation that is carried along in this historical transformation of concepts, and that ultimately leads to the historicization of the formerly optical horizon concept.

2.3 Chladenius's vantage point theory

Let us now engage in the game of the transposition of rhetorical *evidentia* to scientific evidence.[37] If the *horizon opens*, this means that knowledge travels or

34 Transl. by IN. "Semantik der unendlichen Landschaft" (Koschorke 1990, 76–172).

35 Transl. by IN. "Erwachen eines historischen Möglichkeitssinns" (Koschorke, 1990, 77). In modernity, the Pillars of Hercules no longer serve as a boundary or frame, but symbolize an opening for the search for new worlds, in other words a breaking of the frame (cf. Koschorke 1990, 78–83).

36 Transl. by IN. "Dem geöffneten Horizont der Raumerfahrung korrespondiert ein auf die Zukunft hin offener – und das heißt: menschliche Gestaltungsfreiheit ermöglichender – Horizont der Geschichte" (Koschorke 1990, 78).

37 This explains the need to engage with a situation as a condition for hermeneutics (Gadamer 1990 [1960], 273). Cf. Mühr 2012a, 908.

expands. But this also applies to the hypothesis of the opening of the horizon itself, as its own terminology expands.[38] Chladenius's work *General Historical Science in which the Foundation Is Laid for a New Insight into All Kinds of Learning* [*Allgemeine Geschichtswissenschaft, worinnen der Grund zu einer neuen Einsicht in allen Arten der Gelahrtheit geleget wird* (1752)] can serve as an example of this opening or literal "in-sight" [*Einsicht*][39] and expansion "into all kinds of learning" (Chladenius, 1752, title),[40] through optical terminology to hermeneutics. In order to analyze this expansion, I trace the argument in the first three paragraphs of Chapter 5, "Of the observer and vantage points."[41] The heading of the first paragraph is "The observer is central to a narrative" (Chladenius 1752, 91).[42] Here Chladenius argues that "events, and therefore also history, [...] are alterations of their real things" (Chladenius 1752, 91),[43] which would also occur even without witnesses. However, in the recognition [*Erkenntnis*] of history, the observer or witness becomes the necessary medium:

> Only, in the recognition of the events, and the narratives that flow from them, it is equally necessary to pay attention to the observer and his/her traits, as to the matter itself.[44]
> (Chladenius 1752, 92)

This distinction – seen as a process – recapitulates, as Belting (2008, 229) puts it, the step from a theory of seeing to an image theory. According to this quasi epistemologically critical argument, §2 of Chladenius' work explains why this seems self-evident for the recognition of "corporeal things" [*körperlicher Dinge*], but the optical term "vantage point" needs to be expanded for historical recognition (historical knowledge):

> Because it is thus evident with bodies that their changes and traits take a completely different form once the observer has taken a seeing position to them, depending on whether he/she is near to a body or far from it, stands higher or lower, whether he/she pays attention or not. The fixed stars, as all learned people know now, are suns, for those who are

38 Cf. Blumenberg (1975, I, 310–340), who shows how Copernicus himself was styled as a world shaker.
39 The original object of this 'in-sight' was the *camera obscura*. Cf. Belting (2008, 104–143).
40 Transl. by IN. "[...] *in allen Arten der Gelahrtheit*" (Chladenius, 1752, title).
41 Transl. by IN. "Vom Zuschauer und Sehepunckte" (Chladenius 1752, Ch. 5).
42 Transl. by IN. "Der Zuschauer ist bey einer Erzehlung eine Hauptsache" (Chladenius 1752, 91).
43 Transl. by IN. "[...] Begebenheiten, und mithin auch die Geschichte, [...] Veränderungen derer würcklichen Dinge [sind]" (Chladenius 1752, 91).
44 Transl. by IN. "Allein bey der Erkentniß der Begebenheiten, und denen daraus flüssenden Erzehlungen, ist es eben so nöthig, auf den Zuschauer und dessen Beschaffenheit Achtung zu geben, als auf die Sache selbst" (Chladenius 1752, 92).

> close enough to them, but for us they are tiny lights in the sky, because of the indescribable distance. The moon is sometimes full, sometimes half full, sometimes even less illuminated, namely in front of us [...].[45] (Chladenius 1752, 92)

This quote testifies to the origin of the vantage point theory taken from telescopy;[46] it is a direct history of effect [Wirkungsgeschichte] of the rhetorical figure of speech of *evidentia* used by Galileo, with reference to the problem of identifying spatial depth, which is solved by central perspective.[47] But in this process, it takes the dependence of the vantage point as a necessity of the fixing of the image in the telescopic image along, the dialectic of image-fixing and simultaneous relativization or transgression of image-fixedness is traveling!

From here it is a small step to a metalingual expansion of these optical terms into historical science, a step which occurs in §3:

> In sensing/experiencing bodies one pays most attention to seeing [...]. However, to use historical recognition, this concept must also be extended somewhat even for visible things.[48] (Chladenius 1752, 93)

The object-linguistic recognisability [Begrifflichkeit] of the vantage point is extended from a locus or point to an entire *situs*. Chladenius's preliminary definition of the vantage point here is the "locus at which the eye of the viewer is" (Chladenius 1752, 93)[49] and he claims that it has already been explained fully in optics (Chladenius 1752, 93). However, in the course of his chapter, this *locus* [*Ort*] is expanded to a *situs* [*Stand*], which eventually includes the whole soul of

45 Transl. by IN. "Denn so ist bey Cörpern offenbar, daß ihre Veränderungen und Begebenheiten eine gantz andere Gestalt bekommen, nachdem sich der Zuschauer in Ansehung derselben verhält, ob er nahe oder ferne, höher oder tieffer stehet: ob er achtung giebt, oder nicht. Die Fixsterne, wie itzo alle Gelehrte wissen, sind vor diejenigen, die nahe genug sind, Sonnen, vor uns aber, sind sie wegen der unbeschreiblichen Weite, kleine Himmelslichter. Der Mond ist bald voll, bald halb, bald noch weniger erleuchtet, nehmlich vor uns [...]" (Chladenius 1752, 92).

46 Admittedly, Chladenius writes in §12 that he is drawing on the concept of the vantage point as posited by Leibniz, who used it "here and there even in metaphysics and psychology" ["hie und da denselben selbst in der Metaphysick und Psychologie gebraucht hat"] (Chladenius 1752, 101). The relation to optics is not only given immanently, but is also explicitly mentioned in §3. The vantage point as "locus where the eye of the viewer finds itself [...] has already been most clearly explicated" ["Ort, wo das Auge des Zuschauers sich befindet [...] ist in der Optick schon alles auf das klärte aus einander gesetzt worden"] (Chladenius 1752, 93).

47 Cf. Koschorke 1990, 59–70; Witthaus 2005, 83–89; Belting 2008, 180–228.

48 Transl. by IN. "Bey der Empfindung der Cörper giebt man allezeit hauptsächlich aufs Sehen achtung [...]. Zum Gebrauch der historischen Erkentniß aber muß dieser Begriff auch schon bey sichtlichen Dingen etwas ausgedehnet warden" (Chladenius 1752, 93).

49 Transl. by IN. "Ort, wo das Auge des Zuschauers sich befindet" (Chladenius 1752, 93).

the observing individual (i.e. the individual who desires to understand), including his/her emotional and rational capabilities and presuppositions. This extension of the vantage point, which occurs in various stages, culminates in the following definition of the term, reformulated for the historical sciences:

> The vantage point is the inner and external condition of an observer, insofar as a certain and particular way of looking at and perceiving things present flows from that condition. A concept that is equivalent to the most important ones in all of philosophy […].[50]
>
> (Chladenius 1752, 100)

It is worth noting the importance that Chladenius attaches to this new construct. It makes Chladenius's "vantage point" [*Sehepunckt*] a direct precursor of Husserl's concept of the horizon.

2.4 Gadamer's concept of the horizon and the fusion of horizons

Gadamer does indeed adopt the construct of the horizon from Husserl (cf. Gadamer 1989, 245–248 and 1990 [1960], 249–251), but he also reconsiders the problem of the temporal continuum and the issue of instantaneous velocity, as a metaphor for a moment or point in time [*Zeit-Punkt*]. From Husserl's "flow of experience" [*Erlebnisstrom*] of time (Gadamer 1989, 245 and 1990 [1960], 249), it becomes clear that "the discreteness of experience […] is not an ultimate phenomenological datum" (Gadamer 1989, 245).[51] First, this is a critique of Kant, who saw the horizon as a condition for our recognition [*Erkenntnis*], "the determination of the scope and the boundaries of human recognition" (Engfer 1978, 1198),[52] thus, in its former meaning as an edge, a margin, a boundary [*Rand*]. Second, it subliminally actualizes (if we translate metaphors back into the physical realm) the problem of the extent of the *Zeit-Punkt* (or of instantaneous velocity), which is, after all, only a mathematical, and not an empirical, unit, because in this stream of time, the temporal expansion of a point in time

50 Transl. by IN. "Der Sehepunckt ist der innerliche und äusserliche Zustand eines Zuschauers, in so ferne daraus eine gewisse und besondere Art, die vorkommenden Dinge anzuschauen und zu betrachten, flüsset. Ein Begriff, der mit den allerwichtigsten in der gantzen Philosophie im gleichen Paare gehet […]" (Chladenius 1752, 100).

51 Transl. by IN. " … die Einzelheit des Erlebnisses […] kein letztes phänomenologisches Datum ist" (Gadamer 1989, 245).

52 Transl. by IN. "die Bestimmung des Umfanges an der Grenzen der menschlichen Erkenntnis" (Engfer 1978, 1198).

tends to zero. This is a perfect correlation to differential calculus because, although the difference (change) in one *point* cannot actually be stated, nevertheless dx is a mathematical construct to calculate with. Likewise Gadamer (with Husserl) assumes that the ever-changing horizon cannot be described due to its mobility and the mobility of time; nevertheless for *heuristical* purposes of understanding the concept of fusion of horizons, one must first state the term of a fixed horizon.

Third, it points to the opening of the horizon, because the focus is directed precisely at this boundary. The undertaking "critically"[53] reflects its own limitation, albeit no longer in landscape paintings and literary images as Koschorke was to demonstrate, but, about 300 years after Galileo, in a theory of knowledge [*Erkenntnistheorie*]. If we use Koschorke's (2012, 116–136) semiosphere model, adapted from Lotman, as a basis to describe this process, we can speak of a diffusing penetration of meaning that has migrated from the periphery into the (cold) center of the concept of recognition [*Erkenntnisbegriff*], which elicits a nuclear fusion (producing heat, change). "The flow of experience has the character of a universal horizon of consciousness, and only from it is the discrete experience given as an experience at all" (Gadamer 1989, 245).[54] Thus the flow of experience is essential. However, it cannot be represented consciously in this form, but can only be represented as a particularity, which is not in itself essential. The horizon itself – seen as time – is in constant flux; a "fixed" moment (as experience or *Erlebnis*) only exists as a derivation: "even in a perfect 'epoche' – bracketing the being posited by scientific knowledge – the world still remains valid as something pregiven" (Gadamer 1989, 246).[55]

From this purely constructed validity, Husserl derives the construct of the life-world [*Lebenswelt*]. According to Gadamer, "[a]s a horizon phenomenon 'world' is essentially related to subjectivity" (Gadamer 1989, 257),[56] which we, "'exist[ing] in transiency' [or the …] constant movement of relative validity "(Gadamer 1989, 247)[57] have always quasi-experienced as a pregiven. But as a

53 Kant's use of the term "Kritik" also demonstrates this shift from an essentialist whole (as a symbol of knowledge) to its boundaries or limits, because *kritein* is what I can distinguish visually.

54 "Der Erlebnisstrom hat den Charakter eines universalen Horizontbewusstseins, aus dem nur Einzelheiten wirklich – als Erlebnisse – gegeben sind" (Gadamer 1990 [1960], 250).

55 "[…] im Vollzug der 'Epochē,' der Aufhebung der Seinssetzung der wissenschaftlichen Erkenntnis, bleibt die Welt als eine vorgegebene in Geltung" (Gadamer 1990 [1960], 250).

56 "als ein Horizontphänomen […] wesensmäßig bezogen auf Subjektivität [ist]" (Gadamer 1990 [1960], 251).

57 "[…] in strömender Jeweiligkeit seiend" (Gadamer 1990 [1960], 251).

pregiven, it does not enter into our consciousness of our everyday world. It should therefore be remembered that Gadamer's concept of the horizon is not an essentialist horizon of knowledge, as with Kant, but *a practically purely heuristic construct*, which, as a life-world [*Lebenswelt*], normally does not penetrate our consciousness. (That only occurs in the hermeneutic act of understanding.) Koschorke's fundamental hypothesis that the horizon "is not an object that falls within the empirical realm, but is a constituting line of reference for the order of empiricity itself" (Koschorke 1990, 7),[58] thus also corresponds with Gadamer's view.

It also reveals similarities to Chladenius's vantage point, which is equally subjective and prescientific, and cannot be objectified. With Chladenius, the vantage point is expressed as something very individual, but Husserl (like Gadamer) regards it as an anonymous intentionality.[59]

On the other hand, the horizon as a *circle* of vision [Gesichts*kreis*] is more than a *point* [*Punk*] – this argument applies to both Gadamer *and* Chladenius. In his development of the principle of a history of effect [*Wirkungsgeschichte*],[60] Gadamer (1990 [1960], 307; 1989, 300) explicates the horizon concept in conjunction with the notion of "situation." The "situation" is a "standpoint that limits the possibility of vision" (Gadamer 1990 [1960], 307),[61] i.e. "the horizon is the range of vision that includes everything that can be seen from a particular vantage point" (Gadamer 1989, 302). Thus he even uses the same word, "point," which Chladenius uses, and which has embedded itself in scientific discourse on the infinity debate since the definition of the vanishing point in perspectival painting (Euclid). However, Chladenius's vantage point primarily designates a place or *locus*, but one that can be expanded; horizon (also an older hermeneutic term [cf. Engfer 1978] to which Gadamer does not return) is rather the designation of an area. There is indeed a parallel between the panoramic, otherwise

58 Transl. by IN. "[...] kein Gegenstand innerhalb des Gebietes der Empirie [ist], sondern eine konstituierende Bezugslinie für die Ordnung der Empirizität überhaupt" (Koschorke 1990, 7).

59 Gadamer (1990 [1960], 186; 1989, 182–183) points out that Chladenius's vantage point should not be read in the Romantic lineage of a hermeneutic methodology, because it focuses on the interpretation of speeches and writings on reason, and less on the understanding of historical texts. Chladenius does, however, use his vantage point theory to enhance historical understanding.

60 It remains a desideratum for now to read Gadamer's concept of *Wirkungsgeschichte* as a hermeneutic alternative to a physical explanation of the time-space-continuum, for example if compared to *Wirkungsquantum*.

61 Transl. by IN. "Standort, der die Möglichkeit des Sehens beschränkt" (Gadamer 1990 [1960], 307).

unfixed circle of vision[62] and the projected, fixed [*ge-stellte*] circle of vision which one can see when one looks through a telescope. The associated terms "narrowness/expansion" (Gadamer 1989, 302), originally "*eng / erweiterbar*" (Gadamer 1990 [1960], 307), do indeed refer to an ocular, in other words, a lens adjustment, whereas Gadamer's adjective "*erschließbar*" implies a plurality of horizons. But this idea is not realized in Gadamer's work.

The next few sentences refer to a gradual expansion of the horizon (Gadamer 1989, 302) or *Schrittgesetz der Erweiterung des Horizonts* (Gadamer 1990 [1960], 307). This set of metaphors of a hermeneutic expansion of horizons corresponds to increasing lens magnification and perhaps a stronger resolution, but not to a change of perspective (or shift of horizons): someone who lacks a horizon "over-values what is nearest to him" (Gadamer 1989, 302); and someone who has a horizon "knows the relative significance of everything within this horizon, whether it is near or far, great or small" (Gadamer 1989, 302).[63] This recapitulates exactly the above discussion of the recognition of depth which was problematized by Galileo's telescope images.

One has to remember that Gadamer sees the horizon only as a *heuristic* self-design. A few pages later (Gadamer 1990 [1960], 311; 1989, 306) he insists, unmistakably, that the representation of a bounded or fixed and foregrounded horizon of the present is erroneous: "In fact the horizon of the present is continually being formed [...]. There is no more an isolated horizon of the present in itself than there are historical horizons which have to be acquired" (Gadamer 1989, 306).[64] The horizon concept is thus liquified to historical time, analogously to Newton's fluxions, recapitulating the problem of the moment (in terms of differential calculus: How long is a moment in time? Is there such as thing as instantaneous velocity?) to that of time volumes (in terms of integral calculus: How far has an object moved between two points in time whose distance from each other tends to zero? How much historical awareness/consciousness, in temporal depth, is required to understand a historical text?). So here he goes beyond Kant;

62 Only by turning around oneself is it possible to see the entire horizon, and then only with a temporal delay. The Galileian power game of "putting before the eyes" (Witthaus 2005, 53–88) is not possible; the full horizon, as a whole, cannot be seen at once, as part of it is always behind the viewer.

63 "weiß die Bedeutung aller Dinge innerhalb dieses Horizontes richtig einzuschätzen nach Nähe and Ferne, Größe and Kleinheit" (Gadamer 1990 [1960], 307).

64 "In Wahrheit ist der Horizont der Gegenwart in steter Bildung begriffen. [...] Es gibt so wenig einen Gegenwartshorizont für sich, wie es historische Horizonte gibt, die man zu gewinnen hätte" (Gadamer 1990 [1960], 311). However, *de facto*, he does so, cf. Gadamer 1990 [1960], 375–376.

but he actualizes the problem of the (physical) point in time, as addressed above, as *Erlebnis* (Husserl). Hence, Gadamer himself must ask, criticizing himself, if horizons are continually being developed and if therefore there can be no foregrounded horizons, then "why do we speak of the fusion of horizons [...]?" (Gadamer 1989, 306).[65] His own reply: that is the *scientific* difference from the traditional (life-worldly) projection of the historical horizon [*Vergangenheitsvollzug*]:

> To ask the question means that we are recognizing that understanding becomes a scholarly task only under special circumstances [...]. That is why it is part of the hermeneutic approach to project a historical horizon that is different from the horizon of the present.[66]
> (Gadamer 1989, 306)

The development of horizons that in themselves [*für sich*] never existed and will only "recombine with what it has foregrounded itself from" is merely a "phase in the process of understanding" (Gadamer 1989, 306–307),[67] and this process is understood ontologically as an application [*Anwendung*], with which the chapter ends, as the fundamental hermeneutic problem is reiterated, namely the question of how texts are applied in the act of understanding.[68]

This "application" – taking the word application in its mechanistic sense – resembles the problem of representing an effect quantum [*Wirkungsquantum*]. The effect [*Wirkung*] is only effective – it is – by existing. That means it exists, but cannot be determined or "re-presented" in the sense of scientific evidence. As an epistemological model, the notion of a fusion of horizons thus separates something which is not separated *in situ* and therefore has no permanence. But we are reminded that this separation is "necessary to work out the circumstances as a hermeneutic situation" (Gadamer 1989, 306),[69] and that the fusion of horizons is then imported as a construct to resolve these separations. Hence, because the metaphor of fusion erases difference, it homogenizes. The dialectic between solidification and liquefaction at various levels of expression is strikingly similar to Newton's theory of fluxion, which sees fluxions as purely mathematical entities whose ontological status must be negated.[70] We are dealing

65 "[...] warum reden wir dann überhaupt von 'Horizontverschmelzung' [...]?" (Gadamer 1990 [1960], 311).

66 "Die Frage stellen, heißt, sich der Besonderheit der Situation eingestehen, in der Verstehen zur wissenschaftlichen Aufgabe wird [...]. Aus diesem Grunde gehört *notwendig* zum hermeneutischen Verhalten der *Entwurf* eines historischen Horizontes, der sich von dem Gegenwartshorizont *unterscheidet*" (Gadamer 1990 [1960], 311, original emphases).

67 "Phasenmoment im Vollzug des Verstehens" (Gadamer 1990 [1960], 312).

68 Grondin (2000, 170) sees this as realization or making real (*Verwirklichung*).

69 "notwendiger Entwurf im Verstehen" (Gadamer 1990 [1960], 312).

70 In this regard, cf. Boyer 1959, 187–202.

here with the phenomenon that in theory of terminology as well as quantum theory, matter or terms always act semi-objectively or as what Koschorke calls "Dispositive mittleren Härtegrads" (2012, 30): the moment a term is taken or empirically experienced (actualized), it will mutate to something else, because this actualization of it influences its ontological status.

With Gadamer, then, the transfer of the concept of the horizon from the history of physics to the notion of a vantage point (Chladenius) and further to his fusion of horizons can itself be regarded as a (now hermeneutic) fusion of horizons.

3 Summary: The horizon and the limits of its representation

The history of the transformation of visual terminology traced above, from Galileo via Chladenius to Husserl und Gadamer, has shown the interactions between scientific and hermeneutic recognition, as well as the retrotransference and masking of problems in physics, for example regarding the continuum and the calculation of instantaneous velocity as markers for singular effects, respecting a singular experience [*Erlebnis*].

The cult of immediacy, which underlies, for example, Heidegger's animosity to technology, can also be found in Heisenberg's discovery of the Uncertainty Principle (they are contemporaries, after all), as well as in the assumption of a (metaphysical) "a-tomic" quantum of effect (*Wirkungsquantum*), precisely because it cannot be "re-presented." The problem of representation that has penetrated scientific epistemology and rhetoric since Galileo's time as a *Ge-stell* reaches a limit here, because the *Wirkungsquantum* becomes so infinitesimally small that it either "is" – in the sense of "being present" – or represents, in the sense of being traced or measured by instruments, but can no longer do both simultaneously. It is here that the representation paradigm collapses.

Moreover, it is precisely because of this limit of representability that Heisenberg struggled to solve the uncertainty principle; that is, he had to go beyond conventional scientific recognition, which he could only manage to do with the aid of poetry (Goethe's *West-östlicher Divan* and much physical exercise in Helgoland),[71] thereby reproducing the ancient Christian rhetoric of Revelation in

71 In this regard, cf. Partenheimer 1989 und Mühr 2008, 105–107.

the form of *evidentia*, albeit reshaped with pietist motifs.[72] Likewise, the limits of the epistemic paradigm of representation are reflected on in Gadamer's concept of the fusion of horizons. But Gadamer recalls it as mimesis, as an imitation of the world – and in the concept of mimesis we should also recollect the impetus of the concept of *anamnesis* (cf. Grondin 2000, 68). The German terms *Repräsentation* and *Vergegenwärtigung* (visualization, which is one of the key terms in cultural memory studies) state precisely the same but inconceivable issue.

In conclusion, we are dealing with the fact that in a number of disciplines (such as quantum theory, mathematics, literature, hermeneutics and philosophy), there exists a similar epistemic problem around the conceptualization of immediacy. Although, at first hand, it seems that every discipline has developed its own "application" or method to speak of and deal with this problem, the analysis of the history of the term "horizon" has shown that these different solutions are highly entangled. The conceptual result of fused horizons is as abstract without the ontologically questionable concept of fixed horizons as is – for that matter – the concept of a differential derivate without given functions to which it is the derivate.

From these findings of the dynamics of interaction between terms and concepts and different research areas or world views, a complex and in particular very dynamic understanding of how human cognition perceives and models reality emerges. It certainly overcomes conventional or structuralist concepts of deterministic representation.

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72 In this regard, cf. Mühr 2012a, especially pp. 912–913.

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Lukas Mairhofer

Interference

Proposal of a Methodological Metaphor

Abstract: The strict separation of the humanities and the sciences, especially of literature and physics and more generally of different fields of knowledge, has recently come under severe criticism. It is increasingly understood that their interaction plays an important role in the development of scientific concepts as well as philosophical and literary production. However, a methodological approach to this interaction has yet to be developed. Here I propose the metaphor of interference to describe the relation of different fields of knowledge. First, interference is introduced as an epistemological metaphor as it is applied in Science and Technology Studies. Interference describes a type of interaction where the entities are constituted in the interaction rather than preceding it. The concept is then transferred to the interaction of fields of knowledge, where the notion of interference allows us to state a necessary condition for the interaction of different disciplines: the coherence of their fundamental entities. Furthermore, the application of a wide range of methods to one and the same problem is implied in this metaphor. Bertolt Brecht and his interference with quantum physics will be responsible for the storyline as well as the exemplification of the proposed approach.

1 Heisenberg's microscope

Helsinki in winter: That amounts to four hours of sunlight per day, the temperature of the air stays well below the freezing point of water and the railway station is one of the more noticeable buildings in the city. It is in this railway station that, in Bertolt Brecht's *Refugee Dialogues* [*Flüchtlingsgespräche*], two German emigrants meet to discuss the state of the world: The worker Kalle and the physicist Ziffel. They talk about their emigration, about fascism and about the big economic crisis which preceded it. When he describes his difficulties understanding this crisis, Ziffel suddenly introduces quantum physics into the conversation:

> The investigation of the situation meets strange challenges. I have to think about an experience of modern physics, Heisenberg's uncertainty factor. This is about the following: Research on the atomic world requires very strong lenses in order to be able to see the processes among the smallest particles. The light in the microscopes has to be so strong that it causes heating and destruction in the atomic world, true revolutions. Just that

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> which we want to observe we set on fire by observing it. Therefore we do not observe the normal life of the microcosmic world, but a life disturbed by our observation. In the social world similar phenomena seem to exist.[1] (Brecht 1967, Vol. 14, 1420)

"Heisenberg's uncertainty factor" refers to the uncertainty relation which Werner Heisenberg formulated in 1927. He establishes it heuristically in a *Gedankenexperiment*, the γ-ray or Heisenberg microscope (Heisenberg 1927, 174–175). Indeed the light in this microscope causes "heating and destruction," although these effects depend on the wavelength of the light rather than on its intensity, as implied by Brecht. The resolution of a light-microscope is given by $\Delta x = \lambda/2\sin\varepsilon$, where Δx is the smallest resolvable distance, λ the wavelength of the light and 2ε the acceptance angle of the objective (see Fig. 1). When very small objects like an electron are to be resolved, the wavelength of the light should be small, as for gamma-rays. But light with a short wavelength will transfer a large momentum to the electron. In the lens system different momentum-states of the photon cannot be distinguished and thus after the scattering event, we might know where the electron was but not where it goes, that is, what momentum it has. Heisenberg concludes that in quantum physics position and momentum are incommensurable, as the respective measurements disturb one another and cannot be performed simultaneously.

Fig. 1: Illustration of the γ-ray microscope based on Heisenberg's own drawings (Heisenberg 1930). © Provided under the Creative Commons licence by Bryan W. Roberts.

1 Transl. by LM. "Der Untersuchung der Situation stellten sich eigentümliche Schwierigkeiten in den Weg. Ich muß hier an eine Erfahrung der modernen Physik denken, den Heisenbergschen Unsicherheitsfaktor. Dabei handelt es sich um folgendes: die Forschungen auf dem Gebiet der Atomwelt werden dadurch behindert, daß wir sehr starke Vergrößerungslinsen benötigen, um die Vorgänge unter den kleinsten Teilchen der Materie sehen zu können. Das Licht in den Mikroskopen muß so stark sein, daß es Erhitzungen und Zerstörungen in der Atomwelt, wahre Revolutionen, anrichtet. Eben das, was wir beobachten wollen, setzen wir so in Brand, indem wir es beobachten. So beobachten wir nicht das normale Leben der mikrokosmischen Welt, sondern ein durch unsere Beobachtung verstörtes Leben. In der sozialen Welt scheinen nun ähnliche Phänomene zu existieren" (Brecht 1967, Vol. 14, 1420).

This challenges the notion of causality founded on classical physics, where from the initial values of a system in position and momentum space (phase space) all future behavior of the system could be derived. It seemed possible to infer a strict determinism from physics. In quantum physics, however, the determination of the initial conditions themselves is not possible.

Bohr, whom Brecht met later during his exile in Denmark (Bunge 1985, 98), was not happy with the analysis of his protegé Heisenberg, and published several correcting statements (Bohr 1961). He argues that already in classical physics the interaction of the particle with its environment during the measurement process influences the results. In thermodynamics, for example, a measurement of the temperature of a system will change its temperature as this measurement is defined as a transfer of heat (Heisenberg 1969, 147–148). Heisenberg applies this description to the level of atomic processes, where the influence of the observation can no longer be ignored, but Bohr criticizes Heisenberg's failure to understand the extent of the difference between classical and quantum physics. Bohr describes the relation between observables that are correlated classically but cannot be measured simultaneously in quantum mechanics with the notion of complementarity: The measurement interaction constitutes the properties of its subject as well as of its object in the first place, and is not a mere disturbance of these properties. Heisenberg takes his entities to be colliding particles, but in quantum physics the interaction of the electron with light is better described as an interference of waves. Bohr's argument could be put as follows: In quantum physics any measurement is an interference of apparatus and object. Although we interpret the result of the observation as the properties of the object, it in fact depends as much on the apparatus as on the object. Complementary properties such as momentum and position correspond to complementary measurement processes, without which they lack any meaning.

Interference results from the superposition of waves that form a common oscillation, canceling out and enhancing one another. This kind of interaction is not possible for the particles of classical physics, which are defined by impenetrability and non-diverging localization. The source of the superimposing waves can be stones thrown into a lake or light diffracted from a CD, but can also be the slits of a grating diffracting an incoming wave (see Figs. 2 and 3). In this case we can derive the properties of the wave from the interference pattern, if the grating mask is well-known, and on the other hand we can investigate the mask with a well-known wave.

With Heisenberg's microscope, Brecht picks up a thought experiment that had just been developed in contemporary physics and applies it to social phenomena. Thought experiments are readily accessible for such transfers, as they

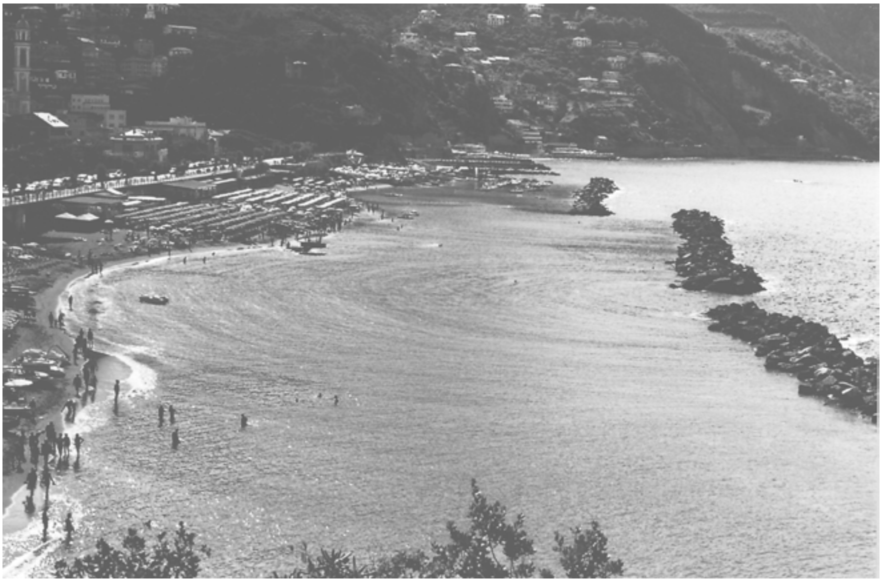

Fig. 2: Plane water-waves incident on an obstacle. Curved wave-fronts emanate from gaps in the obstacle, overlap and interfere. In this case the screen on which the fringe pattern is projected is formed by the sandy beach whose contour clearly shows the maxima and minima of the intensity of the incidenting water-waves. © Lukas Mairhofer.

are used in science as well as in philosophy and literature, as Macho and Wunschel's collection *Science & Fiction* shows. The editors, however, take thought experiments to be purely literary fiction and thus anti-performative:

> Because in the thought experiment the plan, the mental experimental setup, merges with its realization in the empirical experiment. We can assess the consequences of a counterfactual assumption, a strategic alienation, only in our heads; and it is only possible to document these consequences in a narration.[2] (Macho and Wunschel 2004, 11)

2 Transl. by LM. "Denn im Gedankenexperiment verschmilzt der Plan, die mentale Versuchsanordnung, mit seiner Durchführung, dem empirischen Experiment. Wir haben nämlich gar keine Möglichkeit, die realen Konsequenzen in einer kontrafaktischen Annahme, einer strategischen Verfremdung, anders zu überprüfen als im Kopf; und wir können diese Konsequenzen in keiner anderen Form dokumentieren und überprüfbar machen als durch irgendeine Art von Erzählung" (Macho and Wunschel 2004, 11).

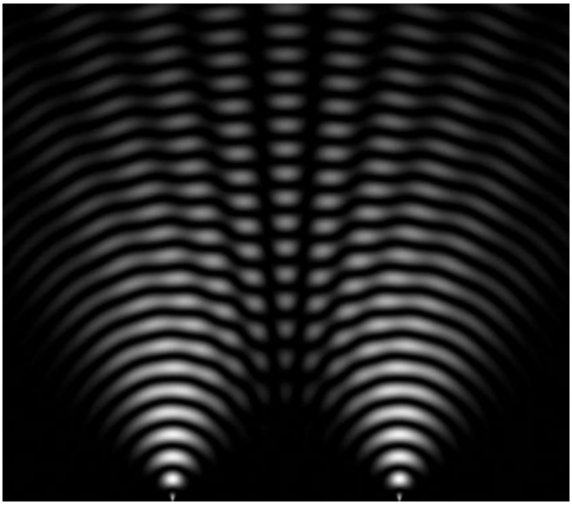

Fig. 3: Simulation of the interference of two waves that form behind a double slit. © Provided under the Creative Commons licence.

In physics, however, the development of technical possibilities and experimental procedures has allowed us in the last four decades to realize in the laboratory a series of thought experiments that were put forward in the early stages of quantum mechanics to investigate fundamental philosophical questions arising from the new physics. Tests of Heisenberg's microscope are being conducted as PhD projects (Dopfer 1998), and the diffraction of large and complex biomolecules at a grating forces them into a superposition of passing through the left and the right slit (Gerlich 2007). This can be translated into Schrödinger's cat if the left slit is associated with destroying the molecule and the right slit with the molecule surviving intact. As a third example, take the EPR-paradox, which Einstein, Podolsky and Rosen developed in 1935 to prove that quantum physics was incomplete, that it did not contain a description of all determining factors acting in the microscopic world. The alternatives were that either causality was violated or the speed of light was not the greatest speed. They considered an entangled pair of objects, which comes from a common source and shares certain properties (for example momentum, polarization or spin) in such a way, that the property is not known before the measurement, but because they are entangled, the measurement of one object will at the same moment give us all the information about the state of the other object (Einstein 1935). Many experiments (see for example Aspect 1982) have been conducted that seem to prove that no such hidden parameters exist and indeed the measurement of the first object determines the properties of the second. But it turns out that the transmission of information still requires a classical channel not exceeding the speed of light. However, entangled quantum systems allow us to set up, for example, communication secure against any eavesdropping, and will soon allow us to crack any encryption based on factorization such as RSA256 without effort (Shor 1997; Ekert 1991). These experiments concern the ontological and epistemological status of the physical world and some physicists now dare to speak of “experimental metaphysics” (Shimony 1984, 36).

Brecht also aims at the realization of thought experiments in the epic theater. In his description of the relation between the audience and the stage, Heisenberg’s microscope appears again (Brecht 1967, Vol. 16, 577). In this way the epistemological function of the experiment in physics is transferred to aesthetic problems and Heisenberg’s microscope unfolds its rich and far-reaching implications, as Hans Blumenberg has predicted for such “absolute metaphors” (Blumenberg 2010, 14–15). Absolute metaphors contain in themselves an epistemological model that tells us how to reflect about a certain entity and its relations to other entities. Formal logic offers no appropriate means to tackle such a metaphor, which itself contains a decision about the assignment of truth values. As a metaphor it transfers this rule of reflection about a known set of entities (in our case this is, somewhat surprisingly, Quantum Physics) to another set of entities (the Epic Theater). Heisenberg’s microscope follows a long tradition of images in which light figures as an expression of truth. This tradition can be traced in western philosophy from Plotinus (Dijksterhuis 1983, 52) to Hegel (1970 [1930], 111–125). The positive reference of the enlightenment to truth is inverted in the twentieth century in Foucault’s *Panopticon*. In the prison under total surveillance, vision takes over the role of light. In this way, truth is turned into a question of power and exhaustive knowledge becomes associated with a totalitarian regime (Foucault 1979).

The light metaphor of truth is intertwined with an epistemic theory that itself has a long history. With diverging implications, it is formulated in Plato’s allegory of the cave, which describes our cognition as the shadows of the pure ideas (Plato 1962, 224–227), as well as in the Aristotelian wax-metaphor, in which objects imprint their traces on our minds as on a sheet of wax (Aristotle, *De anima*, 429b29–430a2). Descartes picks up the metaphor of wax in his *Meditations* (Descartes 2011, 156–160), and in the *Empiriocriticism* Lenin proposes the theory of reflection with an intention that is strictly opposed to that of Plato: "Materialism is the acknowledgement of the objective laws of nature and their approximately correct representation in the human mind" (Lenin 1970, 176).[3]

This volume contains a valuable study by Nikola Kompa on the epistemic role that metaphors play in scientific cognition.[4] The transfer of scientific knowledge to other fields of knowledge, however, is not discussed. Hans Blumenberg describes a transfer of physical theories as metaphorization of scientific concepts and has extensively investigated such a transfer using the example of the Copernican Revolution (Blumenberg 2010, 99–107). But there is a fundamental difference in our case: The Copernican Revolution took place before the specialization and separation of the sciences. The history of this specialization has many layers and happened asynchronously in different countries (Daston 1998). At the beginning of the twentieth century, however, the separation of the humanities and the natural sciences had been completed in Germany. How can such a metaphorization take place in modernity, then – how can the translation between physics and literature work at all? Brecht himself seems to warn us not to take him all too seriously: "How little knowledge one has to pick up to create the impression of profound science on stage" (Brecht 1973, 205).[5] Is Brecht using his reference to quantum physics just to enrich his figure a little bit and give his text the flavor of a certain depth?

2 Interference as methodological metaphor: Interference vs. reflection

With Heisenberg's microscope, Brecht questions the status of our cognition: In this microscope it is impossible to perceive objects objectively, as the perceiving subject becomes part of the experimental setup and thus enters the result of the perception. The composer Hanns Eisler, who was a close friend

3 Transl. by LM. "Die Anerkennung der objektiven Gesetzmäßigkeit der Natur und der annähernd richtigen Widerspiegelung dieser Gesetzmäßigkeit im Kopf des Menschen ist Materialismus" (Lenin 1970, 176).

4 Cf. Nikola Kompa's paper "Insight by Metaphor – the Epistemic Role of Metaphor in Science" in this volume.

5 Transl. by LM. "wie wenig aufgeschnapptes wissen gehört dazu, auf der bühne den anschein tiefer wissenschaft zu erwecken" (Brecht 1973, 205).

of Brecht, later described the important role that the thought experiment played in their discussions:

> When Heisenberg says that the object of the perception is altered by the method of perception, so that we cannot perceive it with absolute precision – that is approximately exactly right –, yeah well, for us that is simply a people's fair.[6] (Bunge 1970, 153)

The metaphor of the γ-ray microscope differs radically from the classical light metaphors of truth. In this microscope, truth is the result of a production and not given by epiphany or reflection, it is performative and not reflective. As it is an experimentally produced truth, it is an approximate and preliminary truth. As early as in the early 1930s Brecht formulated his critique of the theory that reality is merely reflected in the subject:

> Nor are the philosophers like buckets full of water which always reflect the same moon, as clearly as clear as they are being water. From a comparison of the mirror and the reflected image one can know neither the head nor the world, and that is mainly because the heads change the world according to their purposes.[7] (Brecht 1988–2000, Vol. 21, 564)

With Heisenberg's microscope, the epistemological concept of reflection becomes highly problematic, since now the result depends on the purpose of the investigation. The physicist and philosopher of science Karen Barad notes: "In the twentieth century, both the representational or mimetic status of language and the inconsequentiality of the observational process have been called into question" (Barad 2007, 97). She proposes replacing the metaphor of truth as reflection of reality with the metaphor of an interference between subject and object (Barad 2007, 71). With this suggestion she extends a concept that Donna Haraway has put forward in her criticism of the representational character of language (Haraway 1992). Barad deliberately maintains the optical metaphorics of the epistemological process, but she explicitly points out that the concept of interference implies a shift from classical optics to quantum optics (Barad 2007, 81–86). In quantum optics truth is "performative" (Barad 2007, 33), while the image in the mirror is thought to be a neutral representation. This epistemic

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6 Transl. by LM. "Wenn er [Heisenberg] sagt, daß sich das zu Erkennende durch die Methode der Erkennung verändert, so daß wir es nicht genau erkennen können – das stimmt ungefähr genau –, ja das ist für uns ein einfaches Volksfest" (Bunge 1970, 153).

7 Transl. by LM. "Die Philosophen sind auch nicht wie mit Wasser gefüllte Eimer, die immer den gleichen Mond spiegeln, und zwar so klar, wie sie als Wasser eben klar sind. Aus einem Vergleich des Gespiegelten und des Spiegels kann man weder die Welt noch den Kopf erkennen, und zwar hauptsächlich, weil die Köpfe gewisser Zwecke wegen die Welt, die ja immer verschieden ist, noch dazu in ihrer Darstellung, veränderten" (Brecht 1988–2000, Vol. 21, 564).

metaphor holds for a vast range of scientific knowledge as not only quantum physicists experience their influence on the investigated process. The anthropologist in the field, for example, should well be aware that what he or she observes is not an unperturbed social system. As Ursula Rao and Stefanie Mauksch argue, field work is based on dialogue with the subjects of interest and this dialogue always constitutes an intervention rather than a passive observation (Mauksch 2014). For biology Astrid Schrader makes an interesting case: The *dinoflagellae Pfiesteria piscicida* thrives in water containing high levels of nutrients caused by extensive animal farming and was linked to massive fish killings. This triggered a long-lasting quarrel as one side provided experimental evidence for the toxicity of the *dinoflagellae*, but this evidence could not be reproduced by others. After two decades it became clear that the microorganism morphs into a toxic form only in the presence of fish and given specific environmental conditions. Thus the mode of observation determined the behavior of the investigated object, i.e. whether the poison could be found at all (Schrader 2010).

In order to become accessible, however, the interference has to be projected onto a screen – it has to be represented. This step Barad seems to ignore. To account for the many possible representations of one and the same interference, she introduces the concept of an intra-action between wave and mask. In this intra-action several cuts are possible, which will decide what is part of the experimental setup (the apparatus) and what is part of the object. Consider for example the cane that a blind person uses for orientation. This cane is an instrument through which he or she perceives the world, but it can itself immediately become the object of investigation, when the blind person sits down and starts to check it with their fingers for scratches or fractures. I think, however, that this cut itself acts as a projection, and that representation cannot be omitted in epistemological processes. In my understanding, the cut can only be enacted with regard to a third, the screen. The representation then yields an interference pattern that depends not only on wave and mask, but also on the distance to the screen and its properties, such as its resolution. With respect to this distance, different regimes can be distinguished. In the near-field the waves emanating from the mask superpose in such a chaotic way that the resulting pattern cannot be calculated exactly (i.e. analytically) (Case 2009). At certain distances, however, a pattern evolves and the shape of the mask is reproduced. In the far-field, on the other hand, the resulting fringe pattern shows a central maximum and washed out sidepeaks – the image has become blurred and multi-faceted (i.e. Fig. 4).

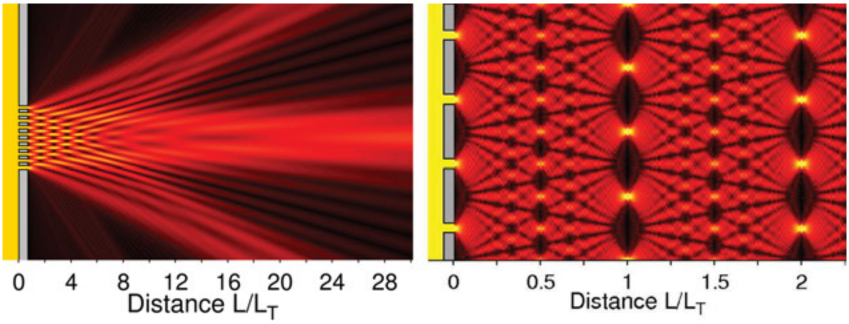

Fig. 4: The left picture shows the transition from the near- to the far-field. In the near-field the mask is reproduced at certain distances. At larger distances from the grating a far-field pattern evolves with a central maximum and several sidepeaks. The close-up on the right shows the so-called Talbot-carpet in the near-field. Pictures from Hornberger 2012, 159–160.

3 Interference as description of the relation between fields of knowledge

In his famous Rede-Lecture the writer and scientist Charles P. Snow stated that two cultures of cognition had developed in academia that neither wanted to nor could communicate with one another anymore. Frustrated, he notes to what little extent knowledge of nature is associated with culture:

> A good many times I have been present at gatherings of people who, by the standards of the traditional culture, are thought highly educated and who have with considerable gusto been expressing their incredulity at the illiteracy of scientists. Once or twice I have been provoked and have asked the company how many of them could describe the Second Law of Thermodynamics. The response was cold: it was also negative. Yet I was asking something which is about the scientific equivalent of: Have you read a work of Shakespeare's?
>
> I now believe that if I had asked an even simpler question – such as, 'What do you mean by mass, or acceleration,' which is the scientific equivalent of saying, 'Can you read?' – not more than one in ten of the highly educated would have felt that I was speaking the same language. So the great edifice of modern physics goes up, and the majority of the cleverest people in the western world have about as much insight into it as their neolithic ancestors would have had. (Snow 1964, 14–15)

Some forty years later, Alan Sokal's felicitous "hoax" with postmodernism (Sokal 2001) seems to show that the gap between these two cultures of knowledge is deeper than ever before. Sokal fooled a few prominent editors of a cultural studies journal by selling them physically untenable statements as justified by cultural sciences. By this he showed that postmodernism in many cases abandoned scientific rigor for the coining of phrases. His conclusion, however, that this hoax sufficiently demonstrated that physics is an objective science solely guided by the constitution of nature and completely independent of the questions that society asks about this nature, is largely unfounded. This correlation cannot be derived scientifically since the questions are not related: Just as a wrong conclusion can be drawn from a correct argument, the conclusion drawn from an invalid argument might still be correct. The demonstration that there exists a reality that is not altered and influenced by our observation demands much more than a hoax article in the journal of sloppy postmodernists.

On the other hand, Snow and Sokal are of course right. Anyone who, for example, attends the early morning lecture at the physics institute of the University of Vienna and in the late afternoon a seminar on philosophy soon gets an idea about how different their styles of thought are. In the afternoon you meet people who work almost exclusively alone and focused on texts. The questions they think about are fundamental and concern the existence of the whole universe and the conditions of the possibility of its cognition. The knowledge developed here has to be free of contradictions and should form a systematically organized unity – even if the demand to create a closed system of thought has been abandoned in the twentieth century, methodological coherence usually still is required.

Before lunch, on the other hand, a collaborative work ethic dominates. Hardly anyone can cope with the demands of the physics courses and the practical work all on his or her own. The knowledge required here is as manifold as its applications. The collection of methods is thus somewhat eclectic and the physicists' models are only expected to describe the situation under discussion sufficiently. Not too many physicists are surprised if they agree only partially with one another. Generalizations from individual experience are treated with a certain caution.

In foundational research, the experiments are often surprisingly fragile and physicists spend most of their time repairing them. In comparison the texts and theories of the philosophers seem fairly robust and reality hardly ever bursts in. These differences in training, tacit knowledge and scientific culture are perpetuated by the current system of funding and publishing.

Interdisciplinarity has become a buzz word often required to open the doors to funding. However, while on paper fostering interdisciplinarity the funding agencies do in fact not know how to deal with such an approach. Their internal structure follows the very separation between the fields of knowledge that they claim to aim at overcoming. Interdisciplinary projects often result from cooperation between related fields, such as physics and chemistry. Honest advisors will tell you that the chances of a grant application addressing both philosophy and physics are vanishingly small. One reason is the review process itself. Since the reviewers' background is usually limited to one discipline, they will understand only half of the proposal. I occasionally wonder why somebody agrees on reviewing an interdisciplinary proposal when being openly hostile to such approaches. The clash between fields of knowledge also have its roots in different traditions of publication. In most sciences what counts are short papers announcing the results of month and years of work. In the humanities on the other hand monographies are of much higher value. This lack of mutual appreciation of different ways of publishing blocks interdisciplinary career paths.

Stating these difficulties will, however, not help us much to understand the interaction of the different fields of knowledge. The concept of interference allows us to grasp this interaction, describing it as a superposition of two systems of knowledge.

To be honest, it was during my experimental work in quantum optics that I developed my understanding of the metaphor of interference. In our Kapitza-Dirac-Talbot-Lau interferometer for matter-waves, complex molecules enter a carefully prepared environment in which no information about their path can be obtained (Gerlich 2007). They do not behave as well-located particles anymore, but rather the motion of their center of mass can be described by a wave function. These matter-waves are diffracted at a grating, each wave passing at least two slits. Each opening in the mask acts as the source of a wave and the superposition of the emanating waves forms a complicated pattern. This interference pattern is recorded as evidence for the wave-like behavior of the molecules. Our setup shows that beyond mask and wave switching their roles as apparatus and object of the observation, even what forms the diffracted wave and what the diffracting element can be exchanged. Whereas in classical interference experiments light-waves are diffracted at material gratings, in the KDTLI a standing light-field acts as the diffraction mask which imprints a phase shift on the matter-wave (Kapitza 1933). Just as light and matter change their roles here, in the investigation of the interference of two fields of knowledge it should be possible to exchange their roles as diffracting and diffracted element. The cut that determines their roles depends on the question of the investigation.

At first glance it might seem that Luhmann's Systems Theory is able to justify such an approach and the introduction of the metaphor of interference is unnecessary. Betül Dilmac, for example, has used this theoretical approach in her published thesis on *Literatur und moderne Physik* (Dilmac 2012). According to Luhmann's theory, autonomous subsystems build up a total system where the environment of each subsystem consists of the other subsystems. The crucial difference, however, is that these systems are considered to be self-generating and isolated, such that they interact only via communication: “The society as well as its partial systems are autopoietic systems whose operations are communications” (Dilmac 2012, 44).[8]

Each partial system has its specific form of communication, a characteristic code that only appears in this system. These codes are thought to be binary, and contain the fundamental operations which reproduce the system. Science for example operates with the code true and false whereas art uses the opposition of beautiful and ugly. A translation between the systems changes the code, such that writers are taken to be interested only in aesthetic aspects of science. This is insufficient to grasp Brecht’s metaphorization of Heisenberg’s microscope, which transfers a concept of truth from quantum physics to aesthetics. Ulrich Sautter postulates that Brecht does not try to connect science and art as two different disciplines but considers them both to be expressions of one and the same intellectual interest in cognition (Sautter 1995, 688). Brecht suspects that physics itself operates with aesthetic categories:

> Today even an aesthetics of the exact sciences could be written. Galilei speaks about the elegance of certain formulas and the wit of experiments, Einstein ascribes a scientific function to the aesthetic sense and the atomic physicist R. Oppenheimer praises the “beauty of the scientific stance which is the most appropriate to the position of man on earth.”[9]
>
> (Brecht 1967, Vol. 16, 662)

Brecht reports that the physicists themselves look for an aesthetic aspect in their work and he goes even further – the political revolt has its own elegance as well:

> After Albert Einstein had read the latest paper written by Niels Bohr he exclaimed: “This is the highest musicality in the area of thought!” Equally well he could have said about the article: An uprising, well planned and powerfully conducted![10]
>
> (Brecht 1967, Vol. 20, 335)

8 Transl. by LM. “Die Gesellschaft genauso wie ihre einzelnen Teilsysteme sind autopoietische Systeme, deren Operationen Kommunikationen sind” (Dilmac 2012, 44).

9 Transl. by LM. “Es könnte ja heute sogar eine Ästhetik der exakten Wissenschaften geschrieben werden. Galilei schon spricht von der Eleganz bestimmter Formeln und dem Witz der Experimente, Einstein schreibt dem Schönheitssinn eine entdeckerische Funktion zu, und der Atomphysiker R. Oppenheimer preist die wissenschaftliche Haltung, die ‘ihre Schönheit hat und der Stellung des Menschen auf Erden wohl angemessen scheint’” (Brecht 1967, Vol. 16, 662).

10 Transl. by LM. “Nach der Lektüre eines neuen physikalischen Aufsatzes von Niels Bohr rief Einstein: ‘Das ist höchste Musikalität auf dem Gebiet des Denkens!’ – Ebensogut hätte man von dem Aufsatz wohl sagen können: Ein Aufstand, schön geplant und mächtig durchgeführt!” (Brecht 1967, Vol. 20, 335).

The differentiation into binary codes seems to found the separation of the fields of knowledge which it tries to overcome. In contrast to Systems Theory, the historian of science Lorraine Daston proposes not only to investigate the relation between natural science and its cultural milieu but to approach science itself as culture (Daston 1998, 17), as science itself creates values and meaning and does not simply borrow them from other spheres which are considered to be cultural (Daston 1998, 29).

With the concept of blending, literary studies offer an interesting approach to a description of the interaction of two such cultures, of what is going on between Brecht and quantum physics. Blending describes cognitive processes that integrate two discrete and clearly distinct concepts (Fauconnier and Turner 1998). It generally operates with the metaphor of space and the relations between logical sets are translated into relations between spaces. The two or more input sets are called input spaces, in our case the measurement problem of quantum physics and the role of the audience in the epic theater. The set of all common features is the generic space, for example the similarities of the entities they operate with and the influence of the observation on the observed process. In the blended space parts of the generic space, and input from the outside world, such as the common historic background that Quantum Physics and Epic Theater share, come together and form a new "emergent structure" (Fauconnier and Turner 1998, 135), which cannot be dissolved into the structure of the input spaces. Here we find a metaphor of cognition and truth in which physics and theater "fuse" (Fauconnier and Turner 1998, 141) in the (artificial) historic setting of two emigrants discussing the world economic crisis.

But the metaphor of Heisenberg's microscope contains an epistemic stance that leaves neither input space untouched. It feeds back and alters them. The measurement problem in quantum physics shakes the very foundations of classical physics, it demands that we rethink notions that lay at its core: causality, time and trajectory, to mention the most important. In Brecht's theater the active role of the audience clashes with the Aristotelian approach that postulates catharsis as the aim of all drama. A completely new style of acting had to be developed and the way the story is told changed dramatically, paving the way for modern postdramatic theater (Lehmann 2008). In blending theory this feedback is described as projection or mapping back from the blend to the input spaces. This projection can change the input spaces by altering their properties and adding new ones. This in turn will change the generic space from which the blend feeds. Together the input spaces, the generic space, the blends and the frame of background knowledge form a "conceptual integration network." The relations between elements of each set are described as the topology of the respective space. A blend will work well if the relations between the projected elements are maintained, that is if the topologies of the blend and one or all of the input spaces agree (Fauconnier and Turner 1998, 163).

If the back-action of the blend on the input spaces is somewhat random, it wouldn't be surprising if after some time the common set vanishes, the generic space becomes empty and the blend is exhausted. In physics, a necessary condition for the evolution of interference fringes is the coherence of the interfering waves, which means that their phase relation is maintained during their propagation. In the description of the interaction of fields of knowledge, coherence can be described such that the back-actions of the blended space on the input spaces alters the input-spaces in a way that maintains the agreement of the topology of inputs and blend. As the interaction continues, the blended space and input spaces so to speak *resonate*. This can constitute a dynamic system that lasts for a certain number of feedback-loops – that is it lasts for a certain time which we might call its coherence time, if we dare to extend the metaphor even further.

Unlike the concepts of reflection and representation, the notion of interference allows us to avoid the production of analogies and homologies. These concepts apply to a comparison between separated notions. In an interference we do not reflect something existing by something else that exists for itself – from an interference an entity evolves in which both interfering moments enter. In order to observe it, we have to discontinue the development of this entity and its state has to be projected and fixed. Depending on where this cut is made, certain aspects of the entity will become visible by leaving traces on the screen, which we can follow (Barad 2007, 164). We might set the cut such that one of the fields of knowledge appears to be the diffraction mask and the other the scattered wave. This allows us to read off the influence of the diffracting element on the scattered system from the interference pattern.

Different cuts will produce different pictures of this interference, the coherent interaction of two or more input spaces. In the case of Bertolt Brecht's theater and quantum physics, the coherence is founded on their common social, historical and cultural environment, and the shared set of notions, methods and problems that it offered.

Both epic theater and quantum physics evolved in the Weimar republic and were shaped by the exile during National Socialism into which not only Brecht but also many physicists were forced. Brecht's *Life of Galilei*, which has at its core the social responsibility of the physicist, was written and rewritten during this exile and is intimately intertwined with Brecht's engagement with physics. When he took up work on this drama during his Danish exile, Brecht sought the advice of Niels Bohr and though the Nobel Prize laureate did not find much time, his assistants supported Brecht (Bunge 1985, 98). In Los Angeles, the last station of his exile, Brecht radically revised the drama, while a few hundred kilometers away the first atomic bombs were built (Mairhofer 2010). In his American exile Brecht's work was stalled and he saw no chance of staging his plays. In this situation he started a discussion with the philosopher and physicist Hans Reichenbach on the problem of causality in quantum physics. The debate somewhat escalated after a lecture that Reichenbach held at UCLA, and which not only Brecht attended, but also Adorno and Horkheimer. The proponents of the Frankfurt School vehemently opposed Reichenbach, who saw neither a need nor a justification for the notion of a strict causality in physics. In Reichenbach's view, physicists appear as "gamblers" whose predictions are just a "best bet" on the result of the experiment. The figure of thought of the gambler reappears in Brecht's last important drama, the *Caucausian Chalk Circle*. The drama has the same causal structure as an experiment in Quantum Physics. The figure of thought of the gambler is intimately connected with a new ethics. In the structure of the play as well as in the formation of its scenes and characters, the concept of game plays a central role. I have described the impact of both the problem of observation and causality in Quantum Physics on the *Caucasian Chalk Circle* (see Mairhofer 2013).

This long-lasting conversation between two such different fields of knowledge as physics and theater was fostered by a common set of notions. As examples, consider the concept of the field, which Faraday and Maxwell transferred from farms and war into physics, where they used it to describe the electric and magnetic interactions between physical objects as entities in their own right, and having the same ontological status as the objects themselves, acting back on their own sources (Maxwell 1954, ix). *Gestalttheorie* emphasized the priority of the relation over the relata and applied not just the terminology but also the mathematical formalism and methods of graphical representation of the field concept developed in physics to psychology and sociology (Köhler 1971, Lewin 1939). Brecht uses the notion of the field to describe how the meaning of a sentence always depends on the network of sentences in which it is uttered. He also applies the notion of the field when he demands that characters should develop during the plot, according to their mutual and dynamic relations. These relations he often frames as collectives, introducing with this term a level between the isolated individual and the abstract mass. Interestingly, this politically charged term was transferred to quantum mechanics by Soviet-Russian physicists to describe phenomena in solid state physics that result from the motion of many particles. The concept of the collective developed into an important tool and finds wide application in physics (Kojevnikov 2012).

This brief outline of the reasons for the coherence of epic theater and quantum physics also demonstrates that many different cuts are possible, and that these cuts will exhibit different features of the interfering entities. The metaphor of interference thus allows us to embrace different representations of the same interaction. Different methodological approaches to one and the same object under investigation can be understood as complementing instead of competing with one another. The historian of science shows us the shared concepts with which epic theater and quantum physics operate. An investigation of the social, cultural and historical background reveals that these notions were developed as responses to shared biographical situations. Traces of this interaction can be found in forgotten manuscripts in the archive that contains the material of Brecht's friend Hans Reichenbach (see for example Brecht 1973, 387 and document number 040-02-09 of the archive). A more discourse-oriented approach discovers shared figures of thought, such as the gambler for quantum physics, Brecht's ethics and in philosophical anthropology (Mairhofer 2013). Finally, a close reading of Brecht's *Caucasian Chalk Circle* demonstrates the influence of quantum physics with regard to the constitution of the characters, the structure of the play and the dominant role of chance in the plot.

It seems to me to be a necessary condition for this process of interference of two fields of knowledge, that the basic entities and their relations, with which the two fields operate, can be translated into one another. For this they have to maintain a similar *Gestalt* and function (where the similarity is more constant than the changing *Gestalten*). The fundamental entities of physics underwent a profound revolution in quantum physics just as the fundamental entities of society did in Brecht's epic theater. The indivisibility of the a-tom and the individual were both radically questioned. Nevertheless these two fields of knowledge kept blending. In this sense I think we can speak of a coherence between the atom in quantum physics and the individual in epic theater.

In an article with quite some impact on the research on Bertolt Brecht, Hans-Thies Lehmann and Helmut Lethen discuss three sources of Brecht's critique of the idealistic fiction of the subject (Lethen 1980, 157). Marx describes the individual as the ensemble of contradictory social relations. According to Freud's concept, the individual evolves in the intersection of antagonistic mental instances; and Nietzsche finally locates the individual in the tension between body and mind. I would suggest adding quantum mechanics to these sources, insofar as the fundamental entities with which epic theater and quantum physics operate show a strong coherence. Quantum mechanics challenges not only the particle character of atoms, but also the continuity of atomic processes, their strict causality and their *Anschaulichkeit,* a term that is not readily translated into English but expresses the idea that a fact is intuitively accessible because it is directly represented by sense impressions (Kojevnikov 2011). In his *Verfremdungseffekt*, Brecht repeatedly disrupts the plot in order to open up the gap between representation and object. He tries to avoid a theater that is *anschaulich* and wants to make the audience think about different possible progressions of the story, thus calling into question the strict causality of the events. Finally, the continuous existence of the fundamental entities itself is questioned, as function becomes more important than essence.

Classical physics is founded on the existence of indivisible atoms which exist prior to any interaction and whose dynamics is then described. Gideon Freudenthal shows how synchronously with the conception of the Newtonian atom the notion of the individual develops and takes its crucial role in the bourgeois theory of the social contract (Freudenthal 1982, 265–270). Both classical mechanics and bourgeois social theory are founded on the assumption that the properties of the fundamental entities are independent of their relations (Freudenthal 1982, 160–161). The First World War proved this assumption of free subjects existing prior to all society to be an "idealistic valorization of the individual" (Lethen 1980, 157).[11] Brecht notes: "War shows the role that the individual is meant to play in the future. The individual as such achieves an intervening effect only as it represents many" (Brecht 1988–2000, Vol. 21, 436).[12]

The new conception of the fundamental entities in both physics and society that developed during the Copernican Revolution is intertwined with an epistemological revolution. In Aristotelian physics only one privileged point of view allows us to correctly describe physical processes: the earth that is thought to rest at the center of the universe. By contrast, in Newton's theory many reference frames allow for a correct description, the inertial systems. Which phenomena correspond to a certain event now depends on the point of view of the observer. But the different observations can be translated into one another. In Newtonian physics, however, this requires the existence of an absolute space, which again distinguishes a certain stance that allows for this translation. Remarkably, Newton develops this theory during the Glorious Revolution, which ends with the proclamation of a constitutional monarchy, where in Parliament different points of view are balanced while the king or queen still occupies the distinguished position of an absolute stance. (Wo)man has been removed from the center of the universe and has been put in the center of its cognition (Blumenberg 2010, 107). In quantum physics this epistemic position is shaken to its

11 Transl. by LM. "idealistische Valorisierung des Individuums" (Lethen 1980, 157).

12 Transl. by LM. "Der Krieg zeigt die Rolle, die dem Individuum in Zukunft zu spielen bestimmt war. Der einzelne als solcher erreichte eingreifende Wirkung nur als Repräsentant vieler" (Brecht 1988–2000, Vol. 21, 436).

very foundations. This again is intertwined with a reconceptualization of basic entities. As early as 1926, when the first mathematical formulations of quantum mechanics had just been found, Brecht compared the figures of his plays with the entities of modern physics:

> Even if one of my persons moves in contradictions, this is only because (wo)man in two different moments is never the same. […] The continuous subject is a myth. (Wo)man is an ever-fragmenting and recomposing atom.[13] (Guillemin 1975, 198)

This echoes the radical critique formulated by the Viennese physicist and historian of science Ernst Mach, who only accepts the existence of sense data. Mach takes it as the main task of science to give an economical description of the sequences of impressions of our senses, and denies any possibility of a representation of the objects themselves. He opposes any "metaphysical" speculation that exceeds a description of our sense data (Janik 1973, 134). Thus he opposes the assumption of the existence of fundamental entities on the part of the object as well as on the part of the subject. Mach "trashes" [zertrümmert] (Brecht) the atom as well as the individual.

This approach found much less resonance among physicists than among historians of science. Although they agree with Mach's critique of metaphysical interpretations of physics, Ludwig Boltzmann and Heinrich Hertz oppose the refutation of the existence of both moments of observation, the subject and the object. Hertz takes physical theories to be models, in which abstract notions are connected to reality by experimental procedures. In Mach's concept we passively contemplate our sense data while in Hertz' approach we actively produce this sense data (Janik 1973, 140). While Mach sets an external limitation on the validity of physical theories by the prohibition of metaphysics, the validity of a model is inherently given by its structure (Janik 1973, 145–146).

Brecht embraces the approach of Hertz and Boltzmann rather than the critique of Mach. He develops a series of models of the constitution of the individual in its contradictory relations. These models are tested on the theater's stage, where the figures build up in the course of the plot rather than being presupposed by it. Niels Bohr on the other hand describes how the properties of the basic physical entities build up in the relations into which they enter in the experiment. He refuses to designate them as particles or waves but instead calls

13 Transl. by LM. "Auch wenn sich eine meiner Personen in Widersprüchen bewegt, so nur darum, weil der Mensch in zwei ungleichen Augenblicken niemals der gleiche sein kann. […] Das kontinuierliche Ich ist eine Mythe. Der Mensch ist ein immerwährend zerfallendes und neu sich bildendes Atom" (Guillemin 1975, 198).

them “individuals” (Bohr 1961, 59). Individual as well as atom in his thought are highly precarious:

> In particular, the apparent contrast between the continuous onward flow of associative thinking and the preservation of the unity of the personality exhibits a suggestive analogy with the relation between the wave description of the motions of material particles, governed by the superposition principle, and their indestructible individuality.
>
> (Bohr 1961, 99–100)

While Brecht does not develop one single coherent concept of the individual, the quantum physicists put forward manifold interpretations of their mathematical formalism and the corresponding experiments. In both fields of knowledge the observers influence the observed process, and its representation in a formal system becomes ambiguous. The continuity of the processes and the distinguishability and thus the individuality of the fundamental entities partaking in these processes is suspended.

The possible interactions among entities are altered along with the entities themselves. Entities no longer enter into their relations with predefined properties but rather constitute themselves in these relations. The determination of the fundamental entities is intimately connected to the determination of their causal relations, as it is these relations that define an entity. It might well be that the entity is even constituted in these relations. Then the epistemic relation between observer and object also becomes precarious, as the object can no longer be perceived objectively, which is expressed in the metaphor of Heisenberg’s microscope.

A shift in the understanding of the category “entity” or “unity” [Einheit] (Kant 1968, 118 (B106)) with which a style of thought operates will necessarily change the style of thought as a whole. The category “entity” proves to be the *a priori* form of cognition postulated by Kant. This *a priori*, however, can no longer be understood in his sense as ahistorical and purely logical, as cognition is not unidirectional but relies on a feedback between knowledge and object. This feedback is achieved through the application of the model to reality; that is, in the practice that results from our insights and is directed at the object. The result of this practice again alters our knowledge.

To conclude, the concept of interference allows us to describe the interaction of fields of knowledge and to describe the necessary conditions for this interaction, the coherence of the basic entities with which these fields operate. This interference is best represented not by a single fringe pattern but by multiple projections that are produced and investigated using a wide range of methods.

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Part III: **Aestheticization and Literarization of Physics**

Bernadette Malinowski

Literary Epistemology

Daniele Del Giudice's Novel *Atlante occidentale*

Abstract: Since the advent of the modern era, the object of scientific inquiry has shifted from things sensorially visible to things no longer sensorially perceptible. Science investigates, increasingly, a literally anaesthetic or anaisthetic *nature*. According to Lyotard, the seamless interweaving of science and technology has caused a "waning of reality" (1984, 77) which in turn has fundamentally called into question the assumption of any correspondence of knowledge and reality, of knowledge and truth. No longer perceptible without technical help, nature eludes scientific representation and, being unrepresentable, can only be presented in an aesthetic mode. Indeed, the (techno-scientific) aestheticization of nature and reality emerges as the flip side of its (techno-scientifically generated) anaesthetization.[1] These tendencies of postmodern thought as described by Lyotard are thematized in Del Giudice's novel *Atlante occidentale* (1985). In the following, I shall use this text as an example of how the postmodern novel poetically as well as poetologically reflects the dialectics and dynamics of aesthetization and anaesthetization[2] pertinent to current scientific inquiry. Throughout my argument, I will place major emphasis on the question of the specifically *epistemological* functions of literature.

1 Heidegger describes a similar dialectic "mechanism" when he conceives of technology as the "consumption" and the "using up of Being" by "armament in the metaphysical sense," in other words, by that "through which man makes himself 'master' of what is 'elemental'" (Heidegger 1973, 103) [cf. Heidegger 1978, 87–88]. As such, technology implies a specifically human relationship and attitude toward reality, a literally *consuming* practice that erases the present, differentiated reality (including human reality) – especially in those instances where this reality is technologically *produced*. Elsewhere, Heidegger marks the "fundamental process of the modern age" explicitly as "the conquest of the world as picture" on the one hand, and as abstraction and mathematization on the other (Heidegger 1977, 134) [cf. Heidegger 1950 [1938], 76 and 92].

2 I shall use the term aesthetization – here and elsewhere – in a sense comprising the notions of making something available to the senses as well as constructing perceptibility via media technology, by fabrication of knowledge, or by cosmetic interventions in, for instance, scientific representations of things sensorially unrepresentable. This usage of the term builds on the etymology of aesthesis, namely perception [sinnlich-körperliche Wahrnehmung] as well as on the traditional philosophical meaning of aesthetics as 1) the discipline that investigates the principles and conditions of sensory perception and 2) the theory of the beautiful and the sublime.

Note: For an extended version of this contribution see Malinowski 2021, 279–363.
Translated by Jasper Verlinden and Winfried Thielmann.

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1 A literary philosophy of science: Daniele Del Giudice's *Atlante occidentale*

Daniele Del Giudice's 1985 novel *Atlante occidentale*[3] tells the story of the friendship between Pietro Brahe, a young Italian nuclear physicist who works in the European Organization for Nuclear Research (CERN) in Geneva, and Ira Epstein, a successful German writer of advanced age with temporary residence in Geneva. It is their shared passion for flying which brings them together: a near mid-flight collision with Brahe's machine caused by Epstein – the conflict between the two cultures is almost graphically conveyed here – forms the starting point of this quickly developing and deepening male friendship.

The plot of the novel is situated in the present. At the same time, the synchronic axis of events is intersected – across names, motifs, chronotopic structures, and above all the literary development of Epstein – by a diachronic one that ties the postmodern world of the novel to the previous, modern epoch: a modernity mainly characterized as Enlightenment. The novel marks, to put it in Del Giudice's own words, a "substantial change in epoch" (Del Giudice 1986, 93),[4] for which it is symptomatic that "things have already commenced turning into non-things" (cf. LL 69).[5] Accordingly, the dialog between Brahe and Epstein, between natural science and literature, essentially centers on questions of the possibilities of perception, representation, and understanding of a waning reality.

The novel attains its decidedly epistemological character on the level of narrative discourse, as well as on the level of plot action – which, in turn, is primarily discursively-dialogically mediated. In order to illustrate the novel's varied epistemological functions, the two experiments conducted by both protagonists – Brahe's physical and Epstein's aesthetic and poetological experiment – will first be presented separately and subsequently analyzed in their manifold references.

3 Daniele Del Giudice: *Atlante occidentale*, Turin 1985, henceforth cited as AO. The English translation *Lines of Light*, from the Italian by Norman MacAfee and Luigi Fontanella, San Diego et al. 1988, henceforth cited as LL. Unfortunately, the English translation, on the whole, does not follow the original as closely as may be desired, which is why the translators of this paper have made some changes to it.

4 "mutamento di epoca sostanziale" (Del Giudice 1986, 93).

5 "cose ormai cominciano ad essere non-cose" (AO 66).

1.1 Brahe's experiment: On the technological construction of visibilities

Brahe works in experimental high energy physics, an area of physics that aims at understanding the fundamental building blocks of the universe. To this end, as in CERN, the European Organization for Nuclear Research in Geneva, so-called collider experiments are conducted: different elementary particles are brought into collision in a particle accelerator through which – in relation to the available energy – the release of new particles is made possible. In this vein, the UA1 and UA2[6] experiments conducted at CERN by the research group centered around the Italian physicist Carlo Rubbia were electron-positron experiments which in 1983 led to the first evidence of so-called W and Z bosons and for which the researchers received the Nobel Prize a year later. According to speculation on the part of Gerhard Regn, Del Giudice could have taken up Rubbia's confirmation of the Z and W bosons and transferred it onto the LEP[7] which was completed in 1989 and thus still under construction at the time the novel was being developed (cf. Regn 1991, 339).

Brahe does indeed work on a collider experiment (AO 140) aimed at the discovery of new particles.[8] The start of the second chapter leads the reader straight to the novel's central theme: the problem of perception, representation, interpretation, and understanding of scientific objects and phenomena devoid of any concreteness.[9]

> At dawn, the last image was still identical to the first one which Brahe had observed at the beginning of the night. From the darkness, there first appeared on the monitor a frame with the serial number, the time, the code of the experiment. Then, from left and right, lines rapidly appeared, some colliding in the center where their impact generated other lines, continuous or dotted, curves, parabolas, ellipses, tiny vortices that coiled

6 UA stands for Underground Area (cf. Knorr-Cetina 2002a, 27).
7 The LEP (= Large Electron Positron Ring) is a collider whose maximum energy output proved to be insufficient to confirm the Higgs mechanism. Because of this, the LHC (= Large Hadron Collider) was built (cf. Knorr-Cetina 2002a, 26–27).
8 Cf. AO 145, where there is mention of the "particelle che loro vedevano per la prima volta quella notte."
9 Accordingly, it is said about Brahe that he works "within the total disappearance of things" ["nell' assoluta scomparsa delle cose"] (AO 68). Brahe's historical namesake is the Danish astronomer Tycho Brahe (1546–1601). Connected to this name are not only relevant scientific insights into planetary movements through the means of new technology, but also organizational and institutional innovations in science: his observatory built in 1576 can be seen as a predecessor of the kind of large-scale "laboratory as research center" that we find today in CERN, for example (cf. Knorr-Cetina 2002b, XIX).

> around themselves. For a time they remained in place, frozen, poised, then everything disappeared again. Every ten seconds, the notes of the tuning fork halted and waned, the numbers hit their limit, and on the screen there was a sort of visual puff. Brahe knew the destination and the nature of each line. The ideal would have been a new line, a line which would be inexplicable and therefore probable, there where it could have been but wasn't. Yet, the visualization in its entirety also resembled something else, an illuminated metropolis seen from above, a night-time photograph of a road streaked with red and white stripes from the headlights of the moving cars, the control panel of a station, colored gems against the black velvet of a jeweler. They were preliminary images, selected, artificial, not the whole event, but only that part that could reveal something new. The totality of the event, the thousands of events of the night, were stored in memory.[10]
> (LL 18–19)

The images which Brahe sees on the monitor do make themselves available to the recipient's imagination. More than that, they excite the recipient's curiosity in that they evoke, above all, the question of what these images are actually images of, which original natural object they depict, and to which frame of reference they relate. No answers are provided to these questions throughout the novel. On the contrary, these questions are repeated in virtually endless variations – they dominate the scientific as well as the literary and everyday world of the novel, and this repetition only serves to increase the information gap. This gap *signifies* and encompasses the entire scientific knowledge connected to the project at CERN and thus also symbolizes the knowledge gap between layperson and expert. Conversely, however, the purposeful omission of *positive* knowledge – in the positivist sense – draws attention to the above-mentioned problematic and thus to such scientific and epistemological questions the answers of which do not leave the *nature* of *positive* knowledge untouched.

10 "All'alba l'ultima immagine era perfettamente identica alle prime che Brahe aveva osservato all'inizio della notte: dal buio si formava sul monitor prima una cornice col numero della serie, il tempo, la sigla dell'esperimento; poi da destra e da sinistra entravano linee rapidissime, alcune collidenti al centro dove l'impatto generava altre linee continue o tratteggiate, curve e parabole e ellissi e piccoli vortici attorcigliati su se stessi. Tutto restava cosí per qualche istante, bloccato, accaduto; poi tutto spariva di nuovo. Ogni dieci secondi le note di diapason si fermavano su un tono calante, i numeri delle quantità toccavano il limite massimo, e sullo schermo c'era questa specie di *paf* visivo. Di ogni linea Brahe conosceva il destino e la natura, e anzi l'ideale sarebbe stata una linea nuova, inspiegabile e dunque probabile, lí dove avrebbe potuto esserci e non c'era; però la visualizzazione nel complesso poteva sembrare tutto: una metropoli illuminata vista dall'alto, la fotografia notturna di una via con striature rosse e bianche di fari d'auto in movimento, il pannello degli scambi di una stazione, perline colorate sul velluto nero di un inanellatore. Erano immagini molto preliminari, selezionate, artificiali, non tutto l'evento ma soltanto quella parte che avrebbe potuto rivelare novità; gli eventi completi, migliaia di eventi di una notte, andavano in memoria" (AO 19).

For Brahe, the images on the screen are part of an experimental practice and scientific discourse. He reads them as discursive images whose epistemic function and argumentative value is strongly determined and restricted to a specific context of use. Their *reading* and interpretation in this context – the context of scientific experiments – presupposes an *order of knowledge*, a fixed system to which the images refer and to which they are allocated, a system into which they are translated and which constitutes their status as scientific images. However, the target language into which Brahe translates the images is merely *one* possibility among many. This is illustrated by the alternatives that he plays through in terms of how the images can be differently perceived, read, and interpreted. Hence, scientific language – whether it is of a conceptual or a mathematical nature – is from the start placed in the *paratactical* structure of a plurality of languages and cultural codes, and in its claim to validity is relegated to the precisely outlined confines of the experiment. At the same time, a difference is established between the open and phantasmatic nature of the visual world on the one hand, and the *definitional* and the unambiguous nature of scientific language on the other, a difference which in the scientific process of translation and interpretation is closed off and dissolved in favor of fixed, identificatory meanings: the image is, so to speak, incorporated into scientific discourse and its specific rules – a process necessarily accompanied by the loss of the image-*other*, especially its aesthetic characteristics such as metaphoricity, polyvalency, and autonomy.[11] Ultimately, the way we perceive appears to be influenced and structured by mental attitudes and expectations, as well as divided into the various forms of technological, scientific, (quasi) naturalistic, and aesthetic perception.

The degree to which consciousness regulates the specific mode of appearance of an object is particularly illustrated in those passages where the *realistic* observations of the narrator are blended with the scientifically modeled observations of his characters. Thus one passage states: "Just behind the bend, Brahe looked at the lake and the mountains; but he looked at it as a purely altimetric movement: mountains, inclined descending lines, horizontal lines resting upon

11 Scientific images are instrumentally, argumentatively, and thus also rhetorically employed – they are "pragmatized" ["vollzugsorientiert"] and have "their purpose by necessity outside themselves" ["ihren Zweck notwendigerweise außer sich selbst"]; accordingly, the iconicity of the image is largely ignored. Boehm speaks pointedly in this context about "weak" images as opposed to "strong" images in art (Boehm 2001, 52–53). On the ambivalence between the aesthetic quality of scientific images and their ascribed claim to objectivity, cf. Daston and Galison 2003, 29–99.

the water, lines rising in ascent" (LL 90).[12] This narrative *blending* not only relativizes the perspectives of narrator and character, but also their respective percepts. Analogously to the perception of the visualizations on screen, here, too, perception proves to be an intentionally directed, yet nonetheless intuitive and instantaneously performed reading and interpretation of the world – thus presuming a world that is accessible as mere sign and image. At the same time, it is once again the concepts and ideas in the mind of the perceiving subject that give shape to the perceived signs and images in their specific mode of appearance. As a result, perception can be described as a simultaneously receptive (in the sense of receiving and reading signs) and poietic act (in the sense of actively processing signs) in which the difference in perception of the same object can be ascribed to the intentional structure of perception as well as to the psychological, physical, and cognitive condition of the perceiving subject.

As a medium, however, the scientific image not only points *forward* in the direction of the epistemic target language, but also, above all, *backward* to its natural referent in nature. The image visualizes *something* of which there is – literally – no image, things "of which there was no image, save those conventional images, formalized by a rigorous fantasy, that carried an arbitrary and powerful relation to things, like the alphabet" (LL 80).[13] The relationship between signifier and signified can no longer be described within the rhetorics of representation. In effect, this cancels any traditional conception of a conventional or ontological correspondence of image and image-independent reality.[14] The place of traditional representations is taken over by processes of construction, enactment, and interaction that, essentially, do produce the images as well as the scientific *objects* under investigation.[15] Scientific images are thus

12 "Al fondo di una curva Brahe ha guardato il lago, e le montagne; ma le ha guardate come un puro movimento altimetrico, montagne lage montagne, linee inclinate di discesa, linee orizzontali a pelo dell'aqua, linee impennate in risalita" (AO 89).

13 "[...] cose di cui non c'era immagine, se non quelle convenzionali e formalizzate di rigorosa fantasia, arbitrarie e potenti, rispetto alle cose, come un alfabeto" (AO 79).

14 Mersch distinguishes between three fundamental historical phases in image culture: 1. The representational function of the scientific image between the seventeenth and the early nineteenth centuries; 2. the "mechanical" or "non-interventionist" recordings from the second half of the nineteenth through the first half of the twentieth century; and 3. the image culture of digitization deriving solely from mathematical algorithms (Mersch 2006, 407–410).

15 Cf. also the contributions of Flach 2006, 281–302, Hagner 2006, 383–404 and Mersch 2006, 405–429; additionally, Lynch and Edgerton 1988, 184–220. The precarious status of scientific images is closely connected with the precarious status of their referents. "In experiments in high-energy physics," according to Knorr-Cetina, "natural orders are reconfigured as sign-based orders" ["In Hochenergiephysik-Experimenten, werden natürliche Ordnungen als not representations, but "constructed visualizations:" they "do not depict the visible, but make [the invisible] visible" (Heßler 2006, 13).[16] They do not depict reality, but rather produce an "effet de réel" (Barthes 1986, 84), an illusion of reality in which the figuratively constituted reality only appears to align with a natural, material reality.[17] As scientific objects and images no longer refer to external referents – they are "substitutive instances," "supplements" that only simulate the presence of a natural referent (cf. Derrida 1996 [1974], 225) – science itself appears as de-referentialized. Nature is no longer the objective referent of scientific thought. Referentiality thus epistemically configured and construed becomes an intrinsic part of the scientific system and constitutes its self-referentiality. The deconstruction of the representational mode inevitably leads to an epistemological dilemma, for even though referents are actually produced by the technical process of representation, the insights gained from this still give rise to the claim of traditional correspondence, namely that scientists can make *true* statements about *real reality*. Scientific images thus rank not only among the most important factors in the aestheticization of the anaesthetic, but also among the most crucial actors in the production of scientific knowledge.

In addition, the production of visibility is undergirded by institutional units of organization, high-tech machineries, and complex processes and chains of reference comprising the instrumental, personal, and economic infrastructure of the laboratory, with its complex equipment and experimental facilities such

Zeichenordnungen rekonfiguriert"] (2002a, 61), i.e. the objects themselves are already no longer in their "natural state;" they are rather *object-signs* [*Objektzeichen*] (cf. Knorr-Cetina 2002a, 45–46) and thus highly cultivated, staged natural objects (cf. Knorr-Cetina 2002a, 47 and 65). Lyotard, too, points out that "[m]ost of these 'immaterials' are generated from computer and electronics technosciences, or at least from techniques which share their approach" (Lyotard 1996, 162), and he explicitly refers to those digital images as "only produced and not reproduced." Regarding the analysis of digital images, especially their "double existence" as "on-screen appearance" and "encoding" cf. Grube 2006, esp. 186–189.

16 Heßler here refers to the term *visualization* [Sichtbarmachung] coined by Hans-Jörg Rheinberger.

17 This *alignment* necessarily involves a forgetting of the pictorial character of the image – along with the *death of metaphor*. Cf. also Grube, who identifies three aspects of the scientific image: 1. the image as an image *of* something that exists independently of the image; 2. the relationship between the image and its object is constituted by technical recording procedures; and 3. the image reveals reality, it surprises and allows for insights into an otherwise inaccessible phenomenon (Grube 2006, 183 and 195). Unfortunately, with respect to this third aspect, Grube does not provide a plausible answer to the question of *how* a virtual image-object can provide information on a *real* natural object, or in other words, *how* it is at all possible to arrive at reliable findings on the basis of technical mapping processes.

as particle accelerators and detectors, computer systems supplied with programs, data sets and encodings, and, last, but not least, the manifold possibilities of medial recording, simulation, and transformation practices – a systemic aggregate whose specific configuration constitutes what can be seen on screen. In this context, Stefan Ditzen talks about a *image mycelium* [*Bildmycel*] that embodies the "totality of prerequisites of the production of an artificial image" (2006, 56).[18] While the image itself hides the premises and procedures of its generation, and scientific research rarely methodologically reflects these premises and their effectiveness on the findings, the novel does expose this "mycelian" image structure as well as its multilayered referential efficacy.

An episode described in chapter seven explicitly establishes the connection between instrumental or experimental prerequisites on the one hand and scientific visualization and perception on the other. Looking for a spare part, Brahe and his colleague Rüdiger walk past the compartments and shelves of a warehouse. The parts are arranged according to their degree of impact on the visualization process. Without ever glancing back, Brahe and Rüdiger quickly walk past the first shelves, which are filled, among other things, with parts required for the creation of a vacuum, insulation pipes, joints made from various alloys, swivel joints, labyrinth seals, and conduit pipes, because "none of this concerned the detectors or the act of seeing, but only provided the basis for the production of that which might be seen" (cf. LL 71).[19] They slow their pace in front of the shelves "where the parts essential to the visualization process began" (AO 70)[20] and where the scintillator plates, optical fibers, and photomultipliers arranged by type and performance are stored. Finally, they stop between various cards for computer cases, process triggers, speech processors – in short, the parts needed for data acquisition – "the summit of sight" (AO 70).[21] The more valuable the materials become for vision, the more slowly Brahe and Rüdiger walk past the shelves. The path from the basic – though at the same time "blind" – materials to the "summit of sight" coincides with a steady slowing down of the walkers' pace until they finally stand still, indicating that at the "summit of sight" sensory perception is entirely replaced by technological

18 "Gesamtheit der Voraussetzungen an der Produktion eines artifiziellen Bildes" (Ditzen 2006, 56).

19 "tutto questo non riguardava i rivelatori e non era ancora il vedere, ma soltanto la base per produrre quello che forse si sarebbe visto" (AO 69–70).

20 "dove cominciavano i ricambi del vedere" (AO 70).

21 "il culmine del vedere" (AO 70).

equipment.[22] The apparatuses of vision by no means eliminate the subject. On the contrary, as they visualize the unrepresentable for the subject, they allow for an *imaginary* visualization of that which "nobody [...] would ever see with their own eyes."[23] The summit of sight thus also marks the point at which blind sensory perception turns into intellectual-imaginary perception. Humans and technology are not shown as disparate, strongly separated and distinguishable entities; rather, the competences and functions that are associated with each respectively constitute a complex interdependent, interactive, and complementary nexus. Humans and their technologies thus form an integrally organized system, a quasi-organological unit.[24]

In addition, the processes of visualization also include the ways of interactively aestheticizing what is represented on screen – manipulations made possible by continuously evolving image editing software. Whereas the active manipulation of digital images on screen – their *cathartic* treatment – is only briefly mentioned in the novel,[25] the falsification of a machine drawing forms

22 Cf. also Knorr-Cetina, who describes the detector as "a kind of ultimate instrument of perception" ["eine Art ultimatives Wahrnehmungsinstrument"] (2002a, 75).

23 "[...] and only through computer reconstruction from microscopic traces could one tell – with rigor, with proof – what had been generated before it transformed itself immediately into something completely different" (LL 71) ["[...] ma solo dalle tracce computerizzate di ciò che era decaduto avrebbe potuto intuire e immaginare, immaginare con rigore e prova, ciò che si era generato per trasformarsi subito in tutt'altro" (AO 70)].

24 The "waning of the senses" cannot be separated from the gradual waning of the body present which, as Lyotard demonstrates, "appears as *material* carrier of meaning upon which a certain number of codes (feelings, movements) are inscribed" ["als *materieller* Sinnträger erscheint, auf dem mit einer bestimmten Zahl von Codes (Gefühle, Bewegungen) Einschreibungen erfolgen" (1985, 55)]. Consequently, "the relationship between mind and matter is no longer one between an intelligent subject with a will of his own and an inert object. They are now cousins in the family of 'immaterials'" (Lyotard 1996, 165). Knorr-Cetina elaborately describes the connection between human and machine through the example of the mega experiments conducted at CERN. First of all, not just the epistemic objects, but also the epistemic subjects are constructed. Hence, both epistemic subjects and objects are to be viewed as components and products of the technological and social machinery (cf. 2002a, ch. 7 and 8). In turn, the technological machinery is anthropomorphized and individualized in the manner of physiological organisms and social and moral beings (cf. Knorr-Cetina 2002a, ch. 5).

25 Thus the search for a new "trigger level" is carried out "by reducing a series of signals and emphasizing others" (cf. LL 108). Purposefully, "Brahe chooses processes and selects the most spectacular ones" (cf. LL 143); elsewhere, there is mention of the "by now very pure, very clear" (LL 146) images, which appear to Brahe "just like photograms" (cf. LL 194). Brahe is by no means ignorant of the cosmetically produced purity of the images and imputes traces of the morally dishonest to this practice – a fact illustrated by the discomfort he experiences with respect to the purity and morality of wild animals (cf. LL 78 [AO 77]). Cf. Heßler, who explicitly the focal point in a meeting between Brahe and the Nobel Prize winner Wang. This blueprint, the only copy of which is in Brahe's possession, is a design for a machine whose individual parts are being developed by various teams in different countries. Brahe cannot or will not grant Wang's request to leave him 20 centimeters. Therefore Brahe decides to counterfeit the drawing ("contraffare il disegno," AO 24) in such a way that he, with the part constructed by himself, appropriates forty centimeters of Wang's territory so that he can show himself to be generous in his negotiations with Wang and offer him the requested 20 centimeters: "I must, however, pretend to give them to him without actually doing so" (cf. LL 23).[26] His colleague Eileen, although she does not approve of these methods, carries out the forgery. The meeting with Wang – staged as a humorous *intermezzo* – goes entirely according to Brahe's wishes. Wang, as is strongly suggested, sees through Brahe's deception. Nevertheless he plays along and lets Brahe have his victory. Artistic performance, manipulation, deception, and fraud are here presented as self-evident aspects of the scientific game, a game which in the end is not about the personal honor of winning, but about scientific success only achieved through team work. During the meeting, Wang reiterates, almost in the way of a refrain, the following aphorism – which can be regarded as the golden rule of the scientific game:

> "To see, [...] one needs great will and energy before and after, because that which has been produced in order to be seen, one does not see while it is happening. One sees it first as intention, then as result." He stared at Brahe with intensity and said: "You and I see it this way."[27]
> (cf. LL 38)

characterizes these cosmetic procedures as *aesthetic action* ["ästhetisches Handeln"]: "This means that scientific practice is led by the search for patterns, structures, coherence, or for that which falls outside of the given parameters, and that the things supposed to be shown are made to stand out by contrast, color, straightening, and emphasis – manipulations that cover up and marginalize things incidental." ["Dies meint, dass die wissenschaftliche Praxis von der Suche nach Mustern, nach Strukturen, nach Stimmigkeiten bzw. nach Herausfallendem geleitet ist und dass das, was gezeigt werden soll, hervorgehoben wird, indem es schärfer gemacht, eingefärbt, begradigt, betont und scheinbar Nebensächliches überdeckt und marginalisiert wird" (Heßler 2006, 23)].

26 "Peró debbo fare finta di darglieli, senza darglieli in realtà" (AO 32).

27 "'Per vedere [...] ci vogliono grande intenzione e grande energia, prima e dopo, perché ciò che è stato prodotto per poterlo vedere non lo si vede mentre accade: si vede prima come intenzione, si vede dopo come risultato.' Ha fissato Brahe negli occhi con intensità, ha detto: 'Lei e io vediamo cosí'" (AO 39). Evidence is shown as a product that emerges from the conjunction of subjective intention and interpretation on the one hand, and technological application and objectivity on the other, and thus as a mode of reasoning beyond the epistemic discourse. Cf. also Mersch, who describes the epistemic function of images as "*authentication through visualization*" ["*Beglaubigung durch Sichtbarmachung*"] which obtains "validity not through reasons, Whereas the passage quoted at the beginning takes its point of departure from the on-screen display and sketches the generation of scientific findings from the scientific image to its interpretation, the walk through the warehouse as well as Brahe's staged deception are used to examine and indicate the individual stages in the production of visibility (those technologies and interactions that generate the scientific world of objects and are inextricably bound up with epistemic processes).[28] This permits a look into the *intrinsic image* – its beginnings and causes. This intrinsic image visualizes what remains invisible in the "computerized traces" ["tracce computerizzate"] and their further processing, namely the instrumental, technical, and semiotic preconditions of their production. The literary discourse exposes the processes that produce the scientific image – its subsurface mycelium – and demonstrates the relevance of these images for scientific discovery. By doing so, the literary discourse works against the theme that dominates the plot: the disappearance of things, or more precisely: the disappearance of the things themselves as well as of the mechanisms underlying their production *within the epistemic discourse*. Without erasing the boundaries between the natural sciences and literature, the fictional image discourse dissects the scientific image discourse for its hidden technological-constructivist and virtual-artificial elements. Scientific image discourse is thus shown to be an integral implication of scientific discourse. This, literally, brings to light the "viscursivity"[29] by which the physics discourse is increasingly marked and which forms a basic component of its self-referentiality. The novel thus transcends the epistemic viscourse for a meta-viscourse whose

but through evidence" ["Geltung nicht durch Gründe, sondern durch Evidenz"]. Evidence, however – in contrast to argument – is not falsifiable: evidence of the visual relies on that "which is made evident *by itself*" ["was *durch sich selbst* einleuchtet"], it is of a striking conclusiveness (Mersch 2006, 416). Yet evidence is also – and this, too, is implied by the rule formulated by Wang – subject to historical conditions, i.e. "each historical formation sees and reveals all it can within the conditions laid down for visibility, just as it says all it can within the conditions relating to statements" (Deleuze 1988, 59).

28 As is generally known, the warehouse, together with the wax tablet, is one of the central memory metaphors. Stemming from the area of sophistry and rhetoric, warehouse metaphors predominantly relate to mnemonics – to the localization of pictorially represented memory content. The images that are stored in the memory warehouse Brahe and Rüdiger walk through are of a self-referential nature: images that depict the conditions and processes of image production and storing. On memory metaphors, cf. Weinrich 1976, 291–294 as well as Assmann 1991, 13–35.

29 "Viscourses" denote, according to Knorr-Cetina, visual representations that increasingly replace the relevance of "pure" discursive practices for the coordination of scientific experiments – regardless of the fact that they are not only instrumentally and mathematically, but also discursively produced (cf. Knorr-Cetina 1999, 248–249).

epistemological function is the self-enlightenment of the epistemic viscourse. As such, the novel conducts, in the truest sense of the word, an *archeology of knowledge*.

1.2 Epstein's poetological experiment

Epstein's poetological experiment starts from his repeatedly stated observation of the "the disappearance of things" (AO 62):[30] "things have already commenced turning into non-things;"[31] they are on the verge of becoming "pure energy, pure light, pure imagination" (AO 68).[32] The diagnosed loss of the empirical dimension is thus attributed – explicitly, by the primary narrative voice, and implicitly, in the repeated indications by Epstein – to the advances of the natural sciences in the subatomic field and the corresponding unrealization of the object. In this context, the entire plot situated at CERN explains Epstein's talk about the disappearance of things and simultaneously forms the foundation and the point of departure ["[il] dato di partenza,"] (AO 103) for his new aesthetics.[33]

The transformation of materials into "in-materials"[34] requires a fundamental reordering of, and reorientation within, reality, quite literally a new *Welt-Anschauung* able to fathom the changed relation between humans and *things*. Epstein's ethical position as an author is that literature and life are inseparable

30 "scomparsa delle cose" (AO 62).

31 "[L]e cose [...] cominciano ad essere *non-cose*."

32 "pura energia, pura luce, pura immaginazione" (AO 68).

33 In the Epstein plot, the phrase "the disappearance of things" functions as a formulaic reduction of the complex scientific field of objects and activities at CERN. The extrapolation of this phrase makes visible all those processes that are associated with the work there. As the marked point of departure for Epstein's aesthetic experiment, this phrase also points back to the scientific education that Epstein must have received and that is referred to in various allusions.

34 Immaterials, according to Lyotard, are not non-materials; they denote a structure in which the conventional opposition between mind and matter has no place any more (cf. 1985, 23). The term "immaterial" merely expresses "that today – and this change has occurred in all areas – material can no longer be viewed as an object in opposition to a subject. Scientific analyses of matter show that it is nothing more than an energy state, i.e. a nexus of elements that are no longer tangible and determined by structures that each only have a localized validity" ["daß heute – und das hat sich in allen Bereichen durchgesetzt – das Material nicht mehr als etwas angesehen warden kann, das sich wie ein Objekt einem Subjekt entgegensetzt. Wissenschaftliche Analysen der Materie zeigen, daß sie nichts weiter ist als ein Energiezustand, d.h. ein Zusammenhang von Elementen, die ihrerseits nicht greifbar sind und von Strukturen bestimmt werden, die jeweils nur eine lokal begrenzte Gültigkeit haben" (1985, 25)].

and have to be made transparent in their interconnection. Even though his life is being affected by the disappearance of things, Epstein does not hesitate to commence his aesthetic experiment in these radically changed conditions. Yet what does Epstein's experiment consist of?

> Yet there must be a secret connection between the disappearing of things and their visibility, because today I see my stories, I've started seeing them more and more. [...] I used to see my stories while I told them, I would see them as I wrote them down. Now, I see them while looking, I see a story entirely from beginning to end simply by looking. And this [...] is my experiment.[35] (cf. LL 63)

Along with the status of things, both the mode of their perceptibility and visibility, as well as the possibilities of their (literary) representation have fundamentally changed. Before, things, despite their hidden referential complexity, nevertheless showed themselves *as* things. Now, because things are in the process of disappearing, visibility and vision are no longer sensorially and aisthetically bound: the look at the *non-thing* is no longer a look that would be directed toward something "external" to the subject; rather, it is a look of an epistemic-technological kind, an epistemically shaped look, so to speak, directed toward an unformed, yet existent "non-thing:" seeing is "pure immaginazione," pure imagination, [vede[re] mentalmente] (AO 145), *theoria*, thinking through looking.

This is the perspective Brahe and Epstein have in common, this is where science and art coincide. As "pura energia, pura luce" and "pura velocità" (AO 68), waning reality possesses no presence any more; accordingly, it is, as Brahe states, "irrapresentabile" (AO 145). Reality's representability is reduced to forms of pure virtuality and artificiality, to the poietical construction of signs devoid of a referent where any analogous relation is dissolved, "in that peculiar and absolute relationship in which everything was at the same time determined and determinant, himself included" (cf. LL 78).[36]

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35 "Però deve esserci un legame segreto tra la scomparsa delle cose e la visibilità, perché oggi io le mie storie *le vedo*, io comincio sempre piú a vedere le mie storie. [...] prima le vedevo raccontando, le vedevo nel momento in cui le scrivevo, adesso le vedo guardando, vedo una storia compiutamente dall'inizio alla fine semplicamente guardando. E questo, [...] è il mio esperimento" (AO 62–63).

36 "in quella strana e assoluta relazione in cui tutto era simultaneamente determinato e determinante, compreso lui" (AO 77).

In addition, Epstein reflects on language in the same way he considers matter: The waning of things coincides with the vanishing of language:

> I might tell you that a story consists of events, an event consists of sentences, a sentence consists of words, a word consists of letters. And the letter is irreducible? Is it the 'last?' No, behind the letter lies an energy, a tension that is not yet form […].[37] (cf. LL 132)

The surface organization of a conventional narrative is gradually stripped down to its individual formal components, up to the point at which form dissolves into formless energy.

Brahe will not be able to make sense of Epstein's deconstruction of language until he *sees*, for the first time and in the company of his colleagues, the new particles his experiment was designed to detect. As a demonstration of the postmodern destabilization and decentering of the subject, the process of perception and discovery is not only distributed among the members of the experiment, but also integrated in a *distributed* narrative:[38]

> But what would remain unforgettable for Brahe, above all, is the moment he passed suddenly from seeing with his eyes to seeing with his mind. The depth of matter in which there were not only four dimensions, but ten, eleven, and those that were as of yet undiscovered and invisible were so tightly bounded, so curved, so fast and impossible to represent, so unstable that he felt the word 'space' splitting; he heard the letters separating, curling into themselves like swirling cylinders, with inside of them other cylinders and volumes, opening and closing instantaneously; but these cylinders and spheres, and strips and strings and spirals did not give an account of anything, because for all that he saw in his mind there were no images, at least not until the distances and proportions grew larger again and he saw how the dimensions folded into themselves again and disappeared into the four known dimensions, where everything was still manifested in the form of dots, fields, waves, particles, including the particles that they saw for the first time that night […] and it became clear to him that, from this, new objects would emerge,

37 "Potrei dirle: una storia è fatta di avvenimenti, un avvenimento è fatto di frasi, una frase è fatta di parole, una parola è fatta di lettere? E la lettera è irriducibile? È l'ultimo?' No, dietro la lettera c'è un'energia, una tensione che non è ancora forma […]" (AO 129).

38 The narrative perspective, too, follows the principle of increasing multiplication and multidimensionality. The primary narrator narrates things that Mark, one of his colleagues, would always remember, while the things Mark would never forget relate to those both Rüdiger and Brahe would never forget either. The very form of the narrative illustrates the multiple perspectives of the process of seeing, a process moving from the outside to the center, from there to the inside, and from there to various branches and plurals. In addition, this poly-perspective is multiplied by several mirrorings: Rüdiger offers a perspective on Mark and Brahe, Brahe offers a perspective on Rüdiger, etc.

> carrying with them new modes of behavior and perceptions and ways of being and feeling, and he suddenly comprehended what Epstein had already understood, and he felt a tenderness for the patience with which Epstein has striven to come to this point, into the lion's mouth to retrieve the bone [...].[39] (cf. LL 147–148)

This transition is narrated in the form of an epiphany (cf. AO 145–146). The passage deals with the sudden transition from sensorial to mental sight, a change commented on by Rüdiger immediately before with the exclamation "It's so beautiful. It's so incredibly beautiful" (AO 144–145).[40] What's actually seen in this transition refers neither to the on-screen image nor to the part of nature the image is meant to represent:

> [...] but what the disappearing lines left to imagine is the idea of a symmetry, so radical and unexpected that what first appeared as a manifestation of different and separate forces could now be considered as unified under one great law, one single law and the simplest, a law simultaneously of difference and identity, what they saw in this moment, as they were used to seeing, was proof and completion.[41] (cf. LL 146–147)

The *object* that is seen is a law of physics, possibly an early stage of the *Theory of Everything*, a mathematical formula whose symmetry expresses the unification of two forces formerly assumed to be disparate. The point of reference for mental vision is thus an abstract theory experimentally confirmed on the basis of computer-generated traces of a natural process adapted to the laboratory.

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39 "[...] ma soprattutto sarebbe rimasto indimenticabile per Brahe l'attimo in cui passò, come di scatto, da ciò che vedeva con gli occhi a tutto ciò che vedeva mentalmente, la profondità di una materia nella quale le dimensioni non erano più quattro, ma dieci, o undici, e quelle sconoscuite e invisibili erano cosí corte su se stesse, cosí curve, cosí veloci e irrapresentabili, cosí instabili, che sentí spaccarsi la parola 'spazio,' sentí le lettere separarsi e ripiegarsi su se stesse come cilindri vorticanti, con all'interno altri cilindri e volumi aperti e chiusi istantaneamente, ma già volumi o cilindri o lacci o lembi o spirali non davano conto di alcunché, per tutto ciò che vedeva mentalmente in quel momento non esisteva immagine, almeno finché ritornando a distanze e proporzioni piú grandi non percepí il riarrotolarsi delle dimensioni su se stesse, e il loro scomparire all'interno delle quattro dimensioni conosciute, dove tutto si manifestava ancora in modo puntiforme, campi onde particelle, comprese le particelle che loro vedevano per la prima volta quella notte; [...] ed ebbe chiaro che da lí sarebbero venuti i nuovi oggetti, portando con sé comportamenti e percezioni e modi di essere e sentimenti, e capí di colpo ciò che aveva capito Epstein, e provò tenerezza per la pazienza con cui Epstein aveva voluto spingersi fin qui, fin nella gola del leone per prendergli la spina [...]" (AO 145–146).

40 "È cosí bello. Cosí incredibilmente bello" (AO 144–145).

41 "[...] ma a quello che le tracce sparendo lasciavano immaginare, una simmetria cosí radicale e sorprendente per cui ciò che prima appariva come manifestazione di forze diverse e separate poteva essere considerato nell'unificazione di una grande legge, una sola e la piú semplice, una legge simultanea della differenza e dell'identitá, di cui in quel momento vedevano, come erano abituati a vedere loro, la prova e il compimento" (AO 144).

Intellectual sight – although tied to technologically (and thus epistemologically) created traces devoid of a natural referent – is oriented toward scientific insight. In this context, however, scientific insight is bound up in the circularity of *mathesis* and *poiesis*.[42] No longer resulting from traditional empiricism, scientific insight has become *knowledge derived from knowledge aiming at knowledge*.

Sensorial perception and interpretation of images and intellectual sight in the sense of *actual* scientific discovery are inextricably linked, yet still separate. Visualizations do arrange and confirm scientific findings (thanks to their evidence, hypothetical ideas can be transformed into positive knowledge). These findings, however, are *not* oriented toward the images but completely abstracted from them. These mathematical-physical findings belong to an altogether different class of knowledge. They are preceded by a theory that – hypothetically and in the terms of probability – describes and anticipates the new particles and their characteristics, and that ideally is in agreement (as it is in the novel) with the on-screen representations, i.e. with the pictorial translations of measured data based on non-visible events. In contrast to this, the process of making sense of the *images* is tied to the machineries of their creation. This interpretation process analyzes the path from the aesthetic representations on screen to the programs, and from there to the mathematical functions defining the programs: "Thus, a proper understanding of the images necessitates a knowledge of the underlying programs and models that nonetheless appears as a knowledge without correlation, but has to be attributed to higher-order cognition" (Mersch 2006, 418).[43]

In this context, "the devices employed – graphs, diagrams, numbers, text, photographs, or digital images – determine what we see in the scientific images" (Heßler 2006, 32).[44] This question, too, is explicitly posed in the novel: "'Do you want them as a table or as microfiches?' the man at the desk asked.

42 Whereby *poiesis* is no longer bound to the nature of genius, but has already been highly automated and virtualized. According to Lyotard, the creative process rather results from a state of the highest complexity rather than from any activity (cf. Lyotard 1985, 15). The technologies are thus no longer primary means to prove previously established hypotheses, but are capable of executing thought processes and having ideas; they virtually carry out the project of making the whole world a prosthesis of human intelligence (an old Cartesian project), to turn reality into a prosthesis. Technology is science in the form of apparatuses (cf. Lyotard 1985, 58, cf. also 83).

43 "So bedarf es eines Wissens der zugrunde liegenden Programme und Modelle, um die Bilder angemessen verstehen zu können, das gleichwohl als Wissen ohne Korrelation erscheint, sondern der Erkenntnis apperzerpiert werden muß" (Mersch 2006, 418).

44 "die Frage, ob im Erkenntnisprozeß Kurven, Diagramme, Zahlen, Text, Photographien oder digitale Bilder verwendet werden, [entscheidet] darüber mit […], was wir in wissenschaftlichen Bildern sehen" (Heßler 2006, 32).

'Rather as a table, then I see them immediately,' Brahe said" (cf. LL 142; AO 187). The expression "them" here does not refer to any specific object; this highly subtle literary device not only re-addresses the tricky question of reference, but also the question of what happens at the interfaces, i.e. at the transition from one form of representation to another.[45] Thus, a focus is established on the epistemological problem of the correspondence of theory and image, i.e. the question of the effectiveness of different kinds of medial representation on existing or arising theories – "every transition into another form of representation changes knowledge" (Heßler 2006, 32).[46] Conversely, the question is, of course, how the choice between different types of visualization is steered by hypothetical knowledge and its corresponding expectations. The hiatus separating theory and image on the one hand, and the complex and manifold interactions between theory and image on the other, imbues scientific findings with elements of instability, insecurity and *aporia* only to be conceived within an epistemology open toward *negative*, *weak* and *liminal* knowledge.

The beauty of symmetry is grounded in the assumed correspondence of the physical theory and an absent *natural* referent whose virtual traces make its presence (seemingly) evident. Science is thus bound up with aesthetic experience. The images point to the manifold "techno-scientific" ["technisch wissenschaftlichen"] processes of their visualization, without ever referring to their actual origins, i.e. without ever constituting genuine reference. Science and technology – both "*matter of facts*" – reveal themselves as "modes of actualizing the infinity of ideas" (Lyotard 1985, 95).[47] Thus, they become supplements to art.[48]

Epstein's experiment in a new aesthetic results in an aporia: an adequate and authentic *representation* of the *non-cose* is for him only possible in a desensorialized, purely mental mode of seeing, i.e. his new aesthetics is ulti-

45 Cf. Heßler 2006, 32 as well as the contribution by Jochen Hennig (2006, esp. 108–113).

46 "jeder Übergang in eine andere Darstellungsform [...] verändert das Wissen" (Heßler 2006, 32).

47 "Modi, das Unendliche der Ideen zu aktualisieren" (Lyotard 1985, 95).

48 Art shifts from an aesthetics of the beautiful to an aesthetics of the sublime, as has been thoroughly demonstrated by Lyotard. The avant-gardist and postmodern aesthetics of the sublime, however, cannot be conceptualized as the complete other to science: the sublime of the avant-garde is, according to Lyotard, hardly nostalgic in the sense of Romanticism: it is rather directed toward the infinity of the concrete experiments to be conducted than toward a conception of an absolute that has been lost. It is therein that the work of the avant-garde coincides with the contemporary world of industrial techno-science (cf. Lyotard 1985, 99–100).

mately aimed against art and literary language altogether; this aesthetics, however, is counteracted by the novel's discourse.[49]

2 Literary epistemology

The novel offers a look into the "epistemic machineries of knowledge production" (Knorr-Cetina 2002a, 61)[50] – i.e. into the complex organizational structures and procedures of physical experiments, into the technological prerequisites and aesthetic practices of scientific image and object generation, into the ultimately semiological and poietical reconfiguration of natural orders, etc. (cf. Knorr-Cetina 2002a, 61). In doing so, the novel confronts science with its preconditions and methods of knowledge production. Exposing the manifold strategies of knowledge production within their institutional framework, the novel characterizes experimental high-energy physics as a self-referential, autopoietic system. In doing so, the novel by no means denies the professed scientific validity of theoretically as well as instrumentally acquired knowledge. However, it does accord scientifically generated knowledge the status of liminal knowledge.

The epistemological function of the novel is to be found above all in that it brings, in the medium of the narrative, to the textual surface the *subtextuality* of scientific knowledge production, (still) largely repressed within scientific epistemology; it traces back scientific knowledge to the fringes of non-knowledge, and thus exposes the *weak knowledge* encoded in the *hard* and *strong sciences*. In the context of the novel, epistemology as enlightenment also means epistemology as *anamnesis*[51] tied to the epistemological function of critique of consciousness and ideology (the latter in the etymological sense of a

49 What is referred to here, by way of example, is the role of the extradiegetic narrator who proceeds contrary to Epstein's aesthetics of a completely immaterial, literally de-literalized "literature;" also to Epstein's plan of composing an "Atlante della luce."

50 "epistemischen Maschinerien der Wissenserzeugung" (Knorr-Cetina 2002a, 61).

51 This anamnestic understanding of epistemology is supported by the memory discourse that is also established in the novel. Indicative of this discourse are the metaphors of the warehouse, the alphabet, and the atlas: the warehouse stores the instruments of sight which in turn correlate with the orders of perception; the alphabet serves the encyclopedization and ordering of knowledge; and the atlas can similarly be conceived of as a topographical storage of knowledge. It is important to note that through each of these metaphors something is made visible that in conventional scientific practice remains hidden (and, at least partially, has to remain hidden for the sake of scientific efficiency).

critique of the image and of pictorial logic). Epistemology – traditionally the place where the sciences procure knowledge about themselves – occurs in the non-scientific medium of literature.

The novel is primarily undergirded by a *meta-epistemic* interest, i.e. it gives an account of the conditions of the generation of scientific knowledge. The narrative emphasizes exactly those aspects of epistemic procedure that remain hidden in conventional research and are consequently also not made public – namely the technological, theoretical, and aesthetic resources for discursive, viscursive and hermeneutic practices and their relevance for the development of unified fields of knowledge, for the formation of theories and the acquisition of insights. In a nutshell: the novel focuses on everything that happens in the deeper layers and in the vestibules of scientific knowledge production, while it leaves out scientific results in the form of positive, propositional knowledge.[52] This look into the deeper layers reveals the ineluctability of imaginative, literary, and rhetorical moments in scientific discovery, in other words: the fictionality inherent to scientific discovery.[53]

How does the novel transfer science into literature? *Atlante occidentale* is precisely not a fictionalization of propositional results of scientific discovery, but a fictionalization of the fictionality inherent in these results. Fiction, as an actual ingredient of scientific discovery, is the scientific fact the novel recreates in the mode of fiction. This depiction of fictionality as a fact of science is not, however, construed as a *battle of two cultures*, but – to take up a central motif of the novel – as a friendly, jovially-affirmative encounter. The friendliness in the encounter between Brahe and Epstein becomes apparent in their open-minded participation in each other's experiments and in their forgoing of discursive power. On the discursive level of the novel this encounter is a friendly reconciliation and amalgamation of the aesthetic and the epistemic, of things sensorial, fictitious, poetic, and imaginary on the one hand, and of truth, abstract insight, and positive knowledge on the other. This reconciliation of the aesthetic and the epistemic results in the demonstration of both being equally important anthropological constituents of all cultural activity. Literature cannot

52 I was able to confirm – with reference to studies in epistemology and the sociology of science – that the novel gives a very realistic account of scientific practice. However, I would like to point out that the questions the novel poses, i.e. the interrelation of digitized images and scientific results or the role of communicative processes in the generation of scientific consensus, have only been addressed by *official* scientific epistemology since the turn of the millennium.

53 This is intended to mean, of course, the fictionality *in* scientific discovery, not the fictionality of scientific insights.

claim sovereignty over the realm of the aesthetic. By the same token, science cannot claim sovereignty over the realm of the epistemic. The categories of the aesthetic and the epistemic thus appear to be removed from science and art. Separated from their disciplinary entanglements, these categories reappear as resources available to all human beings and constitutive of all cultural activity. As a result, these categories have become but dubious tools for determining the relationship between literature and science.

In this context, I have to get back to the maieutic function of the poetics of the novel. As the novel extrapolates the aesthetic and poietic elements immanent to science and establishes an epistemologically functionalized poetics, it not only demonstrates scientific discovery's reliance on art, but also emphasizes the crucial role of poetology and aesthetics in any scientific epistemology. For it is only an epistemology comprising poetology and aesthetics that is able to enlighten science about its aesthetic and ficticious *other*. This is the seminal point of the novel's epistemological poetics. This poetics does not primarily *discover* and present fictionality as an epistemically hidden fact of science, but introduces aspects of a *methodology* that can be rendered productive for a genuinely scientific epistemology of science capable of addressing science's immanent aesthetic and poetic qualities.[54]

Based on these observations, *Atlante occidentale* can be described – in a manner etymologically adequate – as an "epistemological metaphor." Umberto Eco uses this term to designate an artistic form characteristic of a specific epoch, which, through the "transformation of the concept in Gestalt," reflects "the way in which science [...] views reality" (Eco 1989, 13). The purpose of this metaphor, according to Eco, is to mediate "between the abstract categories of science and the living matter of our sensibility" (Eco 1989, 90). In contrast to this, Del Giudice's novel imitates precisely those elements in science that are non-conceptual, Gestalt-like, figurative, and metaphorical. The novel does not "join the accomplishments of science with the general mood of the times in a manner that makes situations only conceivable by reason accessible through imagery and thus available for emotional participation" (Eco 1989, 414). On the contrary, *Atlante occidentale* reveals iconicity, sensuality, and emotionality as the implied *other* to the hypotheses of reason, an *other* that unfolds its

54 Is it possible, one must ask, to conceive of the aesthetic, ficticious and metaphorical deep structures of science with their specific logics, rules and functions without an aesthetics and poetology of science? And since *episteme* is already practiced in a manner that is also poietic and aesthetic – is it at all possible to think of an epistemology without poetology (the latter, on the one hand, in the sense of a reflection of *ars* and *techne* addressing metaphorical and narrative processes, and in the sense of poietology referring to technical production, on the other)?

ineluctable evidence particularly where science operates in the subatomic, anaesthetic area. As for the novel, one has to distinguish between epistemic and epistemological metaphor: The novel is an epistemic metaphor in that it poetically and narratively thematizes the metaphorical qualities of *episteme*; it is an epistemological metaphor in that it poetologically reveals the poeto-logic inherent in *episteme* and calls for an epistemology no longer exclusive of poetology. The novel, in quite a visionary way, develops and applies within the medium of literature an epistemological poetics. This poetics, in demonstrating that scientific and literary discourse fuzzily overlap with regard to the aesthetic and the fictional, could be seminal to a "general narratics"[55] as postulated by Lyotard, a "narratics" which – from the point of view of the novel – ought for its part to be a component of a general anthropology; "however, this is just the beginning" (AO 85).[56]

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55 The aspect of the aesthetic and the fictional, it should be pointed out once more, does not lead to an amalgamation of the discourses of science and literature, and certainly not to a general discourse identity. On the contrary, this aspect is – on a deeper level – something that is implied within the scientific discourse. The term *discourse identity* should only be used to denote the fuzzy intersection where the aesthetic and fictitious implications of science touch upon the fictionality of literature.

56 "ma questo è solo un punto di partenza" (AO 85).

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Angela Gencarelli

The "Poetic Element" of Science

Particle Physics and the Fantastic in Irmtraud Morgner's Novella *The Rope*

Abstract: In her novella *The Rope* [*Das Seil*] (1973), Irmtraud Morgner questions the degree to which particle physics and its search for the elementary components of matter appear fantastic. This is accomplished through a particular literary technique. Morgner montages entire excerpts of original texts from particle physics in her novella. With this material, the text demonstrates how particle physicists rely on a "poetic element" (Morgner 1993, 141) in the production and representation of what cannot be observed, namely, invisible particles. In this way, the novella produces an effect crucial to its fantastic narrative structure: it causes the concepts of the real and the imaginary to collapse.[1]

1 The fantastic side of modern physics

"Black holes,"[2] "red dwarfs,"[3] "ghost particles"[4] – a cursory glance at current media coverage of various branches of modern physics,[5] such as astronomy or particle physics, gives the impression that physicists deal with fantastic things. In his *Essays on the Fantastic* [*An den Grenzen des Staunens: Aufsätze zur Phantastik*], literary critic and author Martin Roda Becher encapsulates this trend as follows:

> Our deficient imagination is aided when cosmic occurrences of enormous dimensions are projected onto the topography and personnel of fairy tales: there are red dwarfs and blue giants, white dwarfs, who, like Rumpelstiltskin, are suddenly swallowed up, there are the

1 The complete article was translated from the German by Nathan Taylor. All translations from the German and all modifications of published translations are by Nathan Taylor, unless otherwise indicated. At times it has been necessary to leave the original German phrase untranslated to avoid awkward expression.

2 See for example Greene 2012.

3 See for example Skalli 2010.

4 See for example Grolle 2012, 117. In his article, Grolle also uses formulations such as "ghost-like particle tracks" or "ghost-like neutrinos."

5 This term denotes the development of physics since the formulation of quantum theory and relativity theory at the beginning of the twentieth century. Central figures of modern physics such as Werner Heisenberg have used this term themselves. See for example Heisenberg 1959.

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> wide-open gates of hell into which those who aggrandized themselves all too much in their lives disappear; demonic hybrids lurk in the backdrops of the cosmic fairy-tale world.[6] (Becher 1983, 78)

For popular-scientific accounts of astrophysical knowledge, falling back on fairy-tale plots seems obvious, given the terms used by physicists themselves such as "red dwarfs" or "blue giants." At the other end of these efforts to popularize science is a natural science that, according to Elmar Schenkel, is gradually distancing itself from everyday reality, and for this reason seems fantastic:

> What is left is the layperson's perspective on a science increasingly alienated from everyday reality, a science that in its incomprehensible architecture exhibits signs of the fantastic in the sense of closed, labyrinthine worlds. In this sense, one can say, modifying Borges, that modern science is a branch of fantasy literature.[7] (Schenkel 2006, 43)

Modern (natural) science, according to Schenkel, exhibits signs of the fantastic in the sense of the uncanny. Yet Schenkel approaches the "darkside" ["Nachtseite"] (Schenkel 2006, 43) of the natural sciences not only from the perspective of the layperson (Schenkel 2006, 45). To a much greater degree, he exposes "absurdities" ["Absurditäten"] (Schenkel 2006, 45) such as the presumption of "monstrous" ["monströse[r]] black holes in the center of the universe (Schenkel 2006, 41) in the more narrow areas of study in the natural sciences themselves.

The scholarship cited here suggests an entire gamut of fantastic aspects in modern physics and the natural sciences in general. It locates the fantastic in popular-scientific portrayals as well as in texts of the natural sciences themselves and delineates various forms of the fantastic ranging from the fairy-tale-like to the uncanny. In light of the "absurdities" ["Absurditäten"] mentioned here, such as black holes, one could also include phantasms in the sense of the unreal amongst the fantastic elements of modern physics. Sociologist of science Karin Knorr Cetina has drawn attention to this type of the fantastic in her study

6 Transl. by NT. "Unserem versagenden Vorstellungsvermögen wird aufgeholfen, indem kosmische Vorgänge von ungeheuren Ausmaßen auf die Topographie und das Personal eines Hausmärchens projiziert werden: da sind die roten Zwerge und blauen Riesen, die weißen Zwerge, die wie Rumpelstilzchen plötzlich verschluckt werden, da ist das weit aufgesperrte Höllentor, in dem verschwindet, was sich zeitlebens zu sehr aufgebläht hat, und in den Kulissen der kosmischen Märchenwelt lauern die dämonischen Halbwesen" (Becher 1983, 78).

7 Transl. by NT. "Es bleibt der Blick des Laien auf eine zunehmend von der Alltagswirklichkeit entfremdete Wissenschaft, die in ihrer unverständlich gewordenen Architektur Züge der Phantastik im Sinne von geschlossenen, labyrinthischen Welten aufweist. In diesem Sinne kann man, Borges abwandelnd, sagen, die moderne Wissenschaft sei ein Zweig der phantastischen Literatur" (Schenkel 2006, 43).

of laboratories, *Epistemic Cultures: How the Sciences Make Knowledge*, using particle physics and its immediate area of study as an example:

> [T]hese objects [particles] are in a very precise sense ‘unreal’ – or, as one physicist described them, ‘phantasmic’ [*irreale Gegenstände*]; they are too small ever to be seen except indirectly through detectors […]. Finally, most subatomic particles are very short-lived, transient creatures that exist only for a billionth of a second. (Knorr Cetina 1999, 48)

Due to the “vagueness” of “epistemic thing[s]”[8] in physics, Knorr Cetina refers to the particles as “*phantasmatic* […] occurences” (Knorr Cetina 1999, 48; emphasis by AG).

2 Particle physics in Morgner’s prose

Precisely such accounts of the fantastic side of particle physics form the starting point of Irmtraud Morgner’s literary engagement with this discipline. The novels and stories of this author, who gained popularity as a feminist and socialist writer in the German Democratic Republic and also in the Federal Republic of Germany in the 1960s and 1970s, have previously been analyzed with regard to their portrayal of gender discourses and socialism.[9] These analyses have overlooked the fact that Morgner is one of many authors – like Hermann Broch, Bertolt Brecht, and Friedrich Dürrenmatt – who have intensively engaged with modern physics.[10] Beginning in the 1960s, Morgner developed an interest in the basic research of particle physics. As archival documents make clear, Morgner, who lacked any particular educational background in the natural sciences, was employed as a laboratory assistant for several months at the *Forschungsstelle für die Physik hoher Energien* [Research Center for High Energy Physics] in Zeuthen,

8 This concept comes from Hans-Jörg Rheinberger who defines it as follows: “They [epistemic things] are material entities or processes – physical structures, chemical reactions, biological functions – that constitute the objects of inquiry. As epistemic objects, they present themselves in a characteristic, irreducible vagueness” (Rheinberger 1997, 28).

9 See for instance Lewis 1995, von der Emde 2004, Westgate 2002 and Wölfel 2007.

10 My dissertation, entitled *Literarische Realitätsprüfung des Phantastischen: Teilchenphysik und Poetik in Irmtraud Morgners Prosa* [*Literary Reality Checks of the Fantastic: Particle Physics and Poetics in Irmtraud Morgner’s Prose*] (Freiburg i. Br.: Rombach, 2017) examines Morgner’s prose texts in their relation to particle physics, an aspect that has not yet been systematically analyzed. In contrast to Morgner’s work, the authors mentioned and their literary treatments of modern physics have been widely researched. See for example Emter 1995.

near Berlin.[11] The center in Zeuthen was among the few research institutes of the GDR that participated in internationally-oriented basic research in the field of particle physics.[12] As a laboratory assistant at the institute, Morgner was part of a large venture to explore "what holds the world together at its innermost."[13] During her time at the institute, Morgner collected textual materials, including a research report and additional publications by physicists who worked there, from which she interpolated long excerpts as montages in many of her prose texts. Indeed, many of her most notable novels, for instance *Rumba to an Autumn* [*Rumba auf einen Herbst*] (1992), *Wedding in Constantinople* [*Hochzeit in Konstantinopel*] (1968), or *The Life and Adventures of Trobadora Beatrice as Chronicled by Her Minstrel Laura* (2000) [*Leben und Abenteuer der Trobadora Beatriz nach Zeugnissen ihrer Spielfrau Laura* (1974)], feature fictional particle physicists who come up with publishable lectures that borrow from this textual source material in particle physics. Morgner montages the excerpts in the narrative texture of her prose in such a way that particle physics' search for invisible elementary components of matter appears to be fantastic. At the same time, the fantastic aspect of the (re-)construction of reality in particle physics, demonstrated by means of its textual excerpts, is functionalized for the fantastic poetics of Morgner's prose.[14]

3 Particle physics and the fantastic in Morgner's novella *The Rope*

At the center of the novella *The Rope*, published in 1974 in an anthology of prose texts by GDR authors, is a dispute about the ontological status of a "scandalous occurrence" (Morgner 1993, 137):[15] one day Professor Barus, the director

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11 Morgner's hitherto undiscovered biographical connections to this field were brought to the fore with the help of the holdings of the German Literary Archive [Deutsches Literaturarchiv] in Marbach my dissertation (Gencarelli 2017, 15–26).

12 For a history of the institute see Stange 2001.

13 Even today, the institute, which after 1990 was fused together with the DESY Hamburg, still advertises with this Goethe quotation: "Was die Welt im Innersten zusammenhält" (DESY 1998).

14 The fundamental ideas in the following analysis of the novella *The Rope* were developed elsewhere in the context of an essay published in the proceedings of the conference *Tendenzen und Perspektiven der gegenwärtigen DDR-Literaturforschung* (Würzburg, October 2013). Cf. for this Max 2016. See also Gencarelli 2016.

15 The English translation of the novella cited in this essay is that of Nancy Lukens (Morgner 1993), entitled *Third Fruit of Bitterfeld: The Tightrope*. The expansion of the title to include *Third Fruit of Bitterfeld* is due to the fact that Lukens' source text for her translation is the of an institute for particle physics, gets word that his colleague, the physicist Vera Hill, has supposedly made the journey between her home and the research institute by "walking on air" ["gehend in der Luft"] (Morgner 1993, 138). This is what the local residents attest in a complaint that two of their "delegates" (Morgner 1993, 140) deliver to the institute director. The professor, however, believes their "claim" (Morgner 1993, 138) to be a "figment of the imagination" ["Erfindung"][16] (Morgner 1993, 141).[17] When he subsequently confronts the physicist about the incident, she states that she made her way to work on a "rope" (Morgner 1984, 218)[18] making use of "time saving shortcuts" (Morgner 1993, 142). However, the assertion of the physicist contradicts the act of "walking on air" attested to by the residents, who do not report anything about the aid of a rope. Because this "scandalous occurrence," whether "walking on air" or on a rope, is never part of the narrated story but merely an object of the characters' "suspicion[s]," "claim[s]" (Morgner 1993, 138), or "allegation[s]" (Morgner 1993, 142), the reader cannot decide whether it is real or fictitious within the world of the story. At the end of the novella, however, the body of the physicist Hill is nonetheless found "shattered on the lawn in front of the public library" (Morgner 1993, 142).

Scholars have mostly focused on Morgner's novella as an example of her asserted central theme, the oft-cited "the entry of woman into history".[19] In this respect, many studies have called attention to the tragedy of Hill's life: The male dominated field of science forces the female physicist to bridge the gap between her professional work and her housekeeping duties by the risky act of

novella with this title that Morgner montages, nearly unaltered, in her novel *The Life and Adventures of Trobadora Beatrice as Chronicled by Her Minstrel Laura* (hereafter abbreviated as *Beatrice*) as the text of the writer and protagonist Beatrice. In what follows, I also draw on Karen R. Achberger's English translation of the novella (Morgner 1984). All longer citations from the novella are additionally cited in the German original in the footnotes.

16 The meaning of fiction in the sense of a "figment" [*Erfindung*] is central to the concept of fiction, as is well known. See Japp 1995, 595.

17 "Erfindung" (Morgner 1973, 155).

18 Here I follow the translation from Karen R. Achberger since she more precisely translates the central motif of the novella, namely, the rope. Nancy Lukens translates "Seil" as "tightrope." The latter term's proximity to the metaphor of tightrope walking, however, is misleading with regard to a crucial aspect of the novella: the central occurrence of the novella, that is, the physicist Vera Hill's movement through air, is a dubious event in the fiction of the novella. Resolving this fantastic occurrence through allegory in the sense of a balancing act between profession and childcare, an allegory often cited in the Morgner scholarship (see Lewis 1995, 144–150), is challenged by the novella itself; for this reason, the term "rope" is more fitting.

19 Transl. by NT. "Eintritt der Frau in die Historie." Morgner herself used this phrase in interviews to describe the central theme of her prose. See for instance Walther 1973, 49.

"walking on air," causing the death of the female subject.[20] Consequently, the novella's "scandalous occurrence" has been interpreted as an allegory for the proverbial *walk on the tightrope* which has to be performed by the single mother and scientist Hill under conditions of patriarchal society. However, this interpretation of the novella misses several central issues of Morgner's text. First of all, the fantastic event of the novella cannot be explained in terms of the allegorical *walk on the tightrope* alone, since the delegates do not testify to the existence of the rope, but only the act of "walking on air." The very title of the novella, *The Rope*, draws attention to this contradiction. Moreover, the novella itself plays with the metaphorical and literal meanings of "walking on air:" While the local residents report an actual act of "walking on air," the institute director dismisses their claim as groundless *speculation* in the figurative sense of "lofty rambling" ["Luftwandelei"][21] (Morgner 1973, 150). Therefore, the novella itself undermines the merely allegorical interpretation of "Luftwandelei." Secondly, by interpretating the fantastic event in terms of allegory alone, the complex structure of the fantastic in the novella cannot be adequately described. Until the dramatic turning point at the end of the novella and beyond, it is not clear whether the fantastic event is just a product of the imagination of the protagonists (a "figment of the imagination" as initially claimed by the director of the institute), or actually took place within the narrated world. This moment of hesitation about the real or imaginary status of the fantastic event within the story is central to Tzvetan Todorov's definition of the fantastic as a narrative structure.[22] However, the novella undermines Todorov's concept of the fantastic – and this is the third aspect overlooked in interpretations of the novella – by incorporating excerpts from actual texts of particle physics into its discourse on the fantastic.

20 See Jeremiah 2003, 46–47; Lewis 1995, 144–150, Stawström 1987, 99–101; Wölfel 2007, 113–118.

21 By using figurative phrases such as "Luftwandelei," the novella makes use of a conventional technique in fantastic literature. According to Tzvetan Todorov, the first feature of fantastic texts "is a certain use of figurative discourse. The supernatural often appears because we take a figurative sense literally" (Todorov 1975, 76–77). The novella intensifies this technique by leaving open whether the figurative or literal meaning of the expression is valid. [Translator's note: The German expression the professor uses here, "Luftwandelei," not only signals "walking on air" but also carries an implication of lofty speculation. To capture both the literal sense of "walking on air" and the figurative sense of airy speculation, "Luftwandelei" has been translated here as "lofty rambling."]

22 See Todorov 1975, 157.

3.1 Investigations of fantastic matter

The dispute about the ontological status of the fantastic event is situated at an institute dedicated to "researching the atomic structure of matter" (Morgner 1993, 137). Physics in general can be considered *the* yardstick for definitions of the fantastic insofar as it provides information about the putatively real or unreal in terms of accordance or discordance with natural laws.[23] In the novella particle physics, in this case embodied by the professor *and* director of the institute, emerges as an authority for defining what is physically real or unreal. Thus Professor Barus places his "investigat[ion]" of "the *matter*" (Morgner 1993, 140; emphasis by AG) reported by the delegates in relation to the particle physics research on the "atomic structure of *matter*" conducted at his institute. Indeed, as the institute director reads the "written charges" (Morgner 1993, 138) submitted personally by the delegates, he simultaneously delivers a polished academic lecture on the probing of matter in particle physics – this lecture in particular can be traced back to actual text excerpts from the aforementioned research reports of the Research Center in Zeuthen:[24]

> When the two men alluded verbally to the scandalous occurrences and presented him the written charges, the professor said: 'In investigating the structure of matter, it is especially important to study the high-energy interaction between elementary particles. Here we are dealing with those excitations which are least perturbed by secondary effects and hence allow the deepest insight into an elemental process that actually takes place in nature […].' [Barus][25] stopped […]. In any case, it would require considerable effort to refute the claim that a female staff member of his institute was walking on air across town twice a day on weekdays.[26] (Morgner 1993, 137–138)

23 A central reference point for the definition of the fantastic is a narrated event's contradiction of given presumptions about reality, especially the contradiction of natural laws of physics. See Todorov 1975, 41; Durst 2010, 29.

24 (Instituts-)Jahresbericht 1963 der Forschungsstelle für die Physik hoher Energien der Deutschen Akademie der Wissenschaften zu Berlin [(Institute) Annual Report 1963 of The Research Center for High Energy Physics of the German Academy of Sciences in Berlin], Zeuthen, 9 January 1964, Archive of the IfH, 23.

25 In her translation of the novella, Nancy Lukens refers to the version of the text that Morgner montages in her novel *Beatrice* under the name *Third Fruit of Bitterfeld*. Morgner modified her novella only insofar as the institute director is no longer named "Barus" but "Gurnemann." In this essay, I refer to the former proper name of the professor since this follows the first publication of *The Rope* as an independent text in the aforementioned anthology. See Morgner 1973.

26 "Als die beiden Männer die skandalösen Begebnisse in Worten andeuteten und das anschuldigende Papier aushändigten, sagte der Professor: 'Bei der Untersuchung der Struktur der Materie kommt der Erforschung der hochenergetischen Wechselwirkung von Elementarteilchen besondere Bedeutung zu. Hier hat man es mit reinen Wechselwirkungen zu tun, die

Here, the professor engages in a routine practice that he "acquired in the course of his tenure as director," namely the "ability to speak while reading" (Morgner 1993, 138). In order to gain time, he performs two tasks simultaneously, namely reading and speaking. In the situation with the local residents, his remarkable stunt serves as a rhetorically manipulative trick to distract the delegates through inaccessible academic prose and sidetrack them from their complaint.[27] The institute director uses the time gained through his trick to search for an argument to support his thesis that the "scandalous occurrence" is a "figment of the imagination." Even if a seasoned physicist finds it easy to refute the act of "walking on air" as a physically impossible event, he still cannot, despite having "gained time by talking," think of "a convincing argument" (Morgner 1993, 139).

The reasons for this only become clear if one treats the actual particle physics subject matter of the director's lecture, beyond its maneuver of distracting the delegates, as relevant to the line of argument. For the content of the speech on particle physics and the report of "walking on air" become intertwined in a particular way through the simultaneous reading and speaking. This seems evident in how the elaborate trick of the institute director is narrated: the particle physics speech is presented as a digression – in the sense of the rhetorical figure that goes by this name – from the delegates' "written charges [*Papier*]."[28] The moment the institute director receives the "written charges," he immediately begins his lecture (see the quote above) and thereby postpones addressing the actual issue of the "scandalous occurrence" itself.[29] The professor pauses three times while speaking. In these pauses, the narrator reports what Barus has just read in paraphrase or indirect speech, as for instance with "the claim that a female staff member of his institute was walking on air across town twice a day on weekdays" in the example above. Only with the continual explanations of the institute director

durch Nebeneffekte am wenigsten gestört werden und daher den tiefsten Einblick in einen in der Natur wirklich vorkommenden Prozeß erlauben […].' Barus verstummte […]. Jedenfalls war die Behauptung, werktags liefe eine Mitarbeiterin seines Instituts zweimal über den Ort, nur mit Aufwand widerlegbar" (Morgner 1973, 149).

27 The delegates' reaction demonstrates that the trick is not ineffective. At one point, the novella suggests that their faces were "contorted with respect and suspicion" (Morgner 1993, 139). Nevertheless, the institute director fails to dissuade them from demanding compensation for the damages incurred through Hill's purported "walking on air."

28 Hans Esselborn understands digression as a "[r]hetorical figure of divagation from the direct course of speech or narrative" (Esselborn 1997, 363).

29 The fact that the circumstances in the delegates' report are deferred until the pause in speech is illustrated in the following parallel passage: "As he read [the delegates' report] through the lower lenses, he spoke: 'Since the study of the structure of particles […]'" (Morgner 1993, 138; added by AG).

do the delegates’ “written charges” unfold; and it is not “the abundance of material” [“Fülle des Materials”] (Morgner 1973, 151; translation modified) that unfolds but only what is filtered through Barus’ reading glasses. The complete circumstances of the complaint are presented only at the end of the lecture on particle physics and, moreover, are presented only in curtailed paraphrase (see Morgner 1993, 140). Thus the reader is not only temporarily distracted from the actual circumstances through the excursus (here used as a synonym for digression);[30] rather, the particle physics speech is placed in the foreground.[31] Insofar as the excursus in the scientific prose of particle physics takes priority over the issue at hand – the report about the “scandalous occurrence” – it proves to be constitutive for the analysis and cannot simply be ignored.[32]

Central, therefore, is the intertwining of these two issues through the professor’s trick. With the help of this intertwining, he not only outwits the delegates; he also outwits himself to an even greater degree: after he finishes both reading the written documents and delivering his speech on particle physics at the same time, he no longer dismisses the “scandalous occurrence” as ungrounded speculation, as he does in the beginning, but proves in fact to be fascinated by the “absurd report” (Morgner 1993, 139):

> Professor [Barus] could no longer resist the allure of the detailed claims […]. [A]lthough he was already in an excited state from the absurd report […]. What pleased him most was the supernatural aspect of the alleged phenomenon.[33]
>
> (Morgner 1993, 139; translation modified)

30 Esselborn points out that the Latin terms “excursio” and “digressio” are closely related and “im Gebrauch manchmal auch identisch [in use sometimes also identical]” (Esselborn 1997, 363).

31 The communicative situation in this narrative sequence suggests this as well: the professor hardly interacts with the delegates, which is why their presence is forgotten at times. Moreover, they themselves never speak directly; instead, they refer to their written report (see Morgner 1993, 138).

32 While scholars have frequently addressed the novella (see Wölfel 2007, 113–118; Jeremiah 2003; Lewis 1995, 144–150; Strawström 1987, 99–101), the function of the professor’s lecture on laboratory practices in particle physics has not yet been investigated.

33 “Professor Barus konnte sich den Reizen, die von den detailliert geführten Behauptungen ausgingen, nicht länger entziehen […]. Obgleich ihn der absurde Bericht bereits in einen angeregten Zustand versetzt hatte […]. [A]m besten gefiel ihm der überirdische Aspekt des behaupteten Phänomens” (Morgner 1973, 152).

To misread the professor's "excited state" as merely erotic arousal would be to underestimate the professor's intelligence and the role of particle physics.[34] Due to the professor's simultaneous speaking and reading, it seems to be ambiguous to which of the "detailed claims," those of the professor or those of the delegates, the passage above refers. It is obvious that not only the delegates' "absurd report" is meant here because the above passage directly follows the elaborations on particle physics and the complete paraphrase of the delegates' report is offered only later. There is, moreover, good reason to read the "detailed claims" as a reference to the lecture on experiments in particle physics since only the latter, and not the complaint of the delegates, is elaborated upon in detail and in the "abundance of material." Additionally, the formulation "excited state" harks back to Barus' lecture in which, shortly before, he speaks of the "excited states of mesons and nucleons" (Morgner 1993, 139; translation modified).[35]

Through the professor's trick, both the professor as character and the implicit reader become aware of a structural similarity between the read and spoken word, and the trick thus comes to serve an epistemological function: the phrase "supernatural aspect of the alleged phenomenon," with which the professor distances himself from his earlier remarks about the delegates' groundless fabrications, aptly describes both the "alleged phenomenon" of the delegates' report as well as the subject matter of the particle physics lecture, namely, particles that are considered to be elementary components of matter. Particles are *unobservable* entities that require a whole series of experimental procedures in order to appear at all, that is, in order to become a "phenomenon." This is why Professor Barus, after identifying the "investigat[ion] [of] the structure of matter" as his object of study, highlights the necessity of studying particles under controlled laboratory conditions:

> Although it is not yet possible to attain the high energy levels of cosmic rays with artificial particle accelerators, the artificially accelerated or produced particles are preferable for use in these experiments to those produced by cosmic rays, since their natural and initial energies are unambiguously identifiable.[36] (Morgner 1993, 138; translation modified)

34 The narration of Barus' trick constantly carries with it these sorts of erotic connotations (i.e. "allure," "excited state"). For instance, the professor uses the time gained through his trick to ponder Hills' appearance and his affair with her (Morgner 1993, 140–141). These aspects of the novella, while certainly crucial for a gender-theoretical reading, do not however explain why the source material in particle physics is cited at such length.

35 "angeregten Zustände von Mesonen und Nukleonen" (Morgner 1973, 152).

36 "Obwohl man mit künstlichen Teilchenbeschleunigern noch nicht die hohen Energien der kosmischen Strahlung erreichen kann, sind die künstlich beschleunigten oder erzeugten

Insofar as the properties of natural particles are, as we can deduce ex negativo, unidentifiable, “artificial particles” must be generated through experiment. Thus with the help of the “artificial particle accelerators” mentioned, “cosmic radiation,” that is, the natural radiation of particles from space, can be replicated in the laboratory. This, however, does not solve the problem of the particles’ unidentifiability. On the contrary, all further experimental procedures must account for this problem. With this in mind, Barus continues in the second part of his speech:

> Since the study of the structure of particles is carried out essentially by means of scattering experiments, we must also know the exact nature of the particle emitted. Thus the hydrogen bubble chamber which contains only protons as scattering centers is the best-suited detector of particle tracks in scattering experiments.[37] (Morgner 1993, 138–139)

In his remarks here, the institute director again addresses a whole series of problems with experimental practice that result from the unidentifiability not only of natural particles but also of those particles created artificially: if the “structure of particles” is identifiable in “scattering experiments,” that is, in collisions made to occur between accelerated particles and target particles, one must now take the unidentifiable “nature of the particle emitted” into account. In order to eliminate uncontrolled collisions with unknown particles, the professor recommends the “hydrogen bubble chamber” because it contains only known protons as “scattering centers.” The hydrogen bubble chamber thus serves a double purpose. On the one hand, the apparatus, filled with liquid hydrogen, provides target particles for a ray of accelerated particles directed into the apparatus, allowing accelerated and collider particles to interact with each other. On the other hand, it acts as a “detector of particle tracks” and thus serves to make the interactions visible. By explaining that particles merely leave “tracks” in the detector, the institute director emphasizes the fact that particles remain invisible to the human eye even after they are created and represented in the experiment. The experimental design, however, does not end with this implied visualization of particles in the detector. In the third part of his speech, the professor extensively discusses the complex reconstruction and identification of particle tracks on photographs from the detector:

Teilchen denen der kosmischen Strahlung für solche Untersuchungen vorzuziehen, da bei ihnen Natur- und Anfangsenergie eindeutig bestimmt sind” (Morgner 1973, 149).

37 “Da die Untersuchung der Teilchenstruktur im wesentlichen durch Streuexperimente erfolgt, ist es darüber hinaus notwendig, die Natur des gestoßenen Teilchens genau zu kennen. Daher besitzt die Wasserstoffblasenkammer, in der nur Protonen als streuende Teilchen vorhanden sind, die besten Eigenschaften als Teilchen- und Spurendetektor bei Streuexperimenten” (Morgner 1973, 150–151).

> Frau Doktor Hill's department[38] is studying films of the interaction between positive pi-mesons with 4 GeV energy in hydrogen bubble chambers. Currently she is dealing with two-armed events. First, she calculates the geometry on the computer. Then the events are studied for completeness with the help of a probability test, using the so-called Fit-Program.[39] (Morgner 1993, 139)

In order to identify particles using their photographed tracks, a complex procedure with many reconstructive steps is necessary. In this procedure, the problem of finding evidence for the existence of invisible particles remains. Drawing on a broader knowledge of experimental practices in particle physics, one could, in the context of this passage, add that a particular type of particle, namely neutral particles that are not electrically charged, complicates the analysis of "scattering experiments." If the "Fit-Program," for instance, is meant to test whether particles retain their charge in collision, and if this is what leads to the conclusion that neutral particles have been created,[40] then it becomes clear that the identification of natural particles does not rest on observable "tracks" but on the mathematical calculation of their possible effects on other particles. In this way, these neutral particles not only make the identification of particle tracks laborious and complicated; they are also difficult to detect themselves. Barus addresses this explicitly when he speaks of the "disadvantage in the fact that neutral particles leave no tracks" (Morgner 1993, 139). We can conclude from the professor's lecture that in order to solve the problem presented by these and other unobservable particles, experimentation in particle physics resorts to complex tricks and ploys to create, visualize, and reconstruct invisible particles.

Against the backdrop of these observations, Barus' description of the "supernatural aspect of the alleged phenomenon" can be understood more precisely with regard to particle physics. Particles exhibit a "supernatural aspect" insofar as they are fictitious things in more than one respect: prior to the implementation of experimental procedures, particles are fictitious in the sense that

38 Morgner modified the original text passage from the research report of the Institute in Zeuthen at this point in Barus' lecture. Along with the formulation that the professor uses to describe Vera Hill's tasks, Morgner truncated the original passage on the evaluation of the photographs from the bubble chamber and shifted the tense from the simple past to the present.
39 "Die Abteilung von Frau Doktor Hill untersucht Filmaufnahmen der Wechselwirkung von positiven Pi-Mesonen mit 4 GeV Energie in Wasserstoffblasenkammern, augenblicklich beschäftigt sie sich mit den zweiarmigen Ereignissen. Zuerst wird die Geometrie auf der Rechenmaschine gerechnet. Dann werden die Ereignisse mit Hilfe des Wahrscheinlichkeitstests, dem sogenannten Fit-Programm, auf ihre Vollständigkeit untersucht" (Morgner 1973, 151–152).
40 In this context, see Kundt and Lanius 1964, 266.

they are “assumed” things.[41] Because they remain inaccessible to the human eye without experimental apparatuses, their existence can initially be postulated only hypothetically. When, in a next step, particles are created using experimental apparatuses, they are fictitious in the sense of something formed or shaped [*etwas Gestaltetem*].[42] For instance, they leave behind evidence of their existence in the apparatus of the particle detector and in this way prove to be formed [*gebildet*] or shaped [*gestaltet*] by an optic medium. Notwithstanding the variety of experimental procedures that tackle the difficulty of visualizing unobservable particles, particles in themselves remain fictitious in the sense of imagined or envisaged things.[43] Indeed, to the extent that they are created and made visible in apparatuses, they leave evidence of their existence; but this evidence is nothing more than “tracks.” Particles are thus not objects of empirical observation in themselves; they are, rather, generated only through apparatuses. The fact that particles in themselves are only accessible in and through the imagination is illustrated in particular through the neutral particles mentioned several times in the professor’s lecture (Morgner 1993, 151, 152). Since neutral particles leave no visual indication of their existence at all, they exist solely in the imagination. Such particles, as well as fictive-imaginary particles in general, approximate fiction in the sense of a “figment of the imagination [*Erfindung*]” (141).[44] It is precisely in this sense that the lecture of the institute director converges with the delegates’ report on the “scandalous occurrence.” The fantastic event no longer stands diametrically opposed to the events of particle physics – the interactions between particles are also distinctly referred to as “events” (Morgner 1993, 139) – along the lines of an unreal phantasm over here and physical reality over there. Rather, both events are connected by a fictive-imaginary moment. The institute director firmly distinguishes between this moment and a phantasm removed from reality. For by finding pleasure in *both*

41 According to Uwe Japp, the terms “assumption” and “hypothesis” belong within the spectrum of meaning of the concept of fiction, though he classifies these terms as “pragmatic fiction” as opposed to literary fiction (Japp 1995, 40).

42 Japp in particular emphasizes these semantic components of fiction in the sense of “Bildung” and “formation [*Gestaltung*]” (Japp 1995, 48).

43 According to Lötzsch, the concept of fiction (more precisely: the Latin *fictio* or *fictum* and the verb *fingere*) encompasses the “activity of forming [*Bildens*], of composing [*Dichtens*], of *representing* [*Vorstellens*], of designing, and therefore the product of this activity, the fabrication, the fictitious assumption, the *imaginative* construction” (Lötzsch 1972, col. 951; emphasis by AG). On the overlaps and differences between the concepts “fictitious” and “imaginary,” see Stierle 2001, 380–381.

44 As already mentioned, the meaning of fiction in the sense of a “figment” [*Erfindung*] is central to the concept of fiction. See Japp 1995, 595.

"alleged phenomen[a]" through his trick of reading and speaking, the professor treats neither the act of "walking on air" nor the invisible particles as mere "lofty rambling [*Luftwandelei*]," that is, as groundless fantasizing. By intertwining the events of particle physics with the fantastic event of "walking on air," he comes to a broader understanding of their similarities. In another passage he thus comes to specify the fictive-imaginary "aspect" as follows:

> To be sure, [Barus] did not deny a *poetic element* to scientific thinking, but he did not think Hill any more gifted than himself, because neither could get along without sensory *auxiliary constructions*.[45] (Morgner 1993, 141; translation modified, emphasis by AG)

Not only must physicists be as "gifted" as artists; with the help of their imagination they design "sensory auxiliary constructions [sinnliche Hilfskonstruktionen]" – particles – that enable knowledge of the real. "In investigating the structure of matter," that is, for their exploration of the real, particle physicists rely on imaginary "auxiliary constructions" since particles themselves are accessible only through imagination. However, as Barus' lecture illustrates, particles are treated as real entities in the epistemic practice of particle physics; specifically, as the smallest material components of the real. The necessary recourse to imagination applies to Hill's scientific task in particular since she works at this intersection of the real and the imaginary. Her task, as the professor explains in the third part of his speech, is to reconstruct and identify particle tracks in the photographs from the particle detector. Hence, she reconstructs the real "tracks" that particles leave behind in an apparatus and from this extrapolates the fictive-imaginary components of the real. The scientific activity of both particle physicists involves a "poetic element" to the extent that they must imagine unobservable particles with the aid of fantasy. If the institute director determines that neither he nor Hill can forego the products of imagination, then, starting from the assumption of this "poetic element" of particle physics, he also treats Hill's act of "walking on air" as an imaginary "auxiliary construction." Therefore, one can conclude on a textual level exceeding the perspective of the protagonists, that the fantastic is not a phantasm removed from reality but an imaginary "auxiliary construction" for the exploration of the real.

The novella, however, does not end on this definition of the fantastic. Rather, it collapses the distinction between reality and imagination entirely: when the professor asks the physicist about the "scandalous occurrence," Hill makes use of an

45 "Barus sprach zwar wissenschaftlichem Denken das *poetische Element* nicht ab, hielt aber die Hill nicht für begabter als sich, weil beide sinnlicher *Hilfskonstruktionen* nicht entraten konnten" (Morgner 1973, 154; emphasis by AG).

“auxiliary construction” but one that functions differently than Barus expects: “[S]he explained to him that without the time saving shortcut on the *rope*, she would not be able to complete her postdoctoral study by the agreed date” (Morgner 1993, 142; translation modified).[46] While the institute director declares the act of “walking on air” to be an imaginary “auxiliary construction,” the physicist, by contrast, employs only the rope as such. The fact that Hill paraphrases the act of “walking on air” as a “rope trick [*Seiltrick*]” (Morgner 1984, 218), makes clear that the “rope trick” is not meant to be taken literally. For in its meaning as a ruse or ploy, “trick” implies the act of faking [*fingieren*]. The rope is therefore an aid used to link the act of “walking on air” to a vivid but imaginary *concretum*. Hill thus uses the “rope trick” as a *mental bridge* [*Denkbrücke*] through which she attempts to make her balancing act between profession and family tangible to the institute director.[47] With regard to the ontological status of the fantastic event, Vera Hill’s act of “walking on air [*Luftwandeln*]” would thus be real (within the fiction of the novella) and the rope simply a fictitious “auxiliary construction.” This would also explain why the local residents do not see the “auxiliary construction,” the rope, and simply report Hill’s “walking on air.” Yet the ending of the novella and its drastic turning point contradicts this resolution of the fantastic event:

> [Barus] spoke earnestly and at length with her about the unreality of this means of transportation. On the following day Vera Hill lost her balance on her way home. The lamplighter discovered her body, shattered on the lawn in front of the public library.[48]
>
> (Morgner 1993, 142)

46 “[S]ie erklärte [ihm], ohne den zeitsparenden Weg über *das Seil* die Habilitation nicht zum vereinbarten Termin fertigstellen zu können” (Morgner 1973, 157; emphasis by AG).

47 For instance: “After work, when she had done the shopping, picked up her son from kindergarten, fixed supper, eaten, drawn pictures of cars and other items requested by her son, bathed him and tucked him in bed with a fairytale, also done dishes or laundry, or mended a hole or chopped wood, and had carried coal briquets up from the basement, then she was able, with the tightrope trick, to be back at her desk thinking about invariances by about 9:00 P.M. Without the trick, an hour later” (Morgner 1993, 142). [“Wenn sie nach Arbeitsschluß eingekauft, den Sohn aus dem Kindergarten geholt, Abendbrot gerichtet, gegessen, Autos und andere Wunschbilder des Sohnes gemalt, ihn gebadet und mit einem Märchen versehen ins Bett gebracht, auch Geschirr und Wäsche gewaschen oder ein Loch gestopft oder Holz gehackt und Briketts aus dem Keller geholt hätte, könnte sie mit Seiltrick gegen einundzwanzig Uhr am Schreibtisch über Invarianzen denken, ohne Trick eine Stunde später” (Morgner 1973, 157).]

48 “Barus sprach lange inständig zu ihr über die Unrealität der Verkehrsverbindung. Anderntags verlor Vera Hill die Balance. Der Laternenanzünder entdeckte ihren Körper zerschmettert im Vorgarten der Volksbücherei” (Morgner 1973, 157).

These last sentences present the death of the physicist as an undoubtedly real event and thereby turn the culmination of an uncertainty about the undecidability between the imaginary and the real into the novella's actual "scandalous occurrence:" though Barus continues to believe in the "unreality" of the female physicist's movements through air, Hill dies traveling "by air" between her place of work and her home. The formulation that Hill "lost her balance" and that her body was found "shattered" seems to suggest that she must have lost her balance walking along the rope as a sort of tightrope walker. According to this logic, what would count as real is Hill's act of walking on the rope and not the local resident's claim of "walking on air" without a rope. But precisely the seemingly negligible evidence of the rope, upon which nothing less than the title of the novella rests, contradicts such a reading. If the rope were a real-within-the-fiction "auxiliary construction," then the residents of the town would have seen not only Hill's "garters" (Morgner 1993, 140) but – above all – the rope. Even an allegorical reading of the ending of the novella – which would bring the vacillation to an end – is dubious for it would take neither the act of "walking on air" nor the rope literally, and for this the text plays too repeatedly and conspicuously with the question of whether the literal or figurative meaning of "*Luftwandelei*" and of "rope trick" is meant.[49] If one were nevertheless to read the end of the novella allegorically, its last sentences would lead such a reading *ad absurdum*: Physics (embodied by the professor) would consequently deal a death blow to art (in the figure of the tightrope walker Hill) wherein the former convicts the latter of unreality. But this conclusion is not plausible for a narrative that aims to show, through an excursus on particle physics and its investigation of the material components of reality, that the fantastic is precisely *not* an unrealistic phantasm. In short: the stunt with the rope is the trick that suspends the "scandalous occurrence" in an inner-fictional tension between the real and the imaginary.

3.2 Fantastic and realistic devices

The novella thus presents *both* its central tricks, that is, the stunt with the rope and the professor's rhetorical stunt, as artistic devices [*Kunstgriffe*] and thereby

49 As already mentioned, the local residents take the "*Luftwandelei*" literally and speak of "walking on air" while the institute director initially dismisses it in its figurative meaning as lofty fabrication. The situation is similar with Vera Hill's "rope trick." Hill uses the rope as a rhetorical trick which Barus subsequently takes literally.

draws attention to its artistic or literary technique.[50] On the level of plot, it is primarily a question of the *rhetorical* devices that the characters require. Through his excursus, the professor wants to distract the delegates with the disciplinary prose of particle physics, and gain time by simultaneously reading and speaking; Hill utilizes the rope as an “auxiliary construction” in order, in a very real sense, to build a mental bridge for the director. The artistic devices function in exactly opposite manners: the “rope trick,” whether real or verbal, creates a short cut and saves time, while the digression on particle physics takes a detour and prolongs time. Along with these pragmatic functions,[51] the artistic devices are meant to serve an epistemological purpose as well: Hill wants to give Barus a leg up with her “rope trick;” by simultaneously reading and speaking, the institute director brings thought into an “excited state.” On the formal level, the particle physicists’ tricks are *poetic* devices. The “rope trick” is a fantastic device to the extent that it brings the real and the imaginary into tension with one another, a tension that remains irresolvable even after the novella ends. The excursus on particle physics is, on the contrary, a realist device. The excursus on empirical-physical reality disrupts the direct trajectory of the narrative by interpolating real bits of text from the field of particle physics into *The Rope* as “reality particles,” as it were.

The parallelization of both artistic devices allow for certain conclusions about the fantastic narrative structure of the novella. According to its conventional definition, the fantastic conflicts with the real and does so insofar as it contradicts physical laws of nature.[52] In the novella, however, the fantastic is structured more complexly, precisely because it takes the physically real as a central reference value for fantastic discourse and incorporates it in the form of an excursus on particle physics. The example of particle physics makes clear that the investigation of the physical components of reality cannot dispense with a fictive-imaginary element. What is more: knowledge of the structure of physical reality proceeds through fiction, namely, through fictive-imaginary particles. In this way, the imaginary and the real are inextricably bound to

50 Shklovsky’s concept of technique leads in this direction: “By ‘works of art,’ in the narrow sense, we mean works created by special techniques designed to make the works as obviously artistic as possible” (Shklovsky 1965, 8). The term that Shklovsky uses here, “priëm,” has been translated elsewhere as “device.” See Shklovsky 1990.

51 With their respective tricks, both particle physicists attempt to confront a dual burden in their everyday lives. Barus faces the dual burden of his role as director of the institute and his profession as a researcher; Hill faces the dual burden of her profession and raising children.

52 See note 23.

one another in particle physics. In multiple ways, *The Rope* thus sublates any dichotomy between the real and the imaginary: the trick with the rope is a fantastic device that leaves open whether the "scandalous occurrence" is real or fictitious within the story so that the opposition between the two must ultimately be surrendered. This conclusion is made all the more plausible through the excursus on particle physics, a science which collapses this dichotomy as well, since it investigates fictive-imaginary things that it affirms as foundational components of physical-material reality. And not only does the content of the textual material from particle physics sublate the boundary between reality and fiction; through the montage of real text elements into the fictional text, the realist or precisely the documentary technique also transcends this distinction. The excursus on particle physics is thus integrated into the novella, on the higher level of a structural similarity to the fantastic, insofar as both particle physics and the fantastic inextricably bind the real and the imaginary to one another and thereby subvert the boundary that separates them. This conclusion can be illustrated through the metaphorics of the path at play in the text's artistic devices, namely, the bridge shortcut and the prolonging detour: the fantastic device offers a direct path to the sublation of the dichotomy between the real and the imaginary in literary fiction whereas the realist-documentary device leads, via a detour through particle physics, to the same outcome; the difference is that the latter subverts this dichotomy by means of textual material concerning empirical-physical reality. The ironic thing about these artistic devices, therefore, is that they turn the novella *The Rope* into a fantastic narrative with an excursus on the seemingly fantastic concept of reality at stake in particle physics.

3.3 The epistemological potential of the novella

By montaging actual text passages from particle physics, whose concept of the real turns out to be fantastic, the novella aims to extend the text-immanent vacillation between the real and the imaginary beyond the boundaries of the fictional text and into the extra-fictional reality of the reader. It becomes clear that Morgner favors a form of the fantastic that transposes the concepts of the real, the fictitious, and the imaginary into one another – or, as Gerhard Bauer puts it: "A favorite technique of advanced literary fantasy is the disarrangement of concepts" (Bauer 2000, 256). With its disarrangement of concepts, Morgner's text no longer fulfills the conventional definition of the genre of the fantastic, as developed for instance by Tzvetan Todorov.[53] Robert Stockhammer articulates this for twentieth-century fantastic literature in general: “In the twentieth century, there is no longer any fantastic literature that *adheres to Todorov’s definition* – or, if such literature still exists, then it is evidently not at the height of its time” (Stockhammer 2000, 25; emphasis in original).[54] Stockhammer attributes the end of fantastic literature as defined by Todorov to the blurring of the “basal distinction between […] ‘the real’ and ‘the imaginary’” (Stockhammer 2000, 24),[55] that is, to the fact that “reality itself […] has become fantastic” (Stockhammer 2000, 25).[56] On the one hand, however, Morgner’s novella demonstrates that an advanced literary fantastic still exists – and even Stockhammer still assumes that a “contemporary modern literature with […] fantastic aspects” (Stockhammer 2000, 25)[57] exists. On the other hand, the fantastic in *The Rope* indeed stands at the “height of its time” as the novella illustrates how the real becomes fantastic through the example of a physical “reality science.”[58]

In this way, *The Rope* sets itself apart from the observations of literary and cultural studies as well as those in the sociology of science on the fantastic objects that particle physicists study. For the novella generates a distinct knowledge of the fantastic in particle physics by offering a glimpse into the poetic side of knowledge production in the field. Insofar as the novella focuses on the importance of “figment[s] of the imagination” in the physical exploration of reality, it achieves an “epistemological dimension” [“epistemologische Dimension” (Klinkert 2010, 21)]. Literature in general, and this applies to Morgner’s novella in particular, “does not normally produce scientifically-valid, new knowledge of the world, but it can engage with existing knowledge and scientific principles to

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53 According to Todorov, the uncertainty of a reader about inner-fictional actuality is a central aspect of the literary fantastic (Todorov 1975, 157).

54 Transl. by NT. “Es gibt im 20. Jahrhundert keine phantastische Literatur mehr, *die Todorovs Bestimmung entspricht* – oder wenn es sie noch gibt, so ist sie offenbar nicht auf der Höhe ihrer Zeit” (Stockhammer 2000, 25; emphasis in original).

55 Transl. by NT. “basale Unterscheidung zwischen […] ‘Realem’ und ‘Imaginärem’” (Stockhammer 2000, 24).

56 Transl. by NT. “Wirklichkeit selbst […] fantastisch geworden ist” (Stockhammer 2000, 25).

57 Transl. by NT. “zeitgemäße moderne Literatur mit […] fantastischen Zügen” (Stockhammer 2000, 25).

58 I borrow this term from Holger Wille, who uses it to describe physics in general (Wille 2003, 343).

generate a meta-knowledge" (Klinkert 2010, 21),[59] as Klinkert puts it. The epistemological potential of Morgner's prose text can be seen in the fact that the novella attributes a different type of the fantastic to particle physics than do the scholars cited above, namely, a version of the fantastic that cannot be grasped with the language of the uncanny (e.g. "monstrous" black holes), of the fairy-tale-like (e.g. "red dwarfs"), or of phantasms (e.g. "ghost particles" as "fantasmatic occurences"). Morgner's novella offers the reader the knowledge that the fantastic side of particle physics, and by extension fantastic literature as well, cannot be dismissed as unreal "*Luftwandelei*," in the sense of groundless speculation or phantasm, but rather that the "figment[s] of the imagination" in particle physics and in the literary fantastic alike may be considered as "auxiliary construction [Hilfskonstruktion]" that underwrite knowledge of the real.

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59 Transl. by NT. "Literatur erzeugt in der Regel kein wissenschaftlich valides, neues Wissen von der Welt, doch kann sie in der Auseinandersetzung mit vorhandenem Wissen und wissenschaftlichen Prinzipien ein Metawissen erzeugen" (Klinkert 2010, 21).

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Dirk Vanderbeke

Possible Worlds

Fantastic Science and Science in Fantasy

Abstract: Taking J.B.S. Haldane's aphorism, that the universe may be queerer than we can suppose, as a guiding idea, the paper discusses literary works which openly or implicitly employ phenomena and concepts of quantum physics and are, thus, irreconcilable with our everyday experiences. Four kinds of texts will be touched upon: a) Fantasy, b) so-called quantum fiction, c) didactic texts which draw on fantastic literature to explain physics, and d) some works of mainstream literature that include more or less bizarre phenomena which may trigger associations with aspects of physics. While fantasy appears to be surprisingly conservative in the creation of alternative realities and unexpected physical phenomena, quantum fiction introduces quantum terminology and usually some of the wilder theoretical hypotheses into the stories, albeit frequently merely as devices to produce fantastic events or to add a scientific flavor to otherwise unremarkable fantastic texts. *Didactic fantasy* in the wake of George Gamow's Mr Tompkins books tends to be rather repetitive and far less able to productively engage the reader's imagination than the original fantastic works like *Alice in Wonderland* or some mainstream novels and stories which do not explain unexpected or bizarre phenomena. They, thus require the reader to actively participate in the construction of fictional worlds which may or may not be informed by quantum theoretical concepts.

1

The history of science in the twentieth century is riddled with aphorisms that indicate the incomprehensibility of findings and discoveries, in particular in the field of physics. In an earlier publication (Vanderbeke 1995, 42–45), I have called those aphorisms *kōans*, because I think that they share some qualities with the puzzling stories, anecdotes or questions used in Zen practice. The scientific *kōans* are usually short, sometimes funny or contradictory, and they present us with an unexpected perspective that allows for extended contemplation. Examples are the statements attributed to Niels Bohr: "Anyone who is not shocked by quantum theory has not understood it", and "Your theory is crazy but not crazy enough to be true" (Gribbin 1985, 5 and 254).

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There is also the litte anecdote told by Bohr and recorded by Heisenberg.

> One of our neighbours in Tisvilde once fixed a horseshoe over the door to his house. When a mutual acquaintance asked him, 'But are you really superstitious? Do you honestly believe that this horseshoe will bring you luck?' he replied, 'Of course not; but they say it helps even if you don't believe it.' (Heisenberg 1971, 92)

Various versions of such *kōans* circulate through publications and the internet, and sometimes they are attributed to various physicists; in consequence, the source is not easily identifiable. For example, in George Gamow's *Thirty Years that Shook Physics: The Story of Quantum Theory*, it is no longer a neighbor who puts up the horseshoe and offers the surprising explanation but Bohr himself (Gamow 1985, 57–58). The best example is possibly the famed aphorism about our ability to grasp our universe – or rather our insurmountable inability to do so: "Not only is the universe stranger than we think, it is stranger than we can think." It exists in slightly different versions and has been attributed to various famed physicists like Heisenberg (e.g. Paulsen 2015, vii) or Eddington (e.g. Glendenning 2007, 1). I don't know whether any of those physicists actually uttered or wrote one of these variants, but there is a verifiable source, an essay by J.B.S. Haldane, one of the most important biologists of the last century: "Now, my suspicion is that the universe is not only queerer than we suppose, but queerer than we *can* suppose" (Haldane 1932, 286).

The title of the essay, *Possible Worlds*, of course suggests that, indeed, more than one world is possible, and Haldane conducts something akin to thought experiments concerning our views about the world:

> I propose therefore to see what light, if any, can be thrown on some of our assumptions by considering whether a plausible world or a coherent experience might not exist in which they are not fulfilled. (Haldane 1932, 261)

Most of the scenarios he discusses are based on altered senses and perception, i.e. how would a being construct the world of its experience if it were intelligent, but restricted to the sensations and stimuli of a dog, a social insect, or a barnacle. Interestingly, some of his examples have since then become the basis of fantastic literature or fables. A protagonist who is able to analyze smells to a degree similar to a dog has been imagined in Patrick Süskind's *Perfume*, and the motif is also included as one of the temporary abilities of Saleem in Salman Rushdie's *Midnight's Children*. The world of social insects, governed chiefly by notions of obligation and duty, has been used by T. H. White in *The Book of Merlin* as a parable of fascism and the mindless obedience required by totalitarian systems.

Some of Haldane's thought experiments, however, touch upon physics. He briefly describes a universe with a "Riemann's or elliptical space, in which all coplanar lines meet once" (Haldane 1932, 261). Looking up he would see the soles of his shoes, and looking round he would be able to "see every point of the place, and most of them from both sides" (Haldane 1932, 261). Haldane might have mentioned that this is also one of the underlying principles of cubism, i.e. presenting an object from several perspectives at once. He does, however, add that "every mathematician with a visual imagination can do this, and Einstein has left common sense space in a badly damaged condition" (Haldane 1932, 261). What we find in this short depiction of an unfamiliar and bewildering world is basically the radicalization of a physical property of our universe that now becomes noticeable on the scale of human perception – I will return to this explanatory strategy later.

All this is, to some degree, fantastic but it is, nevertheless, still fundamentally grounded in a world that is compatible with our notions of reality. Haldane then proceeds beyond these notions and suggests that

> Heisenberg and Born in Germany, and Dirac in Cambridge, are busily clearing away these vestiges of common sense. In the world of their imagining even the ordinary rules of arithmetic no longer hold good. The attempt to build up a world-view from the end which common sense regards as wrong, is, at any rate, being made, and with very fair success. (Haldane 1932, 284)

His essay then ends with the *kōan* quoted above, and a reference to *Hamlet* with the suggestion that "there are more things in heaven and earth than are dreamed of, or can be dreamed of, in any philosophy," which is presented as the conclusive reason why Haldane had no philosophy and must be excused for his dreaming (Haldane 1932, 286).

Haldane writes of the possible but counterintuitive world that quantum physicists *imagine*. Similarly, John Bell in 1986 presented a paper at the Nobel Symposium titled *Six possible worlds of quantum mechanics*, in which he writes:

> To what extent are these possible worlds fictions? They are like literary fictions in that they are free inventions of the human mind. [...] Literary fiction [...] can be professionally good or bad (I think). We could also consider how our possible worlds of physics measure up to professional standards. (Bell 1988, 195)

I assume that the number of possible worlds in quantum physics has increased rather than decreased over the decades since Bell wrote this paper. Both terms, "inventions" and "fictions," of course, indicate this plurality of possible worlds. The nature of the physical world is no longer discovered but constructed in accordance with theoretical premises and experimental results which are not conclusive but allow for different interpretations.

For this chapter I want to take the aphorism quoted above as my guiding idea and look at the way fantasy and imagination are employed in literary works to create counterintuitive worlds. In recent decades, various literary works and even whole genres or subgenres have responded to the theories of modern physics and professed a correspondence between these scientific concepts and the literary imagination. I will touch upon four different kinds of texts: Fantasy, so-called quantum fiction, didactic texts which draw on fantastic literature to explain physics, and some works of mainstream literature that include more or less bizarre phenomena which may trigger associations with aspects of physics.

2

By definition, the fantastic is a literature which includes at least one element that is incompatible with scientific knowledge. Fantastic realms or worlds into which fantastic elements intrude could thus be regarded as thought experiments which tinker with the physical laws of our universe. When we look at actual works of literary fantasy, however, it is remarkable how conservative the physics of the imaginary worlds mostly is. The basic physical laws of our environment are usually intact, and only slight changes which mark an intrusion of the supernatural are introduced.

One of the persistently emphasized requirements for such worlds is, indeed, that they ought to operate according to rules that are recognizable and strict, even if they should differ from those of our own universe. The rules that are invented for the fantastic realities are, thus, indicative of a mechanistic world view – they can be learned and applied by the initiated, and they seem to suggest a reversed version of Clarke's third law, which states that "Any sufficiently advanced technology is indistinguishable from magic" (quoted from Aldiss and Wingrove 1986, 281). Now magic appears to be a sophisticated practice based in the belief in strict relations of cause and effect – a particular spell or technique produces an effect, and if there is no effect, a mistake has been made in the administration of the cause. Thus, "any sufficiently rehearsed magic appears to be indistinguishable from technology."

The need for a general adherence to practical common-sense physics in fantasy was pointed out by J.R.R. Tolkien when he argued that for the creation of Secondary Worlds, "'the inner consistency of reality' is more difficult to produce, the more unlike are the images and the rearrangements of primary material to the actual arrangements of the Primary World" (Tolkien 2006, 140). Accordingly, magic is divorced from the supernatural in *The Lord of the Rings* and has turned into an ambivalent term for a particular kind of knowledge that is available to some but not to others.

> ‘Are these magic cloaks?’ asked Pippin [...]
>
> ‘I do not know what you mean by that,’ answered the leader of the Elves. ‘They are fair garments, and the web is good, for it was made in this land. They are elvish robes certainly, if that is what you mean.’ (Tolkien 1978, 390)

What is magic to the Hobbits is craft to the Elves, the ability to apply the laws as laid down by the deity that created Middle-earth. As high fantasy is firmly grounded in the generic limitations of adventure literature, the “willing suspension of disbelief” (Coleridge 1920, 52) or the “reader’s hesitation” (Todorov 1975, 31) in the confrontation with supernatural events are kept to a minimum, and the fantastic elements are usually restricted to very traditional features that do not differ too much from those already known from fairy tales: e.g. superhuman abilities, action over distance, clairvoyance, etc. What we do find occasionally is a momentary suspension of the second law of thermodynamics, i.e. work can be done without an investment of energy and thus an increase of entropy.

Surprisingly, this also applies to texts that openly declare some allegiance to science and in particular quantum physics, i.e. so-called quantum fiction. In a review of Justina Robson’s weird science fiction/fantasy novel *Living Next Door to the God of Love*, which repeatedly refers to multi-dimensional spaces and non-linear time, Gwyneth Jones writes: “Where cause and effect, space and time, no longer apply, it gets hard to write convincing fiction” (Jones 2005). True, but then the first thing the uninitiated learns with the first introduction to quantum physics is that the phenomena are not particularly convincing. Some of Robson’s quantum fiction novels, *Natural History* (Robson 2003) or *Living Next Door to the God of Love* (Robson 2005), then seem to be far closer to traditional fantasy and/or teen fiction than to science fiction or science, exploiting some aspects of the rather controversial M-Theory mercilessly to produce whatever fantastic effect seems to be required, e.g. faster-than-light travel or non-linear time. The first volume of her so called *Quantum Gravity*-Series, *Keeping it Real*, opens with a short introduction to some fundamental changes our world underwent as a consequence of an “explosion of the Superconducting Supercollider in Texas, at some unknown point in the Lost Year 2015” (Robson 2006, 1).

> The explosion had followed an unknown quantum catastrophe inside the machine. However, it was not the kind of explosion that blew matter to smithereens and laid waste to worlds. Its actions took place in the near-infinitely tiny spaces between one raw energy flicker and the next. It transmuted fundamental particles into new states, altering the fabric of the universe. (Robson 2006, 1)

I don’t know whether this makes any sense to a physicist, but what follows probably won’t. In consequence of the cataclysmic event, five other realities have been discovered which lie parallel to our universe and are now in some kind of contact with our world. These realities are the realm of the Elementals, who are personifications of air, fire, water, earth, metal and wood; Alfheim, home of the Elves; Demonia; Thanatopia; and Faery. The story – as far as I was actually willing to read it – dealt with a half human/half cyborg heroine who acts as a bodyguard for an elvish rock singer and has to protect him from all kinds of perils and assassins.

According to Vanna Bonta's *Flight: A Quantum Fiction Novel*, based on "Quantum theory proposes that matter does not seem to be able to exist without Thought to perceive it" (Bonta 1995, 184), and the novel tells the story of a female thought being who is trapped into shameful materiality in our world by an evil adversary. With the help of some unusual abilities, she pursues beauty and the salvation of the world, which is finally achieved when all of humanity breaks into song simultaneously.[1]

But even in texts that are not as careless with scientific vocabulary and theories, and which actually strive for an advancement of knowledge by unusual strategies, the adherence to common physical parameters is rather strong. This aspect is addressed in a book that tries to fuse fantasy and magic with science, *The Science of Discworld* by Terry Pratchett, Ian Stewart and Jack Cohen.

> Magic, however, is only one aspect of Discworld. There's a lot of science on Discworld, too – or at least rational engineering. Balls get thrown and caught, the biology of the river Ankh resembles that of a typical terrestrial swamp or sewage farm, and light goes in more or less straight lines. Very slowly, though. (Pratchett et al. 2013, 40)

But with this book I enter the genre of fantastic attempts to explain physics.

3

One of the problems that authors and narrators have to face when they introduce modern physics into literature is the decision between mimesis and diegesis, a.k.a. showing and telling. Tom Stoppard's *Hapgood*, for example, a play that merges quantum physics with the complicated strategies and psychologies of espionage, did not find grace in the eyes of the audience nor with most critics. The scientific concepts employed in the play and transferred to the realm of secret services were

1 The ontological superiority of the heroine also allows for some problematic comments on contemporary politics, making a distinction between normal people and those who have seen the light. "People like Ross Perot know about benevolent wisdom. You got to be a loving tyrant if you want to survive in this world" (Bonta 1995, 379).

simply not sufficiently comprehensible. The play offers extensive explanations that we have to follow closely and keep in mind if we want to understand the strange events on stage – apparently an impossible task for spectators (Vanderbeke 2004b, 289–302). This indicates a dilemma: if the counterintuitive scientific phenomena are explained, the text turns into a literary equivalent of a popular science lecture; if they are simply used as the basis for the construction of an unfamiliar reality, they will not be recognized for what they are, and chances are that the text will be dismissed as a weird failure in experimental fiction or drama. After all, we have to keep in mind that the quantum universe we live in is the world of our experience, i.e. a world in which the bewildering phenomena do not appear at a macro-level. They can only be made visible if the laws of the universe are altered and quantum phenomena are raised to a level at which they have a noticeable impact on our experience – which is definitely not the world we live in.

This problem can also be noticed in texts that explicitly claim to be narrative approaches to scientific theories and concepts. In the course of the last century, several attempts have been made to use patterns and motifs of fantastic literature for the explanation of unfamiliar and counterintuitive physical phenomena – some of the thought experiments in Haldane's *Possible Worlds* could be counted among them. This, of course, poses a problem, as the literary text is now a secondary work and dependent on the primary scientific theory or phenomenon it is supposed to transmit. Gillian Beer apodictically claims that:

> Literature cannot, even if it would, take on the task of technical translator when scientists find themselves from time to time in the dilemma that their scrupulousness has sustained agreed meaning but rendered their knowledge and purpose inscrutable to others beyond the trained circle. (Beer 1990, 88)

Of course, it cannot be the role of the literary critic to tell authors what they are supposed to write and what objectives they should pursue in their literary works, but then we can also read the quote as a variant of the claim that the more bizarre phenomena of science are indeed beyond literary transformation or narrativity. This point is also addressed in *The Science of Discworld*:

> What runs Discworld is deeper than mere magic and more powerful than pallid science. It is *narrative imperative*, the power of story. It plays a role similar to that substance known as phlogiston, once believed to be that principle of substance within inflammable things that enabled them to burn. In the Discworld universe then, there is narrativium. It is part of the spin of every atom, the drift of every cloud. It is what causes them to be what they are and continue to exist and take part in the ongoing story of the world.
> (Pratchett et al. 2013, 10)

Scientific phenomena as such are not story-friendly, and experiments are not stories, even if they include some activity and processes. Robert Kelley may have suggested that the scientific paper bears some analogy to detective fiction – "as with the mystery story, we can posit a pleasure derived by the reader of the scientific paper as his or her beliefs about the outcome and relevance of a particular experiment are confirmed" (Kelley 1993, 136) – but this seems to be a forced argument and hardly convincing.

One of the first texts that actually used patterns of fantastic literature to convey the complex and bewildering phenomena of quantum physics and relativity was George Gamow's *Mr Tompkins in Wonderland*, followed by *Mr Tompkins Explores the Atom* (cf. Gamow 1967 and 2009). The title, of course, indicates a close similarity to Lewis Carroll's *Alice in Wonderland*, but in contrast to Alice, Mr Tompkins does not take part in any action. In his dreams, he experiences a series of phenomena of relativity or quantum theory which are upscaled or downscaled to the level of human perception. Here is an example:

> A single cyclist was coming slowly down the street and, as he approached, Mr Tompkins's eyes opened wide with astonishment. For the bicycle and the young man on it were unbelievably shortened in the direction of the motion, as if seen through a cylindrical lens. (Gamow 1967, 2)

The phenomenon is then explained either by himself or by a scientific authority:

> Then Mr Tompkins felt very proud because he could understand what was happening to the cyclist – it was simply the contraction of moving bodies, about which he had just heard. 'Evidently nature's speed limit is lower here,' he concluded, 'that is why the bobby on the corner looks so lazy, he need not watch for speeders.' (Gamow 1967, 3)

Some of the stories come with illustrations or simplistic drawings that show, for example, a shortened bicycle, or anthropomorphic electrons circling a nucleus (some of the images can easily be found on the internet).

In 2009, George Gamow's son Igor Gamow resurrected the figure of Mr Tompkins in a comic book series, but now the graphic simplicity is gone. Instead we get a lot of flashy pictures – Einstein for example appears in the garb of a superhero radiating a formula – but they have lost their clarity and are no longer easy to understand.

There is one little detail that I find particularly interesting. In George Gamow's book as well as in the new version by Igor Gamow, the story ends with Mr Tompkins waking up because he has fallen out of his bed. It seems as if this is a little intertextual reference to Winsor McCay's *Little Nemo in Slumberland*, in which every page ends with Little Nemo waking up – mostly because he has fallen from his bed. I will return briefly to Little Nemo later.

In George Gamow's Tompkins books, the experiences are considerably shorter than the explanations, and the latter occasionally also include mathematical formulas which may be simple or even trivial for a physicist but probably not for the average reader. Thus the text does not employ the counterintuitive aspects of physics for any literary purpose; instead the elements of fantastic literature serve didactic interests and thus lose their narrative momentum.

The approach chosen by Gamow has since become an established pattern for numerous books and articles, many of which press-gang poor Alice into service. In fact, Alice appears to be a permanent visitor in popular science texts and sometimes even in not so popular science texts. As a visitor she is transported into unfamiliar environments where she meets strange characters who claim that this is the relativistic or quantum world and then shower her with explanations that are hardly suitable for adolescents. In chapter two of *Alice and the Quantum Cat* (Shanley 2011), for example, she meets Prof. Flow, and this is one of the first things he says:

> The Quantum Universe is the magical and paradoxical subatomic domain of the quantum where parallel lines converge and things relocate without traversing space. Here measurements like time/space, energy/matter are only quantifiable in very peculiar ways. Phenomena begin to phase out of the everyday classical Newtonian reality you live in and become invisible to you. (Wolf et al. 2011, 24)

In the first chapter of Robert Gilmore's *Alice in Quantumland*, she comes across some builders who throw bricks seemingly at random onto piles that will eventually become a house. When asked about their strange procedure, they answer:

> It's true so it is that the random fluctuations are still large enough to hide the pattern, but since we have laid down the probability distribution for the result we are after needing, we'll be getting there, never fear. (Gilmore 1995, 10)

The encounters and phenomena occasionally come with explanations by an elderly scientist, e.g.:

> Quantum theory describes the behaviour of particles in terms of *probability distributions*, and the actual observations of individual particles will occur at random within these. The probabilities may include classically forbidden processes such as the penetration of particles through a thin energy barrier. (Gilmore 1995, 9)

Some of the metaphors and images have become almost canonical and pass from one book to the next. A good example is Heisenberg's Uncertainty Principle, and the chosen image is a billiard table. This is George Gamow's version:

> Something very queer about it! A player put a ball on the table and hit it with the cue. Watching the rolling ball, Mr Tompkins noticed to his great surprise that the ball began to

> ‘spread out.’ This was the only expression he could find for the strange behavior of the ball which, moving across the green field, seemed to become more and more washed out, losing its sharp contours. It looked as if not one ball was rolling across the table but a great number of balls, all partially penetrating into each other. (Gamow 1967, 65)

In Gilmore’s book, it is Alice who comes to the Mechanics Institute where two men representing Classical Mechanics and Quantum Mechanics play billiards. Classical Mechanics plays very accurately, but Quantum Mechanics only takes a vague stab with his cue.

> After her previous recent experiences, Alice was not really surprised to discover that the ball shot off in every direction at once, so that there was no part of the table where she could say definitely that the ball had not gone, though equally she could not say definitely where it actually was. After a moment the player went over and peered into one of the pockets, then reached in and drew out a red ball. (Gilmore 1995, 32)

The explanation of the phenomenon, of course, follows in both cases. Quite obviously, these are not stories comparable to Lewis Carroll’s books. Instead, they are written as *Annotated Alices*, trying to imitate Martin Gardner’s marvellous achievement (Carroll 1970). But now the events do not form a coherent or, even more important, nonsensical story. It is not the narrative that is annotated but the annotations are illustrated by mini-narratives. Moreover, while Martin Gardner’s annotations are usually marked as suggestions and interpretations of Carroll’s work, now the experiences are no longer open to multiple readings – each event has exactly one meaning, which is explained in the text.

To some extent, this also applies to *The Science of Discworld*. Here the chapters alternate between an account of the creation of a non-magical roundworld universe within Unseen University of Discworld and factual information about the physics governing that universe, which incidentally is similar to ours. The result is, strangely, a defamiliarization of our normal sciences, which are regarded as weird by the magicians of Discworld and then explained by the didactic voice of the scientist teacher in the following chapter. Those aspects of physics that, in fact, challenge our view of reality are merely a minor aspect that the book rushes through. Quantum theory is dealt with on pages 107–110, and the explanations include a short story about a cat that added a third option to Schrödinger’s thought experiment: “in this case there were three determinate states the cat could be in: these being Alive, Dead, and Bloody Furious” (Pratchett et al. 2013, 110). Of the 382 pages, 115 are set in Unseen University on Discworld while 267 pages are explanation.

All these texts explain modern physics, but even if some of the underlying rules are bewildering the reader is presented with factual knowledge about the phenomena and their significance. The imagination is firmly guided toward a correct understanding, and the reader can safely follow wherever the text may lead.

This distinguishes them from those texts that remain open and allow for a plurality of readings – and, of course, Alice is right at the top of this list. Lewis Carroll's heroine has made appearances in various books and articles on quantum theory ever since Arthur Eddington used the poem "Jabberwocky" in *The Nature of the Physical World* to explain that "*Something unknown is doing we don't know what*" (Eddington 1928, 291). And, of course, this is already well expressed in the book itself by Alice when she says "Somehow it seems to fill my head with ideas – only I don't exactly know what they are" (Carroll 1970, 197). In fact, in *Possible Worlds* Haldane also draws on Carroll, suggesting that the Red Queen of Alice anticipates aspects of relativity and leaves off where quantum mechanics begins (Haldane 1932, 270). In Alice, we get phenomena without explanation: they are imaginative, but they also engage the reader's imagination in the attempt to make sense of the paradoxical world. Alice's quest is matched by our own search for the possible rules that govern Wonderland or the sense and meaning that can be attributed to the story.

However, we also encounter an additional strategy that contributes to the strangeness of the experiences: the ambivalence and malleability of language. Objects are recalcitrant, and as the various Quantum Alices show, they do not lend themselves easily to quantum phenomena. Words, on the other hand, are flexible, versatile, and polyvalent. They are open to manipulation and interpretation. As Humpty Dumpty points out, the question is only "which is to be master – that's all" (Carroll 1970, 269). Words can take up multiple meanings or merge various and even contradictory meanings into one oxymoronic concept. It is quite fitting that Eddington chose "Jabberwocky," a poem that is made up of portmanteau words, as his analogy to the inexplicable quantum phenomena.

We could, however, also turn to another work of fantasy, one that again certainly has no connection to modern physics or science, but includes pictures that offer highly imaginative phenomena. In a sequence from Winsor McCay's *Little Nemo in Slumberland* (McCay 1906) we see the main character multiplying and taking every possible way from his bed to the door, and now it is up to us to make sense of it, because we do not get a one-to-one explanation from some authority.

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But then there are various other works of mainstream literature that feature highly imaginative worlds and have been read as anticipations or literary illustrations of almost all the counterintuitive aspects proposed by twentieth century physics. The stories of Jorge Luis Borges (Borges 1999) have, over the last few decades, been discussed with respect to chaos theory (Weissert 1991), field theory (Hayles 1984, 138–168) and quantum theory (Mosher 1994), and they will in all probability also fit various strange scientific theories to come in the future. Similarly, the works of Beckett have yielded prophetic visions of quantum theory (Montgomery 1991), chaos theory (Meriwether 1994) and black holes (Krance 1983). And, of course, everything can be found somewhere in *Finnegans Wake*. All of those readings are ultimately valid, as the stories allow for very divergent interpretations and call for imaginative responses. The fantastic aspects of these texts are not explained but send the reader on a quest for possible explanations, none of which can possibly be exhaustive. As readers, we have to live with the fact that none of those readings is the right one; that the texts offer a multitude of possible worlds that we as readers can explore.

A different kind of approach can be found in Thomas Pynchon's *Gravity's Rainbow*. As Pynchon called one of his first stories *Entropy*, and the word resurfaced in various later novels, critics were invited once more to focus on thermodynamics and to follow all possible textual leads and allusions. But then there are a few other and even more surprising motifs of the text that also demand some kind of explanation, among them the striking sexual behavior of the protagonist. Tyrone Slothrop, for reasons that are ultimately inexplicable, seems to have sexual encounters in wartime London at precisely those locations where the V-Rockets will later strike. It is an absolute match, and when this is discovered, the correspondence between love and death is investigated by one of Pynchon's secret organizations and interpreted as a kind of Pavlovian behavior:

> But the stimulus, somehow, *must* be the rocket, some precursor wraith, some rocket's double present for Slothrop in the percentage of smiles on a bus, menstrual cycles being operated upon in some mysterious way […]. Are there fluctuations in the sexual market, in pornography or prostitutes, perhaps tying in to prices on the Stock Exchange itself, that we clean-living lot know nothing about? Does news from the front affect the itch between their pretty thighs, does desire grow directly or inversely as the real chance of sudden death – damn it, what cue, right in front of our eyes, that we haven't the subtlety of heart to see?

> But if it's in the air, right here, right now, then the rockets follow from it, 100% of the time. No exceptions. When we find it, we'll have shown again the stone determinacy of everything, of every soul. (Pynchon 1975, 86)

The attempt to find a classical cause and effect explanation ultimately fails, and the mystery remains unsolved in the text. However, the reader also learns that the psychiatrist who conditioned Slothrop as an infant later worked on the rocket, and thus we get a triangle, in which Slothrop and the rocket are joined within an entangled system by their connection to Laszlo Jamf. There is no direct indication that this is an allusion to non-locality and quantum entanglement, raised to a macroscopic level, and I want to suggest that it is this very openness which makes the motif so fascinating and so bewildering. It is one of the fantastic elements of the text, a mystical union that can only be explained by supernatural features, but as such it invites interpretation and a search for the underlying rules of the novel. The text offers a few explanations, none of which is particularly convincing. The mysterious connections and their multiple explanations additionally tie in with one of Pynchon's perennial topics, paranoia, i.e. a state of mind which increasingly detects and constructs conspiracies and hidden connections until finally the world is revealed as a place where everything is connected to everything else. The novel thus allows for the construction of possible worlds, not for the discovery of rigid rules that govern its imaginary universe.

One more aspect should be addressed in the discussion of possible worlds, the return of old ideas and motifs in new garbs, and the example of quantum entanglement is once more useful at this point. In Umberto Eco's historical novel *The Island of the Day Before*, set in the seventeenth century, a ship is sent around the world in order to solve one of the most pressing problems of navigation, the *mystery of longitude*. Of course it was not difficult for sailors of yore to ascertain the latitude of a position at sea, but longitude is tricky as it requires a reference time, e.g. Greenwich Mean Time, which was not available until clocks with sufficient accuracy were invented. In the novel an ingenious idea is suggested. As everyone, or at least the initiated, knew at the time, there exists a mystical connection between a weapon and the wound it cuts, and so by the use of a Powder of Sympathy applied to a sword, the wound it had cut could be healed over a distance. Francis Bacon, for example, states that the ointment "may be applied to the weapon, though the party hurt be at great distance" (Bacon 1824, 76), even though it is not quite certain whether he was fully convinced of the treatment.

The navigators in the novel suggest using this phenomenon, but in a slightly different manner. An injured dog is taken aboard and its wound carefully kept open and festering. If at a fixed time a piece of cloth with blood from the dog's wound was brought into contact with the powder, the dog would yelp and so the clock of the ship could be synchronized with the time in England. As Dava Sobel has pointed out, such a procedure was indeed suggested in London in 1688, "whether in desperation or in jest is not known" (Sobel 2014).

As in Pynchon's novel, Eco presents us with a possible allusion to quantum entanglement that now even includes an instantaneous manipulation over distance, and the fact that Eco also mentions several other theories and phenomena of modern science supports the idea that he in fact had quantum physics in mind when he wrote the novel (for an extensive investigation into quantum physics and entanglement in this novel, cf. Brown 2008 passim). But then the Powder of Sympathy makes use of concepts that were quite popular and widespread in the late Middle Ages and the Renaissance, an age in which the belief in magic was still quite powerful. One of the basic principles underlying many magical world views and practices is contagious magic. Frazer explains it as follows:

> Contagious magic proceeds upon the notion that things which have once been conjoined must remain ever afterwards, even when quite dissevered from each other, in such a sympathetic relation that whatever is done to the one must similarly affect the other.
> (Frazer 1996, 43)

As an example, Frazer offers the very treatment also used in Eco's novel, the anointment of a weapon to heal or irritate the wound it has made (cf. Frazer 1996, 47–48). Of course, I do not want to suggest that magic is in any way connected to modern physics, but when we explore the human ability to invent possible worlds, we may find that some of the concepts and phenomena have been around for a long time and that some motifs and ideas may have a particular tenacity and a tendency to return under different guises in very different contexts (cf., for example, Vanderbeke 2004a, passim; Vanderbeke 2015, 135–137). We may then ask ourselves if there may be a cognitive aspect in the *kōan* that guided me through this chapter. If our imagination keeps returning to similar images, concepts and ideas, we can possibly take this as an indication that indeed there are limits to our imagination and that reality may thus be stranger than we can think.

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Maximilian Bergengruen

The Physics of Metaphysics

The Technique of Ghost Apparition in Gryphius' *Catharina von Georgien* and *Carolus Stuardus*

Abstract: The first objective of the article[1] is to illustrate that the ghosts in Gryphius' *Catharina von Georgien* and *Carolus Stuardus* are, unlike what is claimed in Luther's theology, neither the devil himself nor the work of the devil but rather the mouthpiece of the divine spirit. They thus have the task of delivering the highest metaphysical truths. In order to stage the ghost apparitions, Gryphius – and illustrating this is the second objective of argument in the text – draws from the entire technical repertoire of the German Baroque stage. While in the course of the scenes without ghosts only one characteristic element of the Baroque stage is used, namely the quick conversion of the *periaktos* on a perspectivized stage, all of the other 'highlights' of the Baroque stage, especially the use of light and flying machines, as well as lifting and lowering mechanisms, are reserved for the scenes containing ghosts and spirits. The third part of the article shows that these new techniques of stagecraft are based on contemporary practical physics, and in this case on mechanics and optics, with which Baroque dramatic literature, in the course of its self-constitution, conducts a type of performative dialogue.

1 Imitatio Christi

It has repeatedly been pointed out[2] that Gryphius' dramas *Catharina von Georgien* (created in 1647, first print 1657) and *Carolus Stuardus* (created in 1649/50 [A]/1660? [B]; first print 1657 [A]/1663 [B])[3] are very similar: they are often mentioned in the same breath.[4] In both cases, a sovereign is hindered in executing

1 The complete article was translated from the German by Sandra Evans.
2 Cf. the explanation of Mannack as editor in Gryphius 1991, 1095. In accordance with this edition, citations in the following will be cited under Sigle D.
3 I will cite in line with the B version. On the creation of the A and B versions and the different sources that Gryphius used for these versions, cf. Schönle 1933; Berghaus 1984; Habersetzer 1985, 17–18 and 23–38; Stackhouse 1986, 89–95.
4 Cf. for instance Kaminski 1998, 98–121, which discusses the plays in one chapter due to their similarities in topic.

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his authority, and even threatened with death, as a result of the confrontation with a second power. For Catharina this second power is the Persian ruler Shah Abbas, and for Carolus it is Cromwell and the movement of Independents. In the end both rulers will suffer death as martyrs (cf. Steinhagen 1977, 299–302; Parente 1987, 186–208). They are able to face death and, in Catharina's case, stare the preceding torture straight in the eye because they trust in Christ and, what is more, perform the imitation of Christ[5] and consequently replicate his passion. As a result of being so close to and even identifying with Christ, they attain a strength that enables them to overcome the fear of pain and death.

However, the plays are not so similar that the imitation of Christ would be organized in the exact same way. For Catharina, her situation is that she is a prisoner of Shah Abbas, who covets her and wants her to become his wife. If she were to accept his proposal, she would be free on the outside and possess a kingdom; however, in order to do so, she would have to give up her inner freedom:[6] her religion and her loyalty toward her husband even after his death (cf. Szarota 1976, 71).

Now, if Catharina were to reject Shah Abbas's proposal, she would have to be well aware of the likelihood that she will soon suffer torture and then death. As Schings (cf. 1968, 57–68) has shown, she is able to bear the prospect of impending attacks on her body by invoking a stoicism in which the spirit withdraws from the body that is or will be maltreated. This becomes obvious as she, in reference to her role as queen, shouts the central sentence of the stoic doctrine at Salome: "Regire dein Gemütt" (D 190, V. 72).

We find this analogization of ruling the kingdom with self-control of emotions, or in other words the transfer of sovereignty into one's psyche, as early as the *Meditations* of the stoic Emperor Marcus Aurelius: "τὸ κρατεῖν ἑαυθτοῦ" (I, 15; "mastery of self;" Marcus Aurelius 1944, 10–11). This turning back toward the inner life in Marcus Aurelius's text leads to a devaluation of the outer realm, of which one's own body is also a part: "ὁ κόσμος ἀλλοίωσις, ὁ βίος ὑπόληψις" ("The Universe is change, life is opinion;" Marcus Aurelius 1944, 50 and 53). Catharina also thinks this way; in the words of the priest who speaks about her after her martyrdom: "Diß Thraenenthal / die Erd | Diß Angsthauß war nicht mehr des grossen Geistes werth" (D 213, v. 179–180).

5 Cf. with respect to *Carolus* the analysis in Niefanger 2005, 164–170. With recourse to Habersetzer 1985, 37–38, Niefanger provides evidence that the figure of thought of Karl's *Imitatio Christi* originates from the "royalistischen Seite des historischen Diskurses der Zeit" (169). Cf. also Grimm 1986, 6–7.

6 On the ambiguity of freedom and imprisonment in *Catharina*, cf. Feger 1997, 94 et passim.

Furthermore, Catharina considers herself to be a *sponsa Christi*, something also established by Schings (cf. 1968, 69–72). This is in two ways a logical response to the decision with which Shah Abbas confronts her. First of all, by marrying a heathen Catharina would, from a Catholic perspective, violate the "überaus enge Vereinigung Christi und der Kirche" ["Arctissima Christi et Ecclesiae [...] coniunctio"], which symbolizes marriage as such (Buse 1867, 310; cf. Rieks 1996, 23–135). Moreover, from a Protestant perspective,[7] her bond with God through marriage, which indicates that people are "ynn sunden empfangen und geporn," although each sin implicit in sexuality is "verschonet" (Luther 1907, 304) by God, would be destroyed and she would thus be thrust into sin. Hence Catharina clearly understands that with his marriage proposal the heathen Shah Abbas would replace not only her husband, but also the one who created this matrimony, namely the Christian God (cf. Bergengruen 2013).

Second, in love mysticism it is the female soul which unites with the male lover, i.e., Jesus Christ, in the act of mystical union. As is well known, it is Bernard of Clairvaux (1090–1153) who in his sermons fixes and canonizes the tradition of interpretation according to which the expected union of the lovers, as described in the *Song of Songs,* should be understood allegorically as a union of the soul (*anima*, female) with God (male).[8] Gryphius, however, does not directly refer to this tradition, but rather to its specifically Protestant reception.[9] Thus Catharina follows the anti-corporeal stoicism that she has also invoked, as mentioned above. As a martyr with a maltreated body, and with her impending death, she cannot count on her body, but only her soul. It is only this that will later unite with the heavenly groom.

Now, as regards *Carolus Stuardus:* the imitation of Christ as a figure of thought has been referred to many a time in the research literature.[10] Yet the meaning developed here is slightly more differentiated: namely, the notion of the two bodies of the king is actually invoked beyond that in different places in

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7 As a representative of the Caucasian Eastern Church with respect to confession, Catharina is something like a blank space or a projection plane for Gryphius.

8 Cf. the *Song of Songs* tradition of interpretation of spiritual wedlock (instead of wedlock in church), especially in Bernard of Clairvaux, Ruh 1990, 253ff. (with a reference to the foundational work conducted by Ohly 1958, 135ff.), as well as McGinn 1996, 280ff.

9 Cf. Loos 1999, 698–716. The reference to the Protestant tradition of a *Unio mystica* reinforces a fundamental tendency in recent research, within the framework of which Gryphius' Protestant disposition is increasingly emphasized despite his taking on Catholic motifs. Cf. in general Tarot 1987, 226–231; Borgstedt 1999, 563–565 (similarly, Borgstedt 2000, 48–49); Bogner 1999.

10 See Schöne 1968, 167–169, with a focus on the thought of the figuration or post-figuration; as well as Habersetzer 1985, 21–24 and 35–36. On the political dimension of the martyr dramas, cf. Spellerberg 1996, 442–44, and Streller 1993, 110–118, particularly, however, Campe 2000, 283–287.

the drama. However, this notion is understood not in the sense that the physical body stands for the mystical body of the king, but rather in the sense that when the physical body dies (and this is what Carolus Stuardus assumes), the mystical one will continue to exist:

> Jch muß die Trauer-Post an Freund' und Kinder schicken
> Daß Carl itzund vergeh'. Nein! kan der untergehn
> Der zu der Crone geht! der feste Carl wird stehn /
> Wenn nun sein Coerper faellt / der Glantz der Eitelkeiten /
> Der Erden leere Pracht / die strenge Noth der Zeiten
> Vnd diß was sterblich heist / wird auff den Schauplatz gehn /
> Was unser eigen ist wird ewig mit uns stehn[.]
> (D 519, v. 42–48)

That which will be killed, according to the argumentative logic of Carolus, is merely the external body of the body, which essentially belongs to the "Glantz der Eitelkeiten," to the "Erden leere[r] Pracht" etc. Karl's remarks differ from pure Vanitas imagery in that he not only considers immortality to be a "Selen schatz," as the famous sonnet by Gryphius (1963, 48) claims, but also that it is the crown, i.e., the sign of his sovereignty.

The "corona [...] invisibilis" (Kantorowicz 1997, 336) mentioned here represents the *corpus mysticum* of the empire ruled by Karl. In essence, the argument is that the king is in fact more than merely his physical body. Through the crown he wears, he is guaranteed to live on as a representative of his empire and of Christ after he dies. The mystical body of the king, the mystical crown and the mystical kingdom cannot be harmed by the physical death of the ruler.

Kantorowicz pointed out that the notion of the mystical body of the empire is a politicization of a theological theory. The *corpus reipublicae mysticum* is the legal successor of the *corpus ecclesiae mysticum* (cf. Kantorowicz 1997, 194–196 and 207). Originally, however, the notion of the mystical body is valid for all of humanity. In this case, accordingly, it is not the mystical body of the church that is indicated, but rather the body of Jesus Christ.

The notion of the mystical body of Christ, in which all believers, maybe even all persons and possibly even all creatures, are able to partake, is developed in different places in Pauline theology (e.g., 1 Corinthians 6:15, 12:12, 12:18, Romans 12:5 etc.) and is an elaboration of the idea of the state as an organism, a figure of thought already cultivated by Plato and Aristotle.[11] This figure of thought is referred to prominently in Neoplatonic Patristics, for instance by Gregory of Nyssa in *Oratio chatechetica magna* (cf. here Bergengruen 2006).

11 Cf. here the still valuable article by Nestle 1927, 350–360.

Karl of course knows that the notion of the king' mystical body goes back to the notion of the mystical body of Jesus Christ. In this respect he deliberately calls for an imitation of Christ if he himself lays claim to "Der Ewikeiten Cron" (D 545, v. 448), which goes beyond the purely political dimension, in that he makes an analogy between his death and the Passion. Carolus Stuardus is a successor of Christ not only qua royal dignity, but also because he, just like Catharina von Georgien (and also Leo Armenius in the play of the same name), does not eschew the death intended for him, but carries his cross and follows Jesus.

2 Dreams and spirits: Theory

It is striking that those crowned heads who succeed Christ have contact with him in ways not restricted solely to quiet prayer. From the theater's viewpoint, this might result from the fact that this form of dialog is not very meaningful. Gryphius, who very much conceives his plays with actual production in mind (cf. here Flemming 1921, 165), accordingly provides for an entirely different form of communication.

In the preface to *Carolus Stuardus* he writes in reference to Petronius's *Satyricon* (118, 6):

> Freilich gilt hier mit Sicherheit jenes Diktum Petrons: "Historische Tatsachen sind nicht einfach in Verse zu bringen, weil das die Historiker weit besser machen, sondern durch Retardierung und Verwendung mythologischer Figuren" – dazu füge noch Geistererscheinungen und Masken [correct: Geister- und Gespenstererscheinungen] – "und die sentenziöse Prägnanz des Stils erscheint der poetische Geist, damit eher die Weissagung eines Rasenden offenbar werde als ein religiöses Vertrauen durch Zeugnisse einer Rede."[12]
>
> (D 1102, v. 13–21; added by MB)

12 In the original Gryphius writes: "'*Non res gestæ versibus comprehendendæ sunt, qvod longe melius historici faciunt: sed per ambages, Deorum,' adde & spectrorum, Larvarumq; 'ministeria, et fabulosum sententiarum tormentum præcipitandus est liber spiritus, ut potius furentis animi Vaticinatio appareat, qvam religiosæ orationis sub testibus fides*'" (D 446). This section in Petronius's text reads: "non enim res gestae versibus comprehendendae sunt, quod longe melius historici faciunt, sed per ambages deorumque ministeria et fabulosum sententiarum tormentum praecipitandus est liber spiritus, ut potius furentis animi vaticinatio appareat quam religiosae orationis sub testibus fides" – "Historical events are not to be treated in verses, for historians handle such material far better. The free spirit of genius should plunge headlong into oracular utterances, the succor lent by the gods, and the Procrustean control of lapidary phrases; the result should appear as prophetic frenzy rather than as a trustworthy, scrupulous

What is remarkable here is not only the citation selected by Gryphius, but also the amendment he added. Let us begin with Petronius's theory of the theater, which assumes that that which is presented at the theater needs to neither historically nor legally be safeguarded. It is much more significant that the speech contains a theatrical dimension, for instance when it concerns the "Weissagung eines Rasenden" or a vision. So much for Petronius.

Gryphius, however, goes one step further when he weaves his own amendment into Petronius's citation ("dazu füge noch Geistererscheinungen und Masken [correct: Geister- und Gespenstererscheinungen]") and thus also considers the apparition of ghosts a necessary theatrical presentation which is separated from pure historicity. This last addition is not completely unproblematic. The genre might allow for it, but theologically it contains a few pitfalls, at least for a Lutheran such as Gryphius.

What is an apparition of a spirit or a ghost, in reality? According to Lutheran orthodoxy it is none other than the "Teufel" himself, who "des Nachts" is responsible for the appearance of "Gespenst vnd Poltergeister" (Porta 1591, Bl. 328r). The Lutheran stance evolved from its strong belief in the devil on the one hand, and on the other from its dissociation from the Catholic position, which insists that purgatory exists and consequently considers ghosts to be either demons, or rather *animae damnatae*, or *animae purgandae*, i.e., damned persons or souls in purgatory that appear to humans in order to scare them or to plead for their own redemption (Schott 1667, 292).[13]

Let us, however, keep our focus on Gryphius: his insistence on ghosts and spirits being an elemental part of the theatrical plot is not consistent with Protestant doctrine because according to Luther the words of spirits or ghosts are the keenest of competition to the divine word: "Gott wils nicht haben / das du von den Todten lernen / vnd Wahrheit forschen solt." Man should not listen to the word of the evil spirits but "auff Gottes Wort" (Porta 1591, Bl. 329v) alone. Gryphius thus placed himself in a self-made dilemma: the genre of the drama as such and the technical possibilities of performance in practice – something I will talk about later – support the apparition of ghosts; theology, however, does not allow it.

Gryphius is very well aware of the fact that he is caught in this dilemma. In the preface to *Leo Armenius* he feels obliged to defend the "Träume / Gesichter / frembde Bilder" (D 11–12, v. 29–30), and in the preface to *Cardenio und Celinde* he

account attested by witnesses" (Petronius 2003, 129f; Petronius 1996, 113). My translation tries to highlight Gryphius' reading of the passage.

13 See also Rieger 2011, 39–47; Neuber 2005, 31–32; as well as Mahlmann-Bauer 2004, 124–125.

defends the appearance of “Gespenster und Erscheinungen” (D 235, v. 2), i.e., exactly those two elements he, with Petronius beyond, considers to be especially important for the theatrical performance in comparison to the historical one.

The argument accompanying the apologia is divided into two parts. Firstly, Gryphius underlines the metaphysical truth of visions and apparitions. With respect to ghosts he refers to his treatise called *De spectris,* which was still to be published at that point in time (which was, however, never actually released), when he emphasizes that he will prove at a “besonderen Ort” that the ghosts and spirits are not merely “Mährlin oder traurige Einbildungen” (D 235, v. 3).

Secondly, concerning visions, he also maintained that one should not consider them “für gantz eitel” (D 12, v. 10) – irrespective of whether they appear in a literary or in a historical text. Beyond that, he argues (with Petronius and of course Aristotle, *Poetics* 1451) that completely different rules apply to a literary, and to be more precise to a dramatic text, and specifically for visions and apparitions. In the preface to *Cardenio und Celinde* Gryphius emphasizes that this play is a “Gedicht[]” (D 235, v. 6). What this in turn means he has already elaborated on in the preface to *Leo*, where he admits that he allowed a little “Freyheit” “auff diesem Schauplatz” for the “Dichtkunst” (D 12, v. 28–30).

One must interpret this to mean that in the field of dramatic poetry another form of theology – or better, another form of discourse on and confirmation of theology – prevails. The strict Lutheran rules, which maintain that only the devil can be involved in apparitions, are revoked. However, the purpose of this difference is not to question the Lutheran confession as a whole, but quite the opposite: to affirm it using the methods of the theater.

The ghosts in *Leo* and in *Cardenio* do not speak for themselves (not even the evil ones among them); rather they utter nothing less than the word of God. In fact, the very same word of God which competes in Lutheran theory beyond the theater with the words of ghosts, can coincide with them, and even act as verification on (the theatrical) stage.

3 Dreams and spirits: Practice

So much for theory. Let us now look at the visions and apparitions of ghosts in both plays. In the case of *Catharina von Georgien* it is quite easy. There is actually only one ghost: the protagonist herself. Catharina appears to her lover and antagonist Shah Abbas at the end of the drama exactly at the moment he feels remorseful about the murder (“bringt die Mörder umb / die Hand an sie geleget! | Weg Zepter weg! Chach hat hir selber Schuld!”) and wants to kill himself: "Komm komm mein Schwerdt! wir haben Macht uns selbst zu straffen!" (D 221, v. 417–418, 421).

As Shah Abbas sees her, he is not sure whether this is an apparition or a fantasy: "Wie? oder schreckt uns eitel Phantasy!" (D 222, v. 427). However, whatever Catharina is, she delivers a kind of prophecy with respect to the downfall of Shah Abbas:

> Dein Lorberkrantz verwelckt! dein sigen hat ein Ende.
> Dein hoher Ruhm verschwindt! der Tod streckt schon die Haende
> Nach dem verdamten Kopff. Doch eh'r du wirst vergehn;
> Must du dein Persen sehn in Kriges Flammen stehn /
> Dein Hauß durch schwartze Gifft der Zweytracht angestecket /
> Biß du durch Kinder-Mord und Nechstes Blutt beflecket
> Feind / Freunden und dir selbst untraeglich / wirst das Leben
> Nach grauser Seuchen Angst dem Richter uebergeben.
> (D 222, v. 433–440)

This ghostly appearance corresponds very closely to a vision[14] that haunts Catharina from the beginning to the end of the play. Here, not only does she consider the ascent to the throne offered by Shah Abbas a prefiguration of her future torture; what is more, the torture is closely analogous to Christ's way of the cross. This becomes obvious to her with the imagined crowning especially:

> Daß die besteinte Cron die mich vor disem schmueckte
> Diß mein geaengstet Haupt mehr als gewoehnlich drueckte;
> Biß mir das klare Blut von beyden Schlaeffen lif /
> Vnd ich an statt der Cron nur Rosen-Aest ergriff /
> Verdorrte Rosen-Aest / die als ein Krantz gewunden
> Fest umb die Stirn gedruckt auff meinen Haren stunden.
> (D 136–137, v. 333–338)

Before she is then actually tortured, in the last citation she once more makes the implicitly mentioned reference to Jesus Christ explicit: "Schaut JEsus geht voran! ein Augenblick beschwert / | Die Ewikeit erquickt. Creutz / Messer / Zang' und Herdt | Sind Staffeln zu der Ehr'. Jtzt wird der Traum erfuellet" (D 200, v. 351–353). From this it is revealed that the last two visions are interconnected, which specifically emphasizes the christological moment. Through the consequent union with Christ via torture, Catharina is ultimately able to appear to Shah Abbas as a ghost, who makes a prophecy which does not deviate from

14 Even though they have the form of a dream, it is important to distinguish visions from simple uses of the motif of the dream in the Baroque drama (see Borgstedt 1999, 574–575).

the word of god one bit God at all. This spirit thus in no way comes from the devil, but is much more a figuration of (almost) pure divine speech.

Things get a bit more difficult in *Carolus Stuardus*. The topic of dreams/visions does not play a particularly important role here, at least not for Karl, who does not have the impulses that Catharina had. Instead, however, – at least in the B-version, which I am analyzing – there are considerably more apparitions of ghosts. The second *Abhandlung* starts with the appearance of Stafford's and Laud's ghosts and later on the ghost of Maria Stuart also appears. The former are Karl's two most important advisors, whom he had to have executed.

These two did not come in order to take revenge on Karl. They are very well aware of the fact that the English king acted solely in response to the pressure exerted by Parliament. Their intent was to point out the injustice now befalling Karl:

> Er / der sein Leben waget
> Fuer sein verdrucktes Reich / wird von dem Reich vertaget /
> Fuer eines Henckers Fuß / und legt auff einen Streich
> Fuer aller Augen hin sein itzt enthalste Leich.
> (D 474, v. 237–240)

Most of all, however, both of the former advisors to Karl make a prophecy to the English people ("Weh! Weh! muß denn mein Geist sich wittern | Vnd dein Mord-Prophete seyn?" D 470, v. 121–122), that it will soon spill the same blood as Karl did: "Das gantze Land ist voll / | Voll Volck / das bald dein [Karls] Blut mit Blut aussöhnen soll" (D 474, v. 251–252). This prophecy is again taken up in the fifth *Abhandlung* as Poleh in his madness has a vision in connection to which the injustice of this act, like the acts of the ghosts of those who passed away in the second *Abhandlung*, becomes obvious to him. ("Du [Karl] stirbst ohn Schuld; und ich leb' allem Recht zu wider!" D 535, v. 161). And within the framework of this vision the prophecy from the second *Abhandlung* also becomes more concrete: what will be shown is the "*Virtheilung des Hugo Peters und Hewleds*" (D 536), the dead body of "*Cromwels*" and his combatants (D 537), and most of all, "*wie der Bischoff / Carlen den II. krönet*" (D 538).

This also clarifies that in this play too, all ghosts speak one language, namely in that she foretell divine judgement, which will come into being in English politics in the years following Karl's death. This is also and especially true for the ghosts and characters of the visions. They do not speak in their own names either, it is rather God who speaks from inside them and through them.

4 Dreams and spirits: Technique

Let us now look at how the scenes with spirits are conceived technically, beginning with *Carolus Stuardus*. Remarkably, in this drama there are hardly any *didascalia*. Nevertheless, as is the case in Catharina (see below), we can assume a Telari-based transformation stage, as three stylized stage sets alternate, which frame the different figure groupings: Carolus and entourage, Cromwell and entourage, Fairfex and his wife. From this normal form of the transformation stage, the scenes with spirits are now able to come to the fore by an increased use of theater techniques. In order to reconstruct this I will start with the scene containing spirits in the fifth *Abhandlung*.

Via stage direction, Gryphius clearly states how he imagines the ghostly future events, i.e. the killing of the Independents, to occur:

> *Vnter disen Worten oeffnet sich der innere Schau-Platz / […] Der Schau-platz schleust sich.* (D 536) / *Der Schau-platz oeffnet sich zu dem andernmal / […] Der Schau-platz schleust sich.* (D 537) / *Der Schau-platz oeffnet sich zu dem drittenmal / […] Der Schau-platz schleust sich.* (D 538)

In a strict sense, only a curtain, and not a setting can open and close – and this is arguably exactly what Gryphius intended: in the three cases mentioned the rear stage is opened using light and the rear stage curtain ("Schauplatz"). This is where the ghosts enter and exit the stage. And since this takes place far enough away from the audience, it is likely that no further technical aids are necessary to depict the killing of the Independents and the crowning of Karl II as an apparition of ghosts. The last stage direction reveals that this is such an apparition: "*Die Geister verschwinden*" (D 539; emphasis by MB).

Even in the first apparition of ghosts, in the scene where both former advisors of Karl appear in the second *Abhandlung,* Gryphius chooses to use the device of two stage halves. In this case the act begins with a ghost scene, most probably at the rear of the stage, and after a certain point in time an increase in light makes the front of the stage more visible. As the ghost of Maria Stuart appears after the ghosts of both advisors have appeared, Karl is actually also present and in fact "*auff dem Bette*" (D 471). One can assume that Gryphius imagined the scene in such a way that the first two ghosts appear at the back of the stage while the front of the stage is still dark. When Karl and Maria then appear together in the next scene, the front of the stage is also illuminated and thus can be performed on.

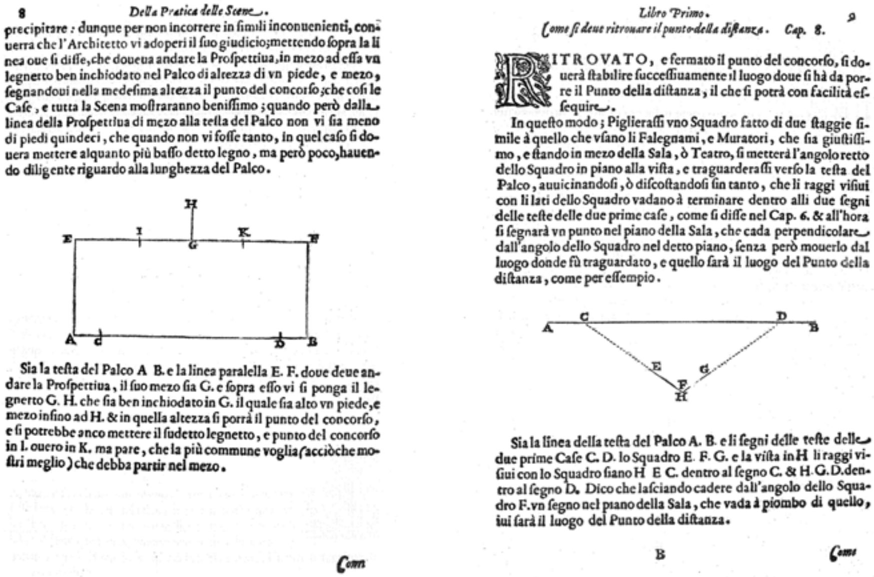
That this is the case is confirmed by the following scene which continues to show Karl "*auff dem Bette.*" He shouts after the disappearing Maria: "Halt / halt betrübter Geist!" (D 474, v. 253). Now this third scene is then performed without ghosts in Karl's chamber/prison. Since there is no change in location, the first two ghosts then probably perform at the back of the stage and the third ghost at the front. The disappearance of the first two ghosts is thus not a problem, since the back of the stage is simply removed from events by dimming the light and using a curtain. How the third ghost disappears is not mentioned. Since he performs at the same stage location as Karl later does, and his vanishing is mentioned explicitly, one can assume (there is, however, no real evidence) that a flying machine that allows Maria to vanish from stage is foreseen.

Let us note that in *Carolus Stuardus* the apparitions of ghosts are planned primarily by opening and closing the rear stage, which is possible because this activity is somewhat removed from the spectators' view, due to distance. This is most probably supplemented by implementing flying machines.

Now let us deal with *Catharina von Georgien*, where the flying machine is a decisive instrument, as I will illustrate shortly. With respect to scene changes, also in the normal mode of operation, this piece uses the transformation stage. In each *Abhandlung* the Telari have to be changed several times on the open stage. A recurring formulation in the stage directions that precede the sequence refers to this: "*Der Schauplatz verändert sich in das Königl. Gemach.*" / "*Der Schau-Platz verändert sich in den Königlichen Lustgarten.*" / "*Der Schau-Platz verändert sich in den Vorhoff des Palasts*" etc. (D 162, D 183, D 210 et passim).

In the second *Abhandlung*, right in the middle of the act for once, another instruction is provided by the director: "*Der SchauPlatz bildet ab den Königl. Verhör-Saal*" (D 160; emphasis by MB). Since there is no explicit change in scene announced, it can be assumed that Gryphius plans to open the rear or front stage (more than likely the rear stage).[15] This can also be deduced from the plot. In the previous *Eingang* Abas speaks with Seinelcan. The "*Gesandte aus Reussen*" (D 160) is subsequently announced, whose request for an

15 Unlike Flemming 1921, 170 and 180, I do not assume that in Gryphius' plays – in fact neither in *Catharina* nor in *Carolus Stuardus* – there is fundamental and constant exchange between the rear and front stage and that the most important events are situated rear stage. Moreover, I do not agree that in *Catharina* the formulation "der Schauplatz ändert sich in" indicates a change between the rear and front stages (compare Eggers 1967, 29, who speaks of a "bipolarity" with respect to the stage halves). To me this appears to be a violent misrepresentation of the cited sentence, which in my opinion illustrates that the stage hitherto performed on *changes*, regardless of whether this is the front or the rear stage. Ultimately, it does not seem certain that the sentence "der Schauplatz bildet ab" in general indicates a change in the stage set. More significant in my opinion is the issue of whether the audience realizes that a change in scene has taken place or not. Cf. the critique of Flemming by Zielske 1965, 130–132. A reference to the link between quick changes in scene and Gryphius' stage direction is also made by Müller 1967, 81.



8 *Della Pratica delle Scene.*

precipitare: dunque per non incorrere in ſimili inconuenienti, conuerra che l'Architetto vi adoperi il ſuo giudicio; mettendo ſopra la linea oue ſi diſſe, che doueua andare la Proſpettiua, in mezo ad eſſa vn legnetto ben inchiodato nel Palco di altezza di vn piede, e mezo, ſegnandoui nella medeſima altezza il punto del concorſo; che coſi le Caſe, e tutta la Scena moſtraranno beniſſimo; quando però dalla linea della Proſpettiua di mezo alla teſta del Palco non vi ſia meno di piedi quindeci, che quando non vi foſſe tanto, in quel caſo ſi douera mettere alquanto più baſſo detto legno, ma però poco, hauendo diligente riguardo alla lunghezza del Palco.

Sia la teſta del Palco A B. e la linea paralella E. F. doue deue andare la Proſpettiua, il ſuo mezo ſia G. e ſopra eſſo vi ſi ponga il legnetto G. H. che ſia ben inchiodato in G. il quale ſia alto vn piede, e mezo inſino ad H. & in quella altezza ſi porrà il punto del concorſo, e ſi potrebbe anco mettere il ſudetto legnetto, e punto del concorſo in I. ouero in K. ma pare, che la più commune voglia (acciòche moſtri meglio) che debba partir nel mezo.

Com

Libro Primo. 9

Come ſi deue ritrouare il punto della diſtanza. Cap. 8.

RITROVATO, e fermato il punto del concorſo, ſi douerà ſtabilire ſucceſſiuamente il luogo doue ſi hà da porre il Punto della diſtanza, il che ſi potrà con facilità eſſequire.

In queſto modo; Piglieraſſi vno Squadro fatto di due ſtaggie ſimile à quello che vſano li Falegnami, e Muratori, che ſia giuſtiſſimo, e ſtando in mezo della Sala, ò Teatro, ſi metterà l'angolo retto dello Squadro in piano alla viſta, e traguarderaſſi verſo la teſta del Palco, auuicinandoſi, ò diſcoſtandoſi ſin tanto, che li raggi viſiui con li lati dello Squadro vadano à terminare dentro alli due ſegni delle teſte delle due prime caſe, come ſi diſſe nel Cap. 6. & all'hora ſi ſegnarà vn punto nel piano della Sala, che cada perpendicolare dall'angolo dello Squadro nel detto piano, ſenza però mouerlo dal luogo donde fù traguardato, e quello ſarà il luogo del Punto della diſtanza, come per eſſempio.

Sia la linea della teſta del Palco A. B. e li ſegni delle teſte delle due prime Caſe C. D. lo Squadro E. F. G. e la viſta in H li raggi viſiui con lo Squadro ſiano H E C. dentro al ſegno C. & H. G. D. dentro al ſegno D. Dico che laſciando cadere dall'angolo dello Squadro F. vn ſegno nel piano della Sala, che vada à piombo di quello, iui ſarà il luogo del Punto della diſtanza.

B Come

Fig. 1: Double page (pp. 8–9) from Nicola Sabbattini. *Pratica di fabricar scene, e machine ne teatri*. Ravenna, 1638 (reprint in Sabbattini 1926, 8–9).

audience the Shah accepts without hesitation. Thus, Abas leaves his chamber to go into the "*Verhör-Saal*" (D 160) where the Russian is waiting. It would seem appropriate here to be able to expand the stage in order to represent this walk adequately and theatrically.

The crucial challenge with respect to the stage lies in the first Eingang in the first Abhandlung: "*Vber dem Schau-Platz oeffnet sich der Himmel / unter dem Schau-Platz die Helle. Die Ewikeit kommet von dem Himmel / und bleibet auff dem Schau-Platz stehen*" (D 125). The opening of the sky is not difficult to master with theatrical means, but the opening of hell is a little more difficult. It is most likely that a lowering mechanism will be used (Fig. 1).

The great challenge I referred to, however, is the flying machine, which is required so that the allegorical salvation can come down to earth from the sky (cf. also Flemming 1921, 176). If one assumes that the beginning and end are conceived analogically, then it makes sense to speculate that the apparition of ghosts described above – and now we return to the original topic – i.e., the appearance of the dead Catharina as a spirit, will again be carried out with the flying machine.

At this point the stage directions are somewhat simple. It is merely mentioned that "*Der Geist erscheinet*" or "*Verschwindet*" (D 222). However, looking

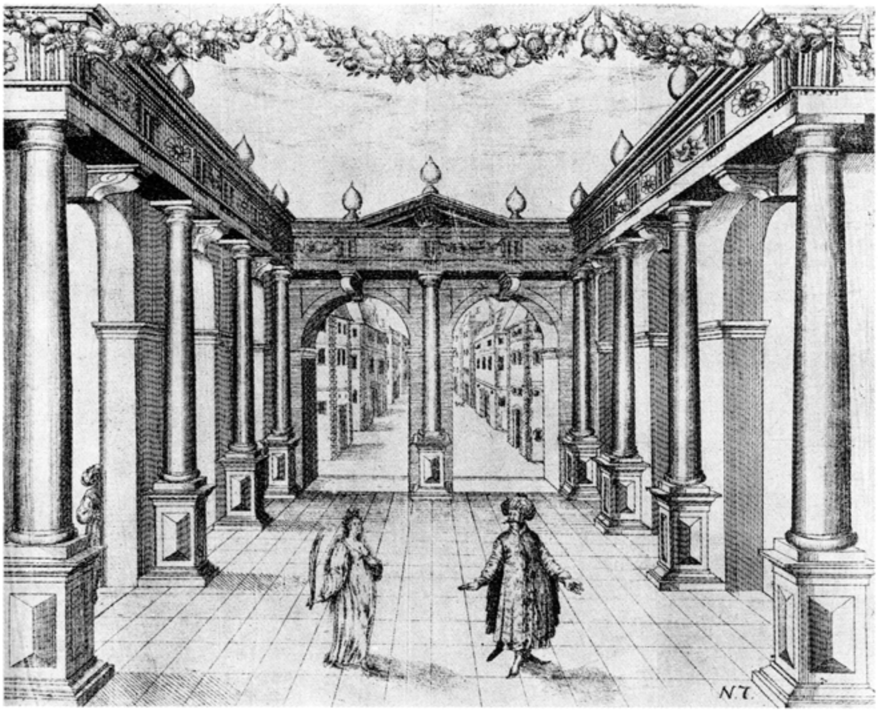


Fig. 2: Catharina von Georgien: 5th Abhandlung, final scene (Gryphius 1991, 928).

at an admittedly idealized graphical rendition of the scene (i.e., not necessarily reflecting the theater in all its technical disposition), the thesis of the second appropriation of the flying machine can certainly be further supported (Fig. 2).

Two flying machines frame the scene changes on the open stage. Through this, Catharina's exceptional position becomes apparent: with her martyrdom and death, she reaches a god-like position, and thus she herself represents a minor salvation. Consequently, she reaches a position where she can consider her situation *sub specie aeternitatis*. Thus, Catharina could also say, with the words of eternity (and Gryphius, who here plagiarized himself): "Was dieser baut: bricht jener Morgen ein! | Wo itzt Paläste stehn | Wird künfftig nichts als Graß und Wiese seyn" (D 126, v. 27–29).[16]

16 Cf. also Schings 1968, 40. It is a variation of the well-known verses from *Vanitas, vanitatum, et omnia vanitas* (Gryphius 1963, 7–8).

5 Physics of metaphysics

Thus far the study has illustrated two results. First of all, the ghosts in Gyphius' works are, in a different way than is intended in Luther's theology, not a mouthpiece of the devil, but rather one of the divine spirit. They have the task of proclaiming future judgements with a certain performative force (whether these judgements are always appropriate is another question which can not be dealt with here). Second, for these particular apparitions of ghosts (and only for them) Gryphius draws from the entire technical repertoire available to the German Baroque stage in addition to the Telari based transformation stage, namely the flying machine as well as the lifting and lowering platforms. Benjamin's statement that the Baroque "Bühne" has its "Gott" in "der Machination" (Benjamin 1991, 261; cf. also Kaminski 1998, 118) is apparently also especially valid for ghosts.

It can thus be claimed that in the dramas of Gryphius there is a direct connection between the highest metaphysical messages and the highest achievements in theater technique. It is self-evident that the effect-oriented scenes containing ghosts were selected by Gryphius not least because they had only been possible on stage at a theater school for a short time.[17] The metaphysical messages (or at least their representations) are particularly dependent on their technical feasibility.

And what is technically possible in the theater is indirectly related to the level of physical knowledge – in this case, from optics and mechanics before Newton. The changes on the Baroque stage in comparison to the Renaissance stage belong exactly to this realm: illusionary thinking is optically perfected and the mechanical movability of the stage is taken to an extreme (Brauneck 1993, Vol. II, 13–27).

Let us begin with the basics of mechanics in stagecraft: a recent study on pre-Newtonian mechanics has pointed out that in early modern times, mechanics was part of natural philosophy. Traditionally, there is a more theoretical line, which refers back to Archimedes, and a more practical one which is based on Hero of Alexandria. Beyond natural philosophy, however, there is a third line of mechanics based on the practical experience gained from the construction of machines (cf. Laird and Roux 2008, 3 and 9).

This third line of mechanics, not theoretical-practical but rather practical-practical, is of central importance for the theater. Independent of theoretical developments in mechanics, practical knowledge on lifting machines, which originated in antiquity, has nonetheless existed since the Renaissance, regarding for instance pulleys, chains and chain gear, as well as the leverage principle. Paradigmatically,

17 On the relationship of Gryphius to the theater stage, cf. Müller 1967, 37.

this knowledge can be identified in Leonardo da Vinci's notes (cf. Maschat 1989, 236 et passim).

This is also and specifically valid for stagecraft in the late Renaissance and Baroque periods. One can for instance recognize this in the *Pratica di Fabricar Scene* by the famous stage designer and architect Nicola Sabbatini. As an artist engineer,[18] Sabbatini possesses fundamental knowledge in optics and mechanics, which he gained from his teacher, the mathematician Guido Ubaldo (cf. Brauneck 1993, Vol. II, 17), and also expounds in his book. This knowledge, however, is applied merely with respect to effect. As Sabbatini discusses in the last chapter of his *Pratica*, which addresses "Von der Leichtigkeit der Praxis," he wants exclusively to achieve "Bewunderung und Entzücken" in the audience (Sabbatini 1926, 277). Ergo: practical physics, not for theory but only for the moment of the effect.

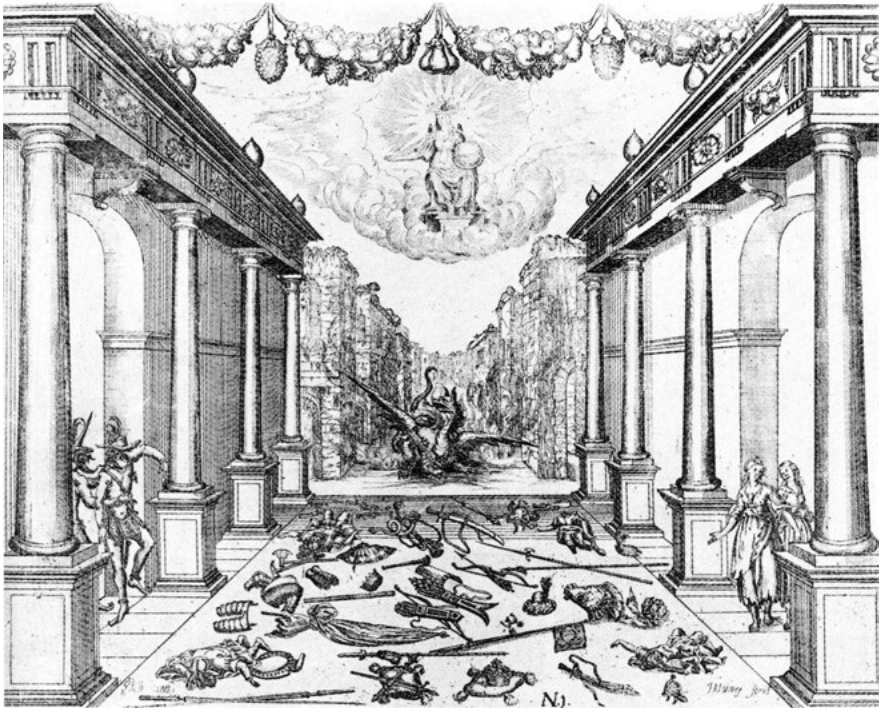


Fig. 3: Catharina von Georgien: Prologue (Gryphius 1991, 928).

18 On this concept, see Maschat 1989, 17.

The same goes for optics as a basis of stagecraft. With the *camera obscura* the Renaissance developed a model of the human eye.[19] And this model is further tested in the theater, and placed in the limelight in exactly that kind of theater which, as Sabbatini writes, places the "Fürsten" at the "Entfernungspunkt," as he calls it (Fig. 3) (Sabbattini 1926, 206; cf. Brauneck 2012, 133), i.e., at the particular point where the *phantasmagoria*, using Panofsky's words, of the "einzigen und unbewegten Auge[s]" (Panofsky 1980, 101) has its place as an outlet of perspectival presentation. The only correct perspective of the stage illusion is thus from the prince's point of view (even if the late Renaissance stage distanced itself from the principle of the central perspective for the benefit of the on-stage performance) (cf. Brauneck 1993, Vol. I, 465). The perception from the prince's seat – or, in the words of Ulrike Hass, the drama of seeing (Hass 2005) – is consequently reconstructed anew in the theater.

It is not surprising in this respect if new theater technique at that time is compared to "Magie" (D'Aubignac 1971 [1715], 322; cf. also Schütz 1984, 92). In the late Renaissance and Baroque periods magic, especially the *Magia naturalis* or later *Magia artificialis*, is the realm where the great natural philosophical and metaphysical projects of the Renaissance are transferred into the technical. With his *Magia naturalis* Giambattista della Porta[20] for instance developed an exact description of the *camera obscura* and subsequently a pre-Newtonian school of seeing. The same would apply to the Jesuits Kircher and Schott and their model for converting the *Magia naturalis*.[21]

The use of magic points to the fact that for authors like Porta this early form of optics – as in mechanics – was not a theory of seeing, but rather a practice of seeing, a practice which serves the purpose of creating an illusion, something to which the concept of magic refers (at least at this late point in time). *A fortiori* theater concerns itself not only with heaven and hell, but also and specifically with the question of how to represent heaven and "wie man eine Hölle darstellen kann" (Sabbatini 1926, 238), i.e., with effects in practice.

In order to formulate a conclusion: the contemporary practical physics mentioned here, in this case in the field of mechanics and optics, is, for literature (at least the theater), just as important, if not more so, than the theoretical physics with which authors of literary works are able to engage in discourse. The physical-technical arts of creating illusions are the performative basis for each and every reflection on theater and for the writing of texts for theater.

19 Cf. Schmitz 1981, 124, using Leonardo as an example.

20 On Porta, cf. Schmitz 1981–1995, Vol. I, 135–138.

21 On Kircher, especially his understanding of nature and technology, cf. Leinkauf 1993, 41–55.

However, they are also helpful in developing structure for literature, since they pre-invent in a mechanical and optical manner what literature in its medium also strives toward: the art of creating illusions and the means of presenting these creations of illusions as such.

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Clemens Özelt

Establishing Evidence through a Shift in Viewpoint

Galileo's Dialogues as a Genre Model in Texts of the Weimar Republic (Einstein, Brecht, Döblin)

Wie die Erde selbst drehte sich unsre Unterhaltung um die Sonne.

(Heinrich Heine)

Abstract: The paper examines dialogues and reflections on dialogues by Albert Einstein, Bertolt Brecht and Alfred Döblin at the beginning and the end of the Weimar Republic, analyzing the aesthetics and the history of the genre in its sociohistorical context. The results can be outlined in the following four theses:

1) During the Weimar Republic, dialogue becomes a productive medium of self-understanding for scientific and social modernity, making it possible to coordinate the dominant discourses of politics, literature and physics. 2) Referring to the Renaissance dialogue, historicizing becomes an important interdiscursive method, providing an insight into the relations of different social systems in historical distance. 3) Dialogue, in the Galilean tradition, offers experimental experiences that effect shifts of paradigm by changing points of view. 4) As an ideologically versatile form, dialogue can structure various societal transitions.

1 Introduction: Galilean turns

Encountering opposition, ideas have to take detours; arguments shift their perspective, stories change their genre, texts their publishers.[1] A notable example of this is one of the best-selling books in history, the *Manifesto of the Communist Party*. For about 25 years, the manifesto, published in 1848 in London, found few readers in Germany, Marx' and Engels' country of origin. In his introduction to the *Modern Edition* of *The Communist Manifesto*, Eric Hobsbawm shows how the distribution of the text was far from straightforward:

1 The complete article was translated from the German by Sarina Tschachtli.

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> [T]he treason trial of the German Social-Democratic leaders, Wilhelm Liebknecht, August Bebel and Adolf Hepner in March 1872 gave the document unexpected publicity. The prosecution read the text of the Manifesto into the court record, and thus gave the Social-Democrats their first chance of publishing it legally, and in a large print run, as part of the court proceedings. (Hobsbawm 1998, 6)

In the German empire of 1872, the court was a confined area where freedom of speech could be exercised legally. In Jürgen Habermas' words, the court was used as an institution of the public sphere [*Öffentlichkeit*] where reason "was to be realized in the rational communication of a public consisting of cultivated human beings" (Habermas 1991, 35). Forty-five years later, another successor of Marx and Engels used the court anticipating a democratic public sphere: Friedrich Adler, the physicist and later Secretary of the Labor and Socialist International. He was prosecuted for the murder of the Austrian Minister-President Stürgkh in 1917. In his plea, Adler recounts his previous history of political engagement; how he lacked a public sphere for his concerns and had to use historical camouflage or other disguises. Adler uses the court as a public forum to find support for his political position, a position that presupposes an entirely different view of the world, as he asserts twice. He does so not by comparing himself to Liebknecht and Bebel, and not even to Marx and Engels. Instead, the physicist represents himself as Galileo Galilei facing the Roman Inquisition (Adler 1919, 51–52). In 1933, Georgi Dimitrov, later Secretary-General of the Comintern, invoked the same scene in front of the Reichstag Fire Trial (the Leipzig Trial). Referring to the former democratic public sphere, Dimitrov insists on the (political) power of a truth made public. He presents the anticipated triumph of socialism as knowledge-based, more than Adler even, with his speech culminating in a final reference to Galileo: Dimitrov was led away with the concluding words, "yet it does move" – the very same sentence that Galilei is said to have muttered after he renounced the Copernican theory to the Roman inquisition (cf. Drake 1978, 353–358, 356). Again, a textual disguise was necessary for wider distribution; the speech was distributed as a "camouflage publication" *Why Not a Musical Instrument?* [(*Tarnschrift*): *Warum nicht ein Musikinstrument?*] (Dimitroff 1934, 27–28; cf. Gittig 1972, 116).

In both scenes, Galileo is called on as a witness to signal a knowledge-based triumph. His triumph is hindered only momentarily by the asymmetrical speech situation, but it will ultimately be ensured when a new public sphere is established. Adler and Dimitrov trusted "in reason's gentle tyranny over people" (Brecht 1980, 29), as Brecht's Galileo phrases it. In this manner, these trials illustrate a specific political self-understanding, but they also frame the time period that will be examined in the following. Set at the beginning and the end of the Weimar Republic, both of these trials involve representatives of the labor movement, and in both cases the hearings developed into defenses of republican values. For this purpose, not only is Galileo called on as a witness, Adler and Dimitrov also stage a court case that references the famous inquisition of Galileo, relying on the form of the dialogue and thus illustrating its specific value. The two socialists both imagined Galileo losing the trial, yet establishing a new worldview. Thus, both of them strove to enact rhetorically a change of viewpoint that re-contextualized the prosecution not legally (before the court), but politically (before the public) – and by making it public in writing.

This principle of changing viewpoints is constitutive for Galileo's dialogues: the evidence established is not a question of seeing something clearly or plainly (this is the role Galileo's Aristotelian Simplicio assumes), but of seeing something differently, re-contextualizing the first impression. Changing a view by using a shift in viewpoint, the dialogues imply progress: they are not only about seeing differently, but also about seeing more and better. According to Hans Blumenberg, these are *experimental experiences* rather than immediate visual or sensual impressions, and they belong to Galileo's basic epistemological principles. He illustrates this with the following sequence from the *Discourses and Mathematical Demonstrations Relating to Two New Sciences* [*Discorsi*]. Salviati, also a protagonist of the *Dialogue Concerning the Two Chief World Systems* and Galileo's representative, states: "See now the power of truth [*la forza della verità*]; the same experience which at first glance seemed to show one thing, when more carefully examined, assures us of the contrary" (Blumenberg 1987, 408–409). This process of insight accounts for the form of the dialogue. In his preface to the *Dialogue,* Galileo argues as follows:

> I have thought it most appropriate to explain these concepts in the form of dialogues, which, not being restricted to the rigorous observance of mathematical laws, make room also for digressions which are sometimes no less interesting than the principal argument.
> (Galilei 1953, 6)

This passage addresses two key issues of this analysis. Firstly, it mentions the usefulness of detours in cognitive processes, as they necessitate a change of viewpoint. Secondly, it reveals Galileo's aspirations to affect public opinion in its use of Italian as a common language (and in avoiding the use of mathematical formulae). Thus, the passage indicates how the dispute with the authorities, referenced by the first sentence of the preface (Galilei 1953, 5), is used to reach a significantly broader public. Therefore, the phrase *eppur si muove* becomes representative of a process of understanding in a shift of viewpoint that is quintessential to the dialogues.

As the inquisitional scene influences the political processes of the Weimar Republic, the *Dialogues* influence the production of texts interlinking physics, politics and literature.

The genre even experienced a revival in its original discipline, physics. Albert Einstein, who knew Friedrich Adler from Zurich, makes use of it in his 1918 *Dialogue about Objections to the Theory of Relativity* [*Dialog über Einwände gegen die Relativitätstheorie*]. After his *Relativity: The Special and the General Theory* [*Über die spezielle und die allgemeine Relativitätstheorie*], Einstein used the genre not only as a way to popularize scientific concepts, but also to produce textual effects that call attention to "the purely fictitious character of the fundamentals of scientific theory" (Einstein 1935, 134), as he explains in *The Method of Theoretical Physics* [*Zur Methodik der theoretischen Physik*].

Bertolt Brecht, fascinated by Dimitrov's speech in court, found himself in a similar situation in the 1930s. Convinced of the validity of Marxist theory, he found that its fundamental premises, such as exploitation, were not part of the working class's self-understanding: not unlike heliocentrism, class relations are not immediately visible, but rely on a specific point of view. The genre characteristics outlined prompted Brecht to model his theoretical text, *The Messingkauf Dialogues* [*Der Messingkauf*], on Galileo's *Dialogue*. Furthermore, this form of scholastic dialogue characteristic for the discourse of physics influences Brecht's texts of the late 1930s: the Einstein-dialogue in *Fear and Misery of the Third Reich* [*Furcht und Elend des Dritten Reichs*], *Refugee Conversations* [*Flüchtlingsgespräche*], and of course the *Life of Galileo* [*Leben des Galilei*]. As such, they also contribute to Brecht's large-scale project of creating *a theatre of the scientific age*.

Whereas Brecht used the historical situation of upheaval for utopian projects, Alfred Döblin took the new world order as an opportunity to trace a dystopian development underneath the narrative of scientific progress. Döblin, who had already dismissed Einstein's book on relativity in 1923, ended his extensive narrative of modern history, *Amazon*, with a final judgment instead of a world revolution. The novel identifies the harmful potential of the natural sciences and the disruptive developments they caused, ultimately to make a case for religious reform. His work can thus be said to find a consistent continuation after 1945 in the reactivation of the religious dialogue in *Immortal Man* [*Der unsterbliche Mensch*] and *The Battle with the Angel* [*Der Kampf mit dem Engel*].

We might ask why texts by authors as diverse as Einstein, Brecht and Döblin refer back to Galileo's *Dialogue*, which was published some three hundred years earlier. This might be better understood in the context of a socio-cultural phenomenon of identity formation around 1900 that has been termed *Renaissancism* and constitutes a historical background for the texts to be examined. In his study analyzing dramas of the period, Gerd Uekermann observes that, somewhat surprisingly, the German middle class found the Florence of the Medici a suitable model of identification (Uekermann 1985, 282). He traces this self-reflection in historical costume, as he terms these processes of self-understanding ("Selbstbespiegelung im historischen Kostüm," Uekermann 1985, 282), back to the belated reception of Jacob Burckhardt's *The Civilization of the Renaissance in Italy*, which was influenced by none other than Friedrich Nietzsche. The Renaissance plays that Uekermann examines became, he argues, a compulsory exercise for young dramatists at the turn of the century. They also show a very selective perception of Burckhardt's delineation of the era, as Uekermann demonstrates conclusively:

> Neither the appropriation of the legacy of antiquity nor the era's scientific and cultural achievements are the concern of Renaissancism, but rather the theme of great, powerful, individually shaped personalities. Most representatives of the genre concentrate not on Burckhardt's ideal of the 'uomo universale e singolare,' of the universally educated individual, but on a type that is treated rather marginally in the 'culture of the Renaissance:' the ruthless man of action and violence, acting beyond all ethical and moral liabilities, the ingenious virtuoso of crime, the perverted outgrowth of the cult of personality.[2]
>
> (Uekermann 1985, 54)

This cult is embodied in Cesare Borgia (Uekermann 1985, 60) who becomes an exemplary figure of reference. Politically, the *man of violence* [*Gewaltmensch*] opposes organized forms of government such as democracy and works against the rising labor movement. According to Uekermann, the heyday of Renaissancism ends as World War I breaks out and the young Weimar Republic is established after the abdication of Wilhelm II in 1918.

In the period between the world wars, however, another form of Renaissancism can be observed, I would argue: one that rectifies the selective perception of the era and adapts to its changing social conditions. This second Renaissancism is concerned with scientific achievements and a collective effort at consensus in a public sphere. It is in this socio-historical context that Galileo Galilei

2 Transl. by ST. "Weder die Aneignung des antiken Erbes noch die wissenschaftlichen und kulturellen Errungenschaften der Epoche sind für den Renaissancismus von Interesse, sondern in erster Linie das Thema der großen, kraftvollen, individuell ausgebildeten Persönlichkeiten. Und die Mehrzahl der Vertreter des Genres konzentriert sich dabei nicht auf Burckhardts Ideal vom 'uomo universale e singolare,' vom umfassend gebildeten Einzelmenschen, sondern auf einen Typus, der in der 'Kultur der Renaissance' eher peripher behandelt wird: den skrupellosen, jenseits aller ethischen und moralischen Verpflichtungen rücksichtslos handelnden Tat- und Gewaltmenschen, den genialen Virtuosen des Verbrechens, den pervertierten Auswuchs des Persönlichkeitskultes" (Uekermann 1985, 54).

surfaces as an ideal figure of identification, and the dialogue as a republican genre. The strongest impulses are to be found on the margins of the era: after the declaration of the Republic (1918) and during the first years of the exile (after 1933, when many intellectuals were forced to flee Nazi Germany), in the course of extensive and intense intellectual discussions of the short democratic interlude of the Weimar Republic.

2 Albert Einstein: A relativistic turn

That the *Dialogue Concerning the Two Chief World Systems* epitomizes the interlinking of physics, politics and literature can be substantiated further by the preface that Albert Einstein wrote for the edition of the text published by Stillman Drake in 1953. Three years before his death, the well-established scientist outlines his own understanding of the history of science by writing the following:

> Galileo's *Dialogue Concerning the Two Chief World Systems* is a mine of information for anyone interested in the cultural history of the Western world and its influence upon economic and political development.
>
> A man is here revealed who possesses the passionate will, the intelligence, and the courage to stand up as the representative of rational thinking against the host of those who, relying on the ignorance of the people and the indolence of teachers in priest's and scholar's garb, maintain and defend their positions of authority. His unusual literary gift enables him to address the educated men of his age in such clear and impressive language as to overcome the anthropocentric and mythical thinking of his contemporaries and to lead them back to an objective and causal attitude toward the cosmos, an attitude which had become lost to humanity with the decline of Greek culture.
>
> In speaking this way I notice that I, too, am falling in with the general weakness of those who, intoxicated with devotion, exaggerate the stature of their heroes.
>
> (Einstein 1953, vii)

The text that follows shows Einstein's preference for a historiography of science very much based on individual achievement. Einstein outlines Galileo as a representative Renaissance man in Burckhardt's sense: as a lone genius fighting not only authorities but also the public. (In this regard, his understanding of Galileo differs significantly from Brecht's.) As a comprehensively educated Renaissance man, Galileo advocates not only a theory, but also a worldview. In doing so, he relies decisively on his "unusual literary gift," "his extraordinary literary talent" (Einstein 1953, xi), to which Einstein refers repeatedly. In his anthology *The World as I See It,* composed during the first years of his exile, Einstein reinforces this individualistic notion of the era. In *Society and Personality,* he traces the "brilliant flowering in the Italian Renaissance" back to "the liberation and comparative isolation of the individual" (Einstein 1935, 9); in *Fascism and Science*, a letter to the Italian Minister of State, Alfredo Rocco, he goes so far as to attribute the prospering of the Renaissance to "the martyr's blood of pure and great men" (Einstein 1935, 31).

The phenomenon of a change of viewpoint can be explored further in Einstein's conclusion, where he counters the common view of Galileo as an empiricist quite forcefully. He writes: "There is no empirical method without speculative concepts and systems; and there is no speculative thinking whose concepts do not reveal [*verraten*], on closer investigation, the empirical material from which they stem" (Einstein 1953, xvii). The so-called betrayal [*Verrat*] of empirical knowledge indicates the importance of the thought experiment in Einstein's scientific self-understanding (which he uncovers, so to speak, in historical garment).

Einstein strove for continuity in his history of science, particularly with regard to classical mechanics. He observes how dialogue provokes thought experiments and a change of viewpoint in Galileo's text, and he reverts to this effect in his *Dialogue about Objections to the Theory of Relativity* in 1918. This short text published in *Naturwissenschaften* does not hold a key position in Einstein's body of work, but it is part of a broader strategy to gain public resonance and recognition for the theory of relativity. Similarly to Galileo, he used this textual format when debating scientific authorities, as for example the Nobel Laureate in physics of 1905, Philipp Lenard. (Einstein received his Nobel Prize only four years after the dialogue's publication, in 1922.) The conversation between the Relativist and the Criticus echoes the dispute about the establishment of a system of coordinates, but this time in the context of the general theory of relativity. The Criticus uses an example that Lenard proposed elsewhere. He states that with good common sense (cf. Hentschel 1990, 74–91), the victims of a train crash would be well aware that it must have been the train, not the environment that stopped with a jar. The Relativist answers in Galilean manner:

> The following counterexample will show how inadvisable it is to appeal to so-called "common sense" as an arbiter in such things. Lenard himself says: so far no pertinent objections have been found to the validity of the *special* principle of relativity (i.e., the principle of relativity between uniformly translatory motions of coordinate systems). The uniformly moving train could as well be seen "at rest" and the tracks, including the

> landscape, as "uniformly moving." Will the "common sense" of the locomotive engineer allow this? He will object that he does not go on to heat and grease the landscape but rather the locomotive, and that, consequently, it must be the latter whose movement shows the effect of his labor.[3] (Einstein 2002, 47)

In the Relativist's opinion, common sense could also suggest that the locomotive's engine needs lubrication, but not the landscape. The principle remains the same: The change of viewpoint is not a question of new empirical data or about seeing something *else*, but about seeing something *differently*. The evidential value of the change of view is established by the shift of the standpoint, in its re-contextualization. Lenard's common sense is challenged in the dialogue, using a thought experiment to outdo and polemically reject his position, similar to Simplicio's empiricism in Galileo's text.

3 Bertolt Brecht: A socialist turn

The history of the *German Physics* [*Deutsche Physik*] shows that the confrontation of Einstein and Lenard was more than an episode in the history of science (cf. Beyerchen 1977): it became a political matter. During the first years of his exile, Bertolt Brecht dedicated the short scene *The Physicists* [*Physiker*] in *Fear and Misery of the Third Reich* to the interacting fields of science and politics. It has only recently been discovered that Brecht contacted Einstein shortly after and sent him a first draft of his *Life of Galileo*. In a short reply, Einstein thanked him for the drama and praised the apt representation of Galileo's *personality* and the contemporary relevance of the historical drama: "the strong relationships to the political problems of the present" (Wizisla 2005, 350).[4]

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3 "Wie wenig es aber angezeigt ist, in solchen Dingen den sogenannten 'gesunden Verstand' als Schiedsrichter anzurufen, zeigt folgendes Gegenbeispiel. Lenard selbst sagt, es hätten sich gegen die Gültigkeit des *speziellen* Relativitätsprinzips (d. h. des Relativitätsprinzips bezüglich gleichförmiger Translutationsbewegung [sic] der Koordinatensysteme) bisher keine zutreffenden Einwände erheben lassen. Der gleichmäßig fahrende Zug könne ebensogut als 'ruhend,' das Geleise samt der ganzen Gegend als 'gleichförmig bewegt' angesehen werden. Wird dies der 'gesunde Verstand' des Lokomotiv-Führers zulassen? Er wird einwenden, daß er doch nicht die Gegend unausgesetzt heizen und schmieren müsse, sondern die Lokomotive, und daß es dementsprechend die letztere sein müsse, in deren Bewegung sich die Wirkung seiner Arbeit zeige" (Einstein 1918, 701).

4 Transl. by ST. "die starken Beziehungen zu den politischen Problemen der Gegenwart" (Wizisla 2005, 350).

This political Renaissancism concludes a long-term development in Brecht's work. During the first years of the Weimar Republic, Brecht's texts are influenced by the reception of Burckhardt at the turn of the century. In his notebooks from 1920, he mentions Burckhardt's *Civilization of the Renaissance in Italy* for the first time (Brecht 2014, 452–453; cf. Gerz 2002, 55). Shortly after, *The Death of Cesare Malatesta* [*Tod des Cesare Malatesta*], a short story written in 1924, also reflects this Renaissancism. In it, Malatesta is turned into a victim of the Renaissance character Francesco Gaja, "a man famous for his elegant way of life and utter nastiness" (Brecht 1983, 49). Gaja wages an elaborate war to revenge insulted relatives. The siege that is the culmination of the story is described as a dreadful theater of insight: "The siege lasted three weeks. Gaja's intention, and the point of his jest, was to give the besieged man enough time to review his whole life and find where the rotten spot lay" (Brecht 1983, 52). Politics is reduced to individual revenge; lifestyle and refinement are perfected to serve torture. Yet, the epistemic potential of this theater is undermined by the text, with the narrator and chronicler finally noting about Malatesta: "It seems certain that up to and including his last hour he did not know why all this was happening, and certain that he did not ask" (Brecht 1983, 52). A comparable constellation can be found in *The Life of Edward II of England* [*Leben Eduards des Zweiten von England*], Brecht's adaption of a historical tragedy by Marlowe (cf. Gaston 2003). It stages a dynamic of revenge and counter-revenge, multiplying the Malatesta-plot. Furthermore, the text recalls the genre of the Renaissance dialogue and drew the interest of none other than Alfred Döblin, who reviewed the play in the *Leipziger Tageblatt* on 21 December 1924 (Döblin 1990, 432–434 and 516).

Characteristics of the turn of the century Renaissancism are apparent in these texts from 1924. Typically for Brecht, his work reflects the English and Italian Renaissance simultaneously; yet, a shift of emphasis can be observed around 1938. He again writes short stories about the Renaissance, such as *The Experiment* [*Das Experiment*], (Brecht 1983, 153–162) and *The Heretic's Coat* [*Der Mantel des Ketzers*], (Brecht 1983, 162–170). However, rather than centering on a *Gewaltmensch,* these revolve around scientists. Thus, Christopher Marlowe and Cesare Borgia, who lends his name to Cesare Malatesta, are replaced by Francis Bacon and Giordano Bruno, followed by Shakespeare and Galileo. Brecht's play *Life of Galileo* (first written in 1939) without doubt represents the best-known recourse to the Renaissance in Brecht's body of work. The play originates in the same period in which he developed a theory of theater in *The Messingkauf Dialogues*. On 12 February 1939, Brecht notes in his journal: "a lot of theory in dialogue form *the messingkauf dialogues* (spurred to use this form by galileo's *dialogues*)" (Brecht 1993, 20). Similar to the *Dialogue Concerning the Two Chief World Systems,* the disputants meet on four different nights. The participants – the Philosopher, the Actor, the Actress, the Dramaturg, and the Electrician – discuss the current challenges, tasks and aims of the theater. Brecht's *Messingkauf* remained a fragment. Only parts of it were published or used for other texts, such as *A Short Organum for the Theatre* [*Kleines Organon für das Theater*]. Thus, there is no cohesive, authorized version of the dialogue.

The Messingkauf Dialogues are exemplary in their use of dialogue to advocate a theory of theater, as they act out and thus clearly display the process. Brecht outlines the essential concerns in a theoretical paratext to the dialogues (as a theory before theory, so to speak), in his *Second Appendix to the Messingkauf Theory*:

> The *self-evident* – i.e. the particular shape our consciousness gives our experience – is resolved into its components when counteracted by the A-effect [alienation effect] and turned into a new form of the *evident*. An imposed schema is broken up here. The individual's own experiences correct or confirm what he has taken over from the community. The original act of discovery is repeated.
>
> The contradiction between empathy and detachment is made stronger and becomes an element in the performance.
>
> *Historicizing* involves judging a particular social system from another social system's point of view. The standpoints in question result from the development of society. Note: Aristotelian dramaturgy takes no account (i.e. allows none to be taken) of the objective contradictions in any process. They have to be changed into subjective ones, located in the hero. (Brecht 1977, 102–103)

The phenomenon I have endeavored to describe, of how a shifting of viewpoint establishes evidence, can also be understood in the familiar terms of the alienation effect. In both instances we find a change of perspective or a re-contextualization; an ordinary phenomenon attains "a new form of the *evident*" when habitualized structures of understanding dissolve. The *historicizing* mentioned in point three plays a central role in this context as it references the interconnectedness of cultural subsystems (in the case of Galileo: physical and societal systems). Point two indicates how the process of comprehension becomes an "element in the performance;" it can take place in public entertainment spaces such as the theater. In the form of a sensuous experience, these processes of comprehension can reach a wide public, something a reference book or scientific theory cannot replace.

Thus, according to Brecht, literature has to be understood in terms of its connectedness with other societal subsystems. What follows from this systematized understanding of literature is, interestingly, that the *Messingkauf* becomes a theory of a process of social interrelation, a process in which elements gain their specific functions and positions in mutual adaption and exchange with one another. In a corresponding passage, Brecht characterizes the relationship between the sciences and societal interests as follows:

> It's because people know so little about themselves that their knowledge of nature is so little use to them. They know why a stone falls in a particular way when you throw it, but why the man throwing it acts in that particular way is another matter. Thus they can cope with earthquakes, but not with their fellows. Every time I leave this island I'm frightened that the boat may go down in a storm. But I'm not frightened so much of the sea really as of the people who might fish me out. (Brecht 1977, 31)

This passage is dialogic insofar as the three images are presented in double views. They imply diverging levels of insight between intellectual power over nature and societal control over such power. It is this discrepancy that, ultimately, nourishes the concerns of what can be termed a societal or socialist turn. This understanding of social functions and societal emplacement affects both scientific discoveries and artistic intention. In conversation with the Actor, the Philosopher comments on the role of the Author (who, programmatically, remains silent throughout the *Dialogues*): "Oh, I'd say the writer's intentions were only of public interest when they provoked the public's interest" (Brecht 1977, 38).

The shifting of perspective is a fundamental structure of the *Messingkauf* and crucial to the process of understanding, which is also delineated more clearly by the multiplication of viewpoints. Whereas the passage above emphasizes the societal impact of a change of perspective, other passages develop the change of viewpoint based on a phenomenology of seeing. Yet, the shifting of perspectives and the social standpoint can be understood as aspects of one and the same process of understanding:

> To describe art as the realm of the beautiful is to set about it in too passive and all-embracing a way. Artists deploy skills: that is the first point. What makes artificial things beautiful is the fact of their being skillfully made. […] Beauty in nature is a quality which gives the human senses a chance to be skillful. The eye is producing itself. That isn't an independent process which stops there. Nor is it one that has not been prepared by other processes, social processes, processes involving other types of production.
> (Brecht 1977, 96)

This fragment from the fourth night establishes seeing as a pre-structured as well as a structuring practice, epitomized in the sentence "The eye is producing itself." Aesthetics, politics, and science presuppose and determine each other in intricate interrelations. In Brecht's approach, the participants in the conversation are supposed to consider and coordinate these diverse interests and connections in a "dialectical twist" at the end of the fourth night (Brecht 1993, 135). With the repetition of these processes of interrelation in the different scenes, a method is rendered visible early on, establishing the *theatre of the scientific age* and negotiating its subject matters in dialogue. The self-reflection of working methods is acted out similarly. A conversation about the thought experiment, which has been established in the examined dialogues, illustrates this method further. Again, Brecht historicizes in this scene, when the dialogue explicitly refers to an earlier era and at the same time implicitly represents his own historical standpoint:

> THE PHILOSOPHER: The Globe Theatre's experiments and Galileo's experiments in treating the globe itself in a new way both reflected certain global transformations. The bourgeoisie was taking its first hesitant footsteps. Shakespeare could never have tailored the part to fit that short-winded character actor of his if the feudal family hadn't just collapsed. Hamlet's new bourgeois way of thinking is part of Hamlet's sickness. His experiments lead straight to disaster.
>
> THE DRAMATURG: Not straight. Zigzag.
>
> THE PHILOSOPHER: All right; zigzag. In a sense the play has the permanence of something makeshift, and I agree that that probably has to be resolved if we're to preserve it. (Brecht 1977, 60–61; emphasis in original)

Enacted in the alternating of the speakers, the principle of understanding becomes, to use Brecht's words, *an element in the performance*. In the dialogue, the dramaturg demonstrates that the change of viewpoint is inherently erratic, not linear. The course of understanding is not straight, but zigzag: *scientia facit saltus*. It does not lose itself in uncertainty; rather, it sharpens its subject matter in the multiplicity of perspectives, resulting in the "permanence of something makeshift." For Brecht, dialogue is not just, as Musil feared, a "polygon of possible opinions" ["Polygon der möglichen Meinungen"] (Musil 2009) that stands in the way of progressive specification. In the conciseness of his interjection, the dramaturg illustrates the ease of this turning point.

Brecht consistently coordinates the discourses of physics, politics and literature on multiple levels, and in doing so accepts the imprecisions of analogies. By experimenting, he draws connections that are at odds with the self-contained spaces of *Hamlet* as a drama, of the Globe Theater as a public sphere, of Galileo's science and of his own present. Thus, his use of dialogue becomes an encompassing principle of construction, not just as an alternating of speakers, but as an exchange of eras, cultures, languages and institutions, people, senses, perceptions and even single words: not straight, zigzag.

4 Alfred Döblin: A religious turn

Brecht understands dialogue as a distinct genre on the one hand, but also uses it as an instrumental form on the other hand, which significantly influences his reorganization of the theater. Both of these aspects can also be discerned in Alfred Döblin's work. He, too, strives to establish dialogue as a genre in itself, yet also uses it as a non-narrative element to diversify his prose. Put simply, both writers, Brecht in his plays and Döblin in his epic prose, approach the phenomenon from two different angles.

An example of dialogization in epic form is the prose text *The Influence of Celestial Bodies on the German Theatre* [*Der Einfluß der Gestirne auf das deutsche Theater*], published in 1924. Apart from short situational sketches, the text consists solely of conversational sequences between the two astronomers L. and O. Both being physicists from Potsdam, they embark on a journey to Mexico to see the "Einstein effect" ["*Einsteineffekt*"] (Döblin 1990, 434) during the solar eclipse. The dialogue opens with the younger colleague O. wearily observing the discrepancy between effort and achievement. First, he contrasts the preparations that lasted for months with the ten to fifteen minutes of observation time; second, he compares the small spatial deviation predicted in the telescope with the geographic extensiveness of the expedition; third, he laments the discrepancy between the investment of dozens of "*Spezialmenschen*" (Döblin 1990, 434), as the text calls them, and the indifference of society to the discovery.

This opening is reminiscent of the polemics that Döblin published a year earlier in the *Berliner Tageblatt*, and later in *Self Over Nature* [*Das Ich über der Natur*], intending ironically to reveal the irrelevance of the theory of relativity to society. In this dialogue between the astronomers, however, the theory of relativity is a vantage point used to diagnose a crisis that affects not only physics but also other societal subsystems, such as politics and the arts: "at the theater, no one knows anymore what it is there for" (Döblin 1990, 440),[5] as one of the characters, namely the older physicist, puts it. This enumeration of societal subsystems is further pursued up to a point of change typical for Döblin's dialogues: he adds religion as a fourth dimension to the triad physics-politics-literature. The older physicist argues:

> This is indeed curious: people say that the major religions have lost their meaning, that they have become churches. To put it bluntly: The spirit has gone to hell. Yet they don't say this about art or the theater. Why not, colleague? The ocular is not adjusted properly;

5 Transl. by ST. "am Theater weiß kein Mensch mehr, wozu es da ist" (Döblin 1990, 440).

> they don't see. Too close or too far away. Imagine a giant arriving at the Gulf of Mexico with us and using our ship as a foot-soaking tub. This would be a misuse of our ship, which was made for traveling. Yet the giant sticks his feet into it, and it works. There once used to be an art, as there used to be peoples, tribes, communities. There used to be a proper theater. And then the giant came. I also don't want to talk about the economy, about politics. The giant takes the theatre, everything remains as it was, and a few centuries later no one remembers what this grandiose, festive, wonderful piece of furniture really was.[6] (Döblin 1990, 440–441)

The same basic structure as in Einstein and Brecht can be seen here: Not-seeing ["*sie sehen nicht*"] leads to an experiment of thought ["*Denken Sie sich*"]. The jump in the narration (from ship to wash-tub) entails a shift in perspective that introduces the dimension of time into the image. As with Brecht, this historical perspective enables us to understand social systems in shifting functional contexts. Without the detour of the narration (introducing a timeline) and its images (introducing the ship in relation to sailors and giants), this would not be evident: the ship's function cannot be deduced from the object itself.

If we believe Döblin's claim that he has indeed read Einstein's *Relativity: The Special and the General Theory* dozens of times, in parts and in its entirety in 1923 (Döblin 1928, 18), then we can safely assume that Einstein inspired the text's effect. In a short preliminary remark, Einstein writes about the aesthetic potential of transgressing dimensions:

> The non-mathematician is seized by a mysterious shuddering when he hears of 'four-dimensional' things, by a feeling not unlike that awakened by thoughts of the occult [ein Gefühl, das dem vom Theatergespenst erzeugten nicht unähnlich ist]. And yet there is no more common-place statement than that the world in which we live is a four-dimensional space-time continuum.[7] (Einstein 1960 [1916], 55)

6 Transl. by ST. "Das ist nämlich das Kuriose: von den großen Religionen sagen die Leute, sie haben ganz ihren Sinn verloren, sie sind Kirchen geworden. Zu deutsch: Der Spiritus ist zum Deibel. Von der Kunst, oder aber dem Theater, sagen sie es nicht. Warum wohl nicht, Kollege? Schlechte Einstellung des Okulars; sie sehen nicht. Zu dicht vorne oder zu weit ab. Denken Sie sich, ein Riese findet sich im Meerbusen von Mexiko zusammen mit uns ein und benützt unser Schiff als Fußbadewanne. Das wäre ein Mißbrauch unseres Schiffes, das zum Fahren eingerichtet wurde. Aber der Riese steckt seine Füße hinein, und es geht. Da hat es mal eine Kunst gegeben, wie es auch mal richtige Völker, Stämme, Gemeinschaften gegeben hat. Es gab mal ein richtiges Theater. Und dann ist ein Riese gekommen. Auch ich will nicht von der Wirtschaft, der Politik sprechen. Der Riese nimmt das Theater, alles bleibt wie vorher, nach ein paar Jahrhunderten weiß niemand mehr, was dies grandiose feierliche herrliche Möbel eigentlich war" (Döblin 1990, 440–441).

7 "Ein mystischer Schauer ergreift den Nichtmathematiker, wenn er von 'vierdimensional' hört, ein Gefühl, das dem vom Theatergespenst erzeugten nicht unähnlich ist. Und doch ist

The phantom of the theater ["*Theatergespenst*"] vs. the theater's staff, four vs. three dimensional space, the historical timeline vs. the present – all these shifts of perspectives are informed by the same logic of progress (even though they pursue different aims). Einstein found them in the texts of Helmholtz and Poincaré – as an interrelation of body and shadow (illustrating the dimensional jump in analogy). Ultimately, we can trace this figure of thought back to the most influential political and epistemological dialogue of the Western world: Plato's *The Republic* [*Politeia*] and the Allegory of the Cave.

Döblin's dialogue from 1924 provides the basic model for his *Amazon Trilogy*, a text he worked on during his Paris exile from 1935 on. The novel tells the extensive story of the European colonization of South America. At the beginning of the second volume's fifth book *historical turning point* [*Zeitenwende*], the novel refers to the scientific discoveries in Europe, usually at the beginnings of chapters. The simultaneity of colonization and scientific discovery invites a comparison between nature's subjection to unitary laws and the subjugation of the indigenous peoples to the colonial masters, reflecting critically on the Renaissance era (cf. Pfanner 2003). Gradually, the Jesuits' religious experiment in South America and the physical experimentation in Europe come into conflict. Subtly indicated at first, the confrontation becomes a conflict in dialogue at the beginning of the third volume *The New Jungle* [*Der neue Urwald*], extending the historical novel's present to the Weimar Republic. The Polish mythical figure Twardowski calls the physicists Copernicus, Galilei and Giordano Bruno to a last judgment in St. Mary's Basilica in Cracow, confronting them, from a historical distance, with the sociocultural consequences of the insinuated changes in worldview. As a reference to the *Prologue in Heaven* in Goethe's *Faust*, this dialogue is the first of two parts of a conversation between Twardowski and the physicists that frames and contextualizes the stories set in the Weimar Republic (Döblin 1988, 8–20 and 110–120).

The resurrection of the three physicists turns the conversation into a *Dialogue of the Dead* in the tradition of Lucian. To begin, Twardowski, a figure not unlike Faust, holds the Cracovian Nicolaus Copernicus accountable for the physical worldview of the present day; the text calls Copernicus the root of all evil ["*Wurzel alles Übels*"] three times. Galileo Galilei and Giordano Bruno are later brought forward as accused, representing the historical reception of the Copernican worldview intricately linked with the subsequent break with religion. As we can see, the conversation hinges once again on the contextualization of seeing.

keine Aussage banaler als die, daß unsere gewohnte Welt ein vierdimensionales zeiträumliches Kontinuum ist" (Einstein 2009 [1916], 36).

The novel undercuts the primacy of seeing in the dialogue between Copernicus and Twardowski, alluding to the skeletons of the dead:

> "Because you are the root of all evil. Confess to it at least now."
> "I saw it differently."
> "Then you should have ripped out your eyes."
> "I calculated it, Twardowski."
> "You should have thrown away your brain."[8]
>
> (Döblin 1988, 10)

Seeing and calculation designate the base operations of modern sciences. Galileo's unwilling retraction before the Roman Inquisition, which was expressed most concisely in "yet it does move," is acknowledged 300 years later as a firm conviction. Galileo now sees more than he saw in his telescope; he grasps the anthropological consequences of the Copernican discoveries and retracts, referencing the sequence of dialogue cited above, with the following words: "I repent. I should have ripped out my eyes, thrown away my brain" (Döblin 1988, 14).[9]

Since Giordano Bruno does not bow to Twardowski's accusations as promptly as Galileo, he is given more narrative space (the two chapters are called *Herr von Twardowski* and *Giordano Bruno* accordingly). Bruno assumes a mediating position between natural sciences and mysticism of nature. The intertextual references that the novel makes to Bruno's dialogues, such as *On the Infinite Universe and Worlds* or *The Ash Wednesday Supper,* intricately and aptly integrate into the trilogy's narrative structure. In *The Ash Wednesday Supper,* Bruno's Copernican Dialogue, Teofilo critically comments on the colonization of South America: "The helmsmen of explorations have discovered how to disturb everybody else's peace, [how to] violate the native spirits of the regions [...]. They showed new ways, instruments, and arts for tyrannizing and murdering each other" (Bruno 1977, 88–89).

Bruno's alter ego announces a *Zeitenwende,* a change of times that will see the instruments and methods of tyrannizing turn against the ones who invented them. Döblin's *Der neue Urwald* also relates to this. The intertextual references show how Döblin attempts to disclose a tradition in the Renaissance that is

8 Transl. by ST. "'Weil du die Wurzel alles Übels bist. Gesteh es wenigstens jetzt.' / 'Ich habe es anders gesehen.' / 'Dann hättest du dir die Augen ausreißen sollen.' / 'Ich habe es berechnet, Twardowski.' / 'Du hättest das Gehirn wegwerfen sollen'" (Döblin 1988, 10).
9 Transl. by ST. "Ich bereue. Ich hätte meine Augen herausreißen, mein Gehirn wegwerfen sollen" (Döblin 1988, 14).

skeptical of the *arts for tyrannizing*. Teofilo delineates another Renaissance, referring to Bruno: “The Nolan, in order to cause completely opposite effects, has freed the human mind and the knowledge, which were shut up in the strait prison of the turbulent air” (Bruno 1977, 89). Yet again, the dialogue creates a shift of viewpoint, resulting in *completely opposite effects*.

This tension determines the final dialogue of Döblin’s novel. Twardowski gives his skeptical diagnosis of the present a dimension of depth (a fourth dimension) by looking back over the devastations of the past centuries. Following his hymn to the era of the machine that celebrates men as creators (Döblin 1988, 16–19), Bruno gives a different prospect of the Nolan’s future. The positions remain irreconcilable:

> “I am the conscience of your time. I am given the power to summon you and to bring you to justice.”
>
> “Twardowski, you have summoned me too early. Five-hundred years still.”[10]
>
> (Döblin 1988, 118)

This temporal tension is not resolved in the dialogue. Rather, another *Zeitenwende* is announced, one that puts the historical readers on the crossroads of the future.

5 Coda: Copernican turns

After several turns (the relativist, the socialist, and the religious), we finally come back to the Copernican turn with Giordano Bruno. However, we are not coming to a full circle. Rather, an entirely different story of Copernican self-understanding can be observed in Döblin’s texts. This further attests to the ideological openness of the dialogue as a genre, capable of incorporating all of the shifts examined. We might tie in these varied observations with Hans Blumenberg’s understanding of the Copernican Revolution as the most resonating event in the history of metaphors of the modern age:

> Enhancement and degradation of men as Copernican readings take likewise what was originally set and discovered not as theoretical truth, not as constructive hypothesis, but as a *metaphor*. And in fact as an absolute metaphor, in that the Copernican transformation of

10 Transl. by ST. “‘Ich bin das Gewissen deiner Zeit. Mir ist die Kraft gegeben, euch zu rufen und zur Verantwortung zu ziehen.’ / ‘Twardowski, du hast mich zu früh gerufen. Noch fünfhundert Jahre’” (Döblin 1988, 118).

> the cosmos is used as an orientation to answer a question that could never be answered with purely theoretical and conceptual means: the question about the position of men in the world […].[11] (Blumenberg 1965, 127)

From this point of view – re-contextualizing one last time – this short history of the genre of dialogue is a small, form-based building block in a Copernican history of metaphors. It constitutes a productive episode in this history of metaphors that, on the one hand, in a short time assembles many and varied readings and, on the other hand, proves to be a valuable trope of self-understanding that thus sheds light on the cultural field of the Weimar Republic.

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11 Transl. by ST. “Steigerung und Erniedrigung des Menschen als kopernikanische Lesarten nehmen gleichermaßen das, was da ursprünglich gesetzt und entdeckt worden war, nicht als theoretische Wahrheit, nicht als konstruktive Hypothese, sondern als *Metapher*. Und zwar als absolute Metapher, indem die kopernikanische Umformung des Kosmos zur Orientierung für die Beantwortung einer Frage bestimmt wird, die sich mit rein theoretischen und begrifflichen Mitteln noch nie beantworten ließ: der Frage nach der Stellung des Menschen in der Welt […]” (Blumenberg 1965, 127).

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Lutz Kasper

Narrating Science – Physics for Non-physicists

Abstract: At first glance, physics and literature could not be more opposite: unequivocal terms, definitions and objectivity on the one side. Ambiguity, feelings and subjectivity on the other side. Both physics and literature also gain different social acknowledgment. While our society and economy are based on scientific and technical knowledge, it is to this day still no problem not to know the second law of thermodynamics (as C. P. Snow remarked about 50 years ago). Not knowing Shakespeare's works, on the other hand, would be extremely embarrassing.

What factors promote or prevent this development? And what role does school physics play here? This article attempts to answer the question of how we can use narrative-based learning environments for developing interest in school physics and improving learning outcomes. As a possible solution, we describe a subjective and literary form of access to the structure of physics for those people who have difficulties with a purely formal lead-in.

1 Poeticizing science? An introduction

Prima facie, literature and natural science clearly differ in their respective practices. Poets describe moments and courses of events, emotions, situations and relations. Although the objects of their contemplation can often be described in concepts, such as love, hate, pity or envy, they transfer them into lyrical or prose texts. Scientists, meanwhile, attempt to reduce momentary observations and courses of events as temporal and spatial processes to as few concepts as possible. Thus they transfer the *prose* of initial thought – the inner monolog of the struggle to understand, of laboratory log books or discussions with colleagues – to relational propositions and, eventually, to abstract symbolism. These propositions are intersubjectively verifiable, a criterion for them being scientific. The same is not necessary for poetry, prose and drama: different criteria apply to them.

Literature and natural science are also distinguishable by the recognition they receive from society. Physics as a science does not receive recognition from society in the sense that we may not have to hide scientific knowledge, but it is not really

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needed in order to be a successful public person. This fact is attributed here to the key role of the school as an institution. School is key, if we are to hold out the prospect of ameliorating this problematic lack of recognition. In the following, the topic *natural sciences and literature* is considered from the perspective of science education. Thus we are addressing, in a wider sense, education in physics for all those who are inclined or compelled to deal with it. More specifically, we will examine the process of learning physics at school level, and what connects learning about physics with learning about literature.

2 Is there a lack of appreciation for the natural sciences in society?

Countless changes in our everyday surroundings can be traced back to scientific research and creativity. Technical innovation has always exerted a revolutionary influence on all areas of society. In the fourteenth century it was the inconspicuous compass that ultimately enabled seafaring nations to create a new world order, while in the nineteenth century the railways made the world move closer together. However, the specific scientific phenomena shaping current developments remain alien to the majority of people. The result is an increasing *black-box-effect* in our daily lives. While we are the *masters* of a continuous stream of new technologies, our ignorance of them increases with our exposure to them. That is, we are enthusiastic consumers of devices of astonishing capacities and performance levels but we rarely ask ourselves: "Where does this actually come from?" Even more rarely do we pursue this question seriously. This seems to be a clear indicator of low interest in scientific issues or simple helplessness in the face of highly advanced technology.

Society's assessment of the natural sciences can be regarded as dramatic when we consider science in relation to the general concept of education. A much-quoted, provocative statement candidly declares: "While we do not have to hide knowledge in the natural sciences, it is not part of education in general" (Schwanitz 1999, 482). Subsequently, the author of the remark was criticized so vehemently for mapping his own horizon onto a generalized ideal of education (e.g. Fischer 2001) that his publisher decided to omit the quoted passage from later editions of his book. Nevertheless, this kind of perspective resonates in society. Public authorities sometimes demonstrate their scientific (and mathematical) ignorance in the public sphere – not always inadvertently or unwittingly. Nor is this a recent phenomenon. Fifty years ago, C. P. Snow proclaimed in a famous lecture on the *mutual incomprehension* of what he postulated to be two distinct cultures:

> I now believe that if I had asked an even simpler question [instead of asking about the Second Law of Thermodynamics] – such as, What do you mean by mass, or acceleration, which is the scientific equivalent of saying, *Can you read?* – not more than one in ten of the highly educated would have felt that I was speaking the same language. So the great edifice of modern physics goes up, and the majority of the cleverest people in the western world have about as much insight into it as their neolithic ancestors would have had. (Snow 1959, 16)

A peculiar situation arises from the following phenomenon: the *hard sciences* in particular are in fact credited, despite the occasional pretense at abhorring them, with being highly relevant to society. A reluctance to engage in physics or chemistry, combined with a recognition of the significance of these subjects, gives rise to a feeling of a lack of competence that is a kind of inferiority syndrome, a condition we will also encounter in the classroom situation.

From the perspective of the natural sciences, we have to ask whether the situation is really that desperate. Why does the public sector as well as social media regularly strive to present scientific topics to wider audiences? Some of the *media scientists* hosting TV and live shows or video channels have gained celebrity status. Regardless of the quality achieved in these shows, they appear to satisfy an existing demand – not just from specialists – for information and education. In this sense there is no indifference when it comes to the natural sciences and their results. Therefore, it is crucial to make resources available to people that actually help them in their understanding of scientific concepts. This would include, on the one hand, “faces”, entertainers and role models, who set the example of being enthusiastic about science; and on the other hand, good stories and images that develop in the minds of the audience, tying in with what is already familiar or known.

3 Unfulfilled expectations: Science at school

Having considered society as a whole, we should now focus attention on those who are already part of society but who have not yet unfolded their full formative and creative potential, namely children and adolescents at school. How much do young people recognize, accept and favor the natural sciences, and specifically physics, as school subjects?

In students’ perceptions there are, arguably, two kinds of natural science. The first they know from the media, an exciting one that lets us send a manned spacecraft to Mars within the foreseeable future, that continues to speed up our computers, makes our computer screens ever sharper, etc. Then there is a parallel science, that seems completely unconnected with the former: physics as it is taught in the classroom. In what follows I will address physics as a school subject, which is probably primarily responsible for students' scientific image of the world, as well as the attitudes they hold toward physics throughout their lives.

For a longitudinal insight, as it were, let us first of all look back at a twenty-five-year-old survey of students at secondary schools (grade 7 to 10) in Baden-Württemberg (Muckenfuss 1995). In this sense, the study is not representative. However, several similar studies from the same period yield similar results. The students were asked to name their three favorite and three least favorite subjects. Among the three favorite subjects, physics almost made it to the mid-table. In the result of the three least favorite subjects, however, physics placed first! As a side note, it must be said that the big subjects, German and mathematics, polarize students most. The runaway leader among the favorite subjects was sports (Physical Education). Particularly painful from the perspective of physics is the fact that elementary-school children on the verge of attending secondary school come to physics and chemistry with high expectations. This is clearly borne out by the surveys of student interests. However, these expectations are increasingly frustrated with every additional school year. From year five to eight the stocks of physics and chemistry are in freefall, only to stagnate at the lowest level until the end of school! Over the same period, we see a steady increase in students' assessment of the significance of physics for society. The aforementioned inferiority discrepancy widens with every school year and evidently prepares students for the assessment of physics in society as a whole.

The Sasol survey (Sasol Olefins & Surfactants GmbH 2005), conducted ten years later, can be seen to fit in almost seamlessly with the earlier studies. The upper age spectrum of the surveyed students represents the range of the youngest students from a decade earlier. What is striking is the similarity in the resulting ranking: Physical Education is still by far the most popular subject, while physics and chemistry bring up the rear. These are stable findings! The international study known as PISA 2006 falls squarely in the same period. The latter survey yielded, among other things, evidence that fifteen-year-old students from all of the participating countries on average ascribe high importance values to the natural sciences (cf. OECD 2007). Here too, was a clear discrepancy from the markedly lower subjective value of the natural sciences and scientific thinking.

Another ten-year leap finally takes us almost into the present. While no current surveys regarding the popularity of school subjects are available, we can, however, obtain relevant information, on the popularity of subjects from a study by the *Deutsche Physikalische Gesellschaft* (DPG). In 2013, the DPG collected and analyzed data from all over Germany on the provision of instruction and the electoral behavior of students concerning their choice of physics courses

(Heise 2014). More than 210 schools took part in the survey. The study revealed a significant difference between girls and boys regarding their choice of scientific subjects of priority in secondary schools (grade 7 to 10) where such a choice existed. It is striking that at the grammar school level (grade 11 to 12 or 13, in Germany called *Gymnasium*) the proportion of boys choosing physics remains more or less unchanged. Girls choose quite differently. The difference indicates a serious problem that is surely related to the widely accepted image of the natural sciences. This image seems hardly compatible with the expectations entertained by female students. Even if they have chosen physics or chemistry for the last two years of school and achieve good grades in these subjects, they often *veer off the road at the last minute* and decide against studying natural sciences at university. Schools squander a great number of opportunities here to draw on this talent pool in order to produce the next generation of scientists. That is a problem for society, since in Germany there is great demand for young people with excellent qualifications in science and cutting-edge technologies, and precious little by way of supply. What is more, it is a cultural loss in the sense that this effect, having been caused at school, appears to enhance the aloof image of the natural sciences, which is already ingrained in the majority of the population.

4 Symptoms and findings: An interim conclusion

The majority of people have little to do with physics or related fields once they leave the education system. Some of them accede to key positions and thus shape society as a whole. The findings on recognition, ignorance or outright disapproval of physics within societal as well as scholastic contexts give little cause for satisfaction. To put it in a nutshell: while physicists enjoy respect they are rarely regarded as role models. School seems to play a crucial role in this situation, since graduates make up the adult population. After all, school is the place where most people have their only – or only direct – encounter with physics. It is true that physics is rationally accepted as a part of the curriculum. It does not, however, speak to its addressees on an affective level. Thus most students would endorse the statement that physics, while it is arguably important and useful, does not fill them with enthusiasm!

Even without going into a thorough analysis, we can conjecture a number of causes for this situation. Many physical concepts – particularly those of modern physics – can only be grasped after strenuous effort, if at all. The vast majority of society is excluded from this knowledge. Additionally, there is the association of physics with danger and destruction, which has been an element of public opinion since the emergence of nuclear physics. It is a disturbing factor even for experts. Thus the physicist Hans-Peter Dürr (who died in 2014), who had been assistant to Werner Heisenberg and a PhD student with Edward Teller, reported the unsettling insight that it was precisely *his beautiful physics* that had spawned the atomic bomb.

Literature has it easier. We can enjoy literature profoundly; draw energy, joy and knowledge from it, even if we are neither authors nor scholars of literature. The same holds true for the visual arts and music. In general, this cannot be said of physics and people without any specific physical and mathematical training. Herein lies a serious difference regarding the attention people are prepared to bestow on a subject. This gives rise to the question of whether a novice or layman can derive any pleasure from physics at all. From a didactic point of view, this question could prompt an investigation into possible ways of raising levels of motivation and interest, thus leading us back to school as an institution. For it is precisely here that most people have their first (and often last) contact with physics. Therefore, the attitude of society as a whole is essentially shaped by the individual's experience with school physics. This may hold equally for other disciplines. But it is of crucial importance to physics because physics plays a negligible role in the area of active leisure time. Thus we may presume that school is the key to reducing the existing imbalance between the contribution physics makes to culture and its acceptance in society.

Of course, this is not the first time this ambivalence has been addressed. Ways to resolve it have been sought for decades. From the deficit in motivation and interest surrounding physics, as we have described it above, derives an almost traditional effort to improve the teaching of physics at school level. These efforts, which have exclusively targeted the content of teaching, focusing on the question of what is to be taught, have so far accomplished no change. It is of at least equal importance to consider the *how* of teaching physics. The question of how to teach physics leads to a plethora of methodical approaches. In the remainder of this essay I want to present one specific option from among these, connected to literature and the targeting of affective changes.

5 Physics and literature: Windows offering insight

Literature and science have been in a very much longer, but also very much closer relationship with one another than is commonly expected of two such differing ways of seeing the world. Scientists often tell the story of their discoveries and solutions in *factual accounts*, such as personal diaries and laboratory notes. Often we can recognize ideal-typical moments of stories. The *narrative* of a solution process for a scientific problem typically contains descriptions of actions that are justified by beliefs, theories or causal relations. Stories may describe difficulties encountered, complications met and expectations thwarted. Even the violation of norms can illustrate comprehensive innovation. For example, the observation of the rotating plane of oscillation of a Foucault pendulum may disturb every-day-concepts. Competing versions of argumentation may place the narrative under the proviso of a perspective (cf. Kasper 2007, 54). It is precisely such features that make proceedings worth telling.

However, even *real* literature has always reported on spectacular discoveries in contemporary science. Moreover, literature makes reference, among other things, "sensational scientific controversies, hermeneutic hierarchies and other questions of method within the subject" (Thums 2011, 44). Here, the natural sciences acquire emotions and a face. We find anchors for identifying with people and we begin to find more importance in the field of natural sciences. In this way, cultural significance and educational value can be ascribed even to fictional representations. Contemporary literature has always been considered a medium capable of making science more popular. The art of the writer consists in making their readers go along with changes in perspective. Writers make readers take on the role of, for example, a scientific researcher, and compare their own thinking and feeling with that of the protagonist.

Whether this can be harnessed for teaching natural sciences at school depends, most of all, on the actual gains for learning processes that can be derived from insights into the inner world of real (historical) or fictitious personalities. It seems that adolescents are particularly susceptible to the subjective experience of turning nature into a projection surface for their own inner states.

We may assume that at least some proportion of students is open-minded toward a subjective, emotional approach to nature in parallel to the factual, objective approach. They may find the approach of getting to know the inner worlds of strangers, the thoughts and emotions of other people, and comparing them to their own, more accessible than traditional pedagogy. A path of subjectivity and aesthetics that meets this need can lead to the gates, but also into the heartland, of physics. A possible way will be shown in what follows. Enrichment through an affective component could therefore counteract the long-lamented rejection of the subject.

At this point, it is perhaps apt to pause and become aware of a contradiction. Subjectivity and aesthetics are not the most prominent features of physics teaching. Physics as a discipline is characterized by its logical structure and mathematical relations. The textbooks for schools and universities lack a human face, to say nothing of human emotion, in presenting the subject's results. It seems to be the point of science to exclude the subjective. The proposed subjective-aesthetic approach to nature appears diametrically opposed to this: an approach which makes students susceptible to emotion, one which contains a human component, one which has not been purged of error or struggle, and one which does not exclude moral values.

Let me head off one possible misunderstanding straight away: physics as a discipline is so successful precisely because it is scientifically objective, because it has broken away from subjective and emotional dependencies. An introduction to this way of seeing the world has to remain among the goals of a school that professes to provide a well-rounded education. Of course, not every person finds easy access to it. Accessing the conceptual edifice of physics is not a smooth or plain undertaking. Sometimes the very entrance is dimly lit and there are occasional snares and pitfalls. Some will never find the entrance at all. But perhaps they could, if only we built alternative avenues and bridges.

One such bridge could be built by narrative, and in that sense literary, arrangements. The literature market seems to uphold this claim. Despite having suffered through physics classes, many people are fascinated by narrative fiction as well as biographies in the field of the natural sciences. Contemporary science bestsellers, such as Dava Sobel's *Longitude* or Lisa Randall's *Knocking on Heaven's Door*, bear this out. Such popular scientific titles aside, great numbers of literary works with strong connections to scientific themes have been successful over the years, as far back as the novels of Jules Verne in the nineteenth century. A current example is provided by Thomas Lehr's novel *42*, a philosophical thriller that confronts its readers with questions about modern physics.

Apart from the evident appeal scientists have to writers, there are examples of a clear need for poetic means of expression in physics. The American physics Nobel laureate Richard Feynman formulated the intuitively difficult relation of mass and energy in a haiku:

> Principles
> You can't say A is made of B
> Or vice versa
> All mass is interaction.
> (Gleick 1992, 5)

In spite of such examples, the possibility of this connection's viability continues to amaze. It would seem that physics and literature are characterized, in their very features and techniques, by an almost binary semantics: objective – subjective; rational – irrational, quantitative – qualitative; unambiguous – ambiguous.

Identical objects could hardly appear more different when presented in physics and in literature. Like almost no other phenomenon, the rainbow has spurred poets and writers to similes and fantasies. The colorful rainbow, depending on rain and sorrow for its very existence, is employed in literary descriptions as a symbol, subject to cultural context, of peace, hope or love. Physics, by contrast, achieves its *demystification* when it explains the rainbow as an optical phenomenon in the atmosphere caused by dispersion.

Similarly, we are familiar with two moons: the moon of the poets and the moon of the physicists. What is to the former a *serene companion*, *wanderer's escort* or a *blessing of lovers*, the latter (in this instance the astronaut James Lovell, who visited the moon in 1968) describe as follows: "Okay, Houston, The moon is essentially gray, no color; looks like plaster of Paris or sort of a grayish deep sand" (James Lovell at a press conference in 1968, NASA; cf. Brooks, Grimwood and Swenson 1979). The educational theorist Martin Wagenschein, who also holds a PhD in physics, raises the hypothetical question of what people, if asked, would consider to be the *real* moon. The answer is obvious since "the moon of the poets is a perfect, if welcome, delusion." We submit to the scientific moon "because of the precision of its data […] the correctness of which can be verified by anyone" (Wagenschein 1983, 156). However, the commitment to one of two moons only succeeds by the *authoritarian* act of suppressing the other and leads to an impoverishment (cf. Wagenschein 1983). It is, after all, necessary and instructive to gain an understanding of what the one rainbow has to do with the other, or what the one moon has to do with the other.

It is against this background that we will consider the question: How can physics and literature be combined to their mutual benefit in the didactic context? Perhaps a mathematical metaphor is helpful here: if the natural sciences, or the subject of physics, represented the sides of a square, then the diagonals would be the realm of literature. Mathematicians describe the two lengths as incommensurable although they belong to the same geometrical figure. Arguably, the worldviews exhibited by physics and literature are also incommensurable although both belong to the same culture. Yet a last point needs emphasizing. Physics and literature should be understood as two aspects of the same culture that are of equal value. Likewise – at least here, we can carry the analogy of the square further – they have points of contact! I only mention these points of intersection as points of departure for alternative approaches to the so-called hard sciences.

In the beginning, natural science, like so much else, is language. Initially stammering, science begins with the inner language of the people in the lab or at the computer. Later they look for, arrange, and order concepts, comparing and analogizing. By good fortune, such processes sometimes survive in the form of autobiographical texts, lab logs or, as already reflected on, correspondence with colleagues. At this point, we are still firmly in the realm of internal perspectives. During this stage, namely in the transition from prose report to scientific account, emotions are still very much part and parcel of physics: amazement, wonder, admiration and frustration. In short, this is one of the points of contact between literature and physics that is worth pursuing. Another intersection is what natural philosophers and proponents of Romantic Physics at the end of the eighteenth and the dawn of the nineteenth century called for and lived as the *poeticizing of all sciences*. One intriguing example is Novalis' unfinished novel *Heinrich von Ofterdingen*.

One pedagogically useful point of contact between literature and natural science is a certain stage of scientific development: that during which a problem or a phenomenon has already given rise to the first distinguishable scientific models or theories which, by necessity, compete with one another. Usually this competition forms the point of departure for vigorous debates, conducted by rigorous technical arguments, which occasionally play out on a political or personal level.

The subject-didactic value of these discourses lies in the remarkable fact that historical and individual developments in knowledge and concepts often move along parallel lines. To err is part of the phylogenetic as well as the individual development of cognition. Historical errors on the part of the natural sciences are lurking in almost every law of physics and in many of the boxed textbook phrases that students are meant to commit to memory. Packed inside them are stories about the paths researchers have traced through the labyrinth of science, which have sometimes led them astray or into dead ends, stories about the roads to success, or the roadblocks, and the allurements that often put the goal out of sight; stories about what the researchers felt along the way. Hence, these are stories not yet purged of the human element of natural research. An understanding of the natural sciences – not just of their results but also of their processes – cannot be achieved by guiding students along the shortest or most *correct* path through the labyrinth. Rather, it can be achieved by allowing them to grasp the structure of the maze as a whole, preferably by allowing them to acquaint themselves with it by walking it *in their own shoes*. Such access to nature (and the science of it) requires a kind of mediation that includes – in addition to the essential techniques that are inherent in the culture of the discipline: the experimental, deductive, inductive and mathematical methods – narrative components. Narrative sections of physics courses in a wider sense could be created by *unpacking* the stories hidden behind the formal condensations (cf. Kasper 2011, 160).

An example from the historical development of knowledge of the phenomenon of geomagnetism is provided by no less a figure than Christopher Columbus himself. Fortunately, the logbooks of his voyages have survived, affording us the chance to share a momentous personal experience: the actual discovery of magnetic declination on his first voyage in 1492. In Washington Irving's literary biography of Columbus, based on Columbus' logbooks, we find the following passage on this discovery:

> On the 13th of September, in the evening, being about two hundred leagues from the island of Ferro, Columbus for the first time noticed the variation of the needle; a phenomenon which had never before been remarked. He perceived about night-fall, that the needle, instead of pointing to the north star varied about half a point, or between five and six degrees to the northwest, and still more on the following morning. Struck with this circumstance, he observed it attentively for three days, and found that the variation increased as he advanced. He at first made no mention of this phenomenon, knowing how ready his people were to take alarm, but it soon attracted the attention of the pilots, and filled them with consternation. It seemed as if the very laws of nature were changing as they advanced, and that they were entering another world, subject to unknown influences. They apprehended that the compass was about to lose its mysterious virtues, and without this guide, what was to become of them in a vast and trackless ocean?
> (Irving 1834, 640)

A description of the situation of the discovery of magnetic declination that provides even more drama is found in the German translation of the logbook. According to this version, Columbus faced the threat of open mutiny and being thrown overboard.

> Donnerstag, den 13. September [1492]: Wüsste ich nicht, dass der Allmächtige seine schützende Hand über mich hält, müßte nun auch ich den Mut verlieren. Ich stehe einem Rätsel gegenüber, auf das vor mir wohl noch kein Seefahrer gestoßen ist. […] Die Magnetnadel wies, anstatt auf den Nordpol zu zeigen, ungefähr einen halben Strich nordwestlich. Eine Erklärung? Ich weiß keine! […] Freitag, den 14. September: Je weiter wir nach Westen fuhren, desto mehr weicht die Nadel ab. […] "Die Grundgesetze der Natur gelten nicht mehr," hielt er [Juan de la Cosa] mir schreiend vor. Hinter de la Cosa standen die anderen. […] Von ihren finsteren Gesichtern war nur zu deutlich abzulesen, dass sie planten, mich über Bord zu werfen. Ich versuchte, ihnen die Abweichung zu erklären – vergeblich! (Grün 1983, 83–84; additions by LK)

We know, of course, that Columbus was not thrown overboard and that a short while later he made the discovery with which his name is associated to this day. A heron appeared in the sky above the ships with exquisite timing, indicating the vicinity of land and thus sparing the captain from mutiny. This little snippet alone raises fruitful questions for vivid science teaching. What caused the aberration or declination of the compass needle in the first place? How was Columbus able to measure it? What is the explanation for the change in declination on the ship over the course of his East-West Atlantic crossing?

A far more complex example from the realm of physics is provided by the concept of heat, which had been contentious for centuries. This historic and well-documented process is reflected in almost all its facets in the inadequate physics conceptions of today's students at schools and universities. That is the reason, above all others, why this example lends itself perfectly to narrative, drama and, most of all, introductions to the essence of natural sciences. The instance in question is a moment in the eighteenth century that is compelling in light of both its scientific and human interest. I have in mind the first (of several) highlights in the controversy between proponents of phlogiston hypotheses and those advancing a kinetic explanation of heat. It is also one of the roots of the movement toward the emancipation of women. The protagonist of this story is Émilie du Châtelet, also known as divine Émilie. Probably a highly gifted child, she grew up in the wealthy conditions of Parisian aristocracy and, as a young woman thirsting for education, pushed the limitations of her times. Women were barred from entering universities. Émilie, however, was privately educated by prominent teachers, such as the mathematician and philosopher Pierre-Louis Moreau de Maupertuis. Moreover, she conducted an affair with Voltaire that lasted many years. They lived together in a chateau (which belonged to her tolerant husband!) where they built a laboratory and a scientific library to match the universities of their time. In 1737 the Paris Academy announced a handsome sum of prize money for the best scientific essay on the subject The Nature of Light, Heat and Fire. Voltaire, a fervent advocate of Newton's ideas, entered the competition. Unbeknownst to him, Émilie also took part. In her anonymous essay, she proposed ideas that basically anticipated the postulation of thermal radiation, ideas that were implemented in experiments by William Herschel some eighty years later. Incidentally, neither Voltaire nor Émilie won the academy's prize, which went to Leonhard Euler. Both of their essays, however, were included in a volume containing the best five contributions. I have described elsewhere how this material may be developed, on the basis of a fictitious dramatic classroom example, into a concrete idea for teaching (Kasper 2014).

6 Scientific controversies as dialectic approaches for learning processes

Regarding the dynamics of the development of scientific cognition, there are structural similarities between the history of the natural sciences and individual learning processes. In both cases knowledge is developed discontinuously. In science, stages of competing theories are often dominated by the formation of ever-more auxiliary hypotheses to the theory until the theory is no longer feasible and a paradigm shift occurs. Strictly speaking, this is about the competition of a series of theories, or progressive systems of theories (cf. Lakatos 1974). Such series of theories develop if the occurrences of anomalies necessitate the amendment of the theory by adding auxiliary hypotheses to protect or isolate the heart of the theory or even by semantic reinterpretations of concepts. The necessity of such auxiliary hypotheses for *ailing* theories is almost programmatic for scientific development. Famous examples include the Ptolemaic system of cosmology and, more recently, the Bohr atom model. It is not rare for the formulation of an anomaly to become part of the hard core of a rival theory. Often such processes of paradigm shift generate well-documented controversies. So let us take these debates, let us stage and prepare them for the classroom, for a kind of teaching that actually picks up the students from where they stand. Let us walk with them the detours, which were taken in history and which are perhaps necessary to help them accomplish their very own conceptual shift.

Fostering metaconceptual knowledge depends heavily on providing an appropriate learning environment: "To help students to increase their metaconceptual awareness it is necessary to create learning environments that facilitate group discussion and the verbal expression of ideas" (Vosniadou 2001, 186). What is formulated here is the need for a linguistic-communicational appraisal of technical themes. A possible way of implementing this consists in a dialectical approach to physics teaching, for example by staged controversies. What we offer the students are proposals rivalling their own inadequate concepts. For this approach to succeed it is important for teachers to be familiar with the *hard cores* of students' notions and to perceive the construction and structure of their *insulating protection*. Only then can we be successful in developing competence by means of conflict-inducing processes. Fictitious controversies (based on historical facts) implemented in multimedia are suitable for the design of correspondingly appropriate lessons (cf. Kasper 2008). The didactic value added to the subject of physics consists in both an "increased metaconceptual awareness" concerning the development of models and knowledge, and a process of developing technical concepts. To engage learning processes it is of crucial importance to focus, above all, on the epistemic features inherent in the controversies. These include, for example, challenging premises and assumptions, and a usually open-ended as well as *soft* rationality, which transcends purely inductive and deductive logical rules of inference, e.g. by allowing prudence as a criterion for rationality (cf. Dascal 2006, 29).

Finally, I would like to counteract the impression that controversies apt for staging in classrooms can only be found in history. Addressing current scientific debates, which are focused mainly on ethical issues and which are yet to be resolved, provides excellent potential for scientific as well as social education.

Examples of such contentious issues are found in discussions of nuclear energy, cold fusion, pre-implantation genetic diagnosis, creationism and intelligent design, anthropogenic climate change, the (un)restricted use of nanotechnologies and many more.

7 Conclusion

Many people find a formal or objective access to contents of physics as a school subject quite difficult. So they will often leave the school without adequate concepts in physics and with a lack of interest in scientific questions. On the other hand, physics as a science is successful because it is free from all subjective and emotional dependence. Nevertheless, we see in story-telling-based learning environments, enriched with subjective and emotional perspectives, an alternative way, which facilitates entry to the edifice of physics for students. For this purpose, the development of fictitious learning units based on real scientific debates and real competitive scientific theories may be particularly suitable. Apart from mediating actual physics content, the 'human aspect' of science is revealed, and it helps to increase students' metaconceptual awareness. Therefore we see in this approach an important contribution of physics to general education and maturity.

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Ignatius McGovern

The Making of *A Mystic Dream of 4*

Abstract: A book with the title *A Mystic Dream of 4* (McGovern 2013, 3) suggests elements of spirituality, Freudian psychology and number theory. These themes do play out in minor roles but the larger purpose is revealed in the word "Making" in the title of this article: *to make* derives from ancient Greek as *poiesis*, the root of the word poetry; in Scottish Gaelic, the poet is known as a *makar*. But its more general meaning, of course, is to physically construct something. Perhaps the something here is a book of poetry? – actually, it is best described as poetic biography, as the subtitle reveals: *A sonnet sequence based on the life of William Rowan Hamilton*. Even so, what has this to do with the topic *Physics & Literature*?

Broadly speaking, there are two answers to that question. The first, which is of less importance, concerns the author. I have just retired after 35 years as Professor of Physics at Trinity College in Dublin. My research area was what is now known as Nanoscience and my specialty was Synchrotron Radiation Spectroscopy, work that brought me frequently to Berlin. A photograph from when I used to *make* experiments there has me standing beside a vacuum chamber that displays the warning notice "System is Hot!" I like to contrast that photograph with a more recent one of me reading my poems at a literary festival, not least because that same warning notice might equally apply here too. For, if I examine the two photographs more closely, it seems to me that the physicist exhibits a gentle light-fingered touch, while the poet offers clenched fists! Is this my imagination, or should it be the other way round? Moreover, how can these two pictures be merged into one consolidated entity? Are these personal queries at all relevant to the topic at hand?

Returning to the main theme, the second, and more important, reason for considering this book is its subject. William Rowan Hamilton was a nineteenth century Irish mathematician; indeed, he is arguably the greatest mathematician of his time; in evidence of that, when the American National Academy of Sciences elected its first foreign members in 1864, Hamilton's name was top of the list! He had made significant contributions in a number of areas, many of which bore greater fruit in the following century; for confirmation, ask any physicist about the symbol H (the Hamiltonian) in Schrödinger's wave equation! Equally significant, at least for ELINAS-style purposes, he was also a poet!

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So, I suggest that here is more than enough to keep this book *on the books*, so to speak: a physicist who is also a poet writing about a mathematician (actually a mathematical physicist) who is also a poet; a system exhibiting crude mirror symmetry and some vestiges of a double helix? In the latter regard, I intend to weave into the formal description of the making of this book, something of the personal issues about science/poetry that sometimes confront me in the small hours.

But, let me start with the book, and with the first line of the book, its title. In the best tradition of T. S. Eliot's remark "bad poets borrow, good poets steal", *A Mystic Dream of 4* is taken from a line of Hamilton's own poem about his discovery called *The Tetractys* (Graves 1885, 525). The polymath Hamilton was also a Classics scholar and the tetractys is the Pythagorean mystic symbol of 10 points, arranged as a triangle of one, two, three, and four membered lines, and representing Unity, Power, Harmony and Cosmos. In English-language poetry, a tetractys is a syllable-counting form with five lines. The first line has one syllable, the second has two syllables, the third line has three syllables, the fourth line has four syllables, and the fifth line has ten syllables. (See Appendix for my tetractys poem *Stone*, inspired by Klaus Mecke's (2014) lecture at the ELINAS inaugural conference.) Hamilton's poem, however, is a sonnet!

THE TETRACTYS

Or high Mathésis, with its "charm severe
Of line and number", was our theme; and we
Sought to behold its unborn progeny,
And thrones reserved in Truth's celestial sphere;
While views before attained became more clear;
And how the One of Time, of Space the Three,
Might in the chain of symbol girdled be:
And when my eager and reverted ear
Caught some faint echoes of an ancient strain,
Some shadowy outline of old thoughts sublime,
Gently He smiled to mark revive again,
In later age, and occidental clime,
A dimly traced Pythagorean lore;
A westward floating, mystic dream of FOUR.

My title then truncates the last line of the poem. *The Tetractys* was written in 1846, three years after his significant discovery of what he termed the Quaternion. Hamilton had been working on and off for ten years on a mathematical problem. He had been trying to extend the idea of complex numbers from two to three dimensions. But on 16 October 1843, while walking with his wife from his home in Dunsink Observatory to Dublin city center (a distance of ten kilometers) he suddenly realized that he needed a fourth dimension. Hamilton recounts the discovery in a letter to his son Archibald:

> An electric circuit seemed to close; and a spark flashed forth, the herald (as I foresaw, immediately) of many long years to come of definitely directed thought and work, by myself if spared, and at all events on the part of others, if I should even be allowed to live long enough distinctly to communicate the discovery. Nor could I resist the impulse – unphilosophical as it may have been – to cut with a knife on a stone of Brougham Bridge, as we passed it, the fundamental formula with the symbols, i, j, k; [...]. (Graves 1885, 435)

The further development of quaternion algebra consumed the remaining twelve years of Hamilton's life but it never attained the heights he hoped for, as *the vector men* took hold of its best parts! But, like many discoveries, its time came a century later with applications both in video-gaming, as in the tumbling cartoon character, Lara Croft, and in spacecraft guidance: the pioneering astronaut Neil Armstrong paid homage to Hamilton's bust in the Long Room Library during a visit to Trinity College, saying "this is the guy that got us home!"

I am conscious that I have seemed to stray from the centrality of this article, the making of the book. But it is necessary to give a little historical background, and not only to justify my title. Quaternions, at least on the surface, offer the simplest of Hamilton's mathematical successes, and suggest that they should be a strong presence in the making of the book. In that regard I must be grateful to Hamilton for writing that his quaternions were: "born, as a curious offspring of a quaternion of parents, say of geometry, algebra, metaphysics, and poetry" (qtd. in Brown 2013, 113).

And this was not just clever word-play, he really did believe that poetry was an integral part of his scientific work! Fortunately, his sixty years span of life divides neatly into four parts, which I have labeled for these four *parents*. Indeed the first sonnet in each part is in the voice of one of these. For example, the opening sonnet of Part I is in the voice of *Geometry*:

GEOMETRY

Once, any pupil could define me best:
"points, lines, angles and figures", could amuse
The table with the Christmas cracker jest
About 'the squaw' on the hypotenuse!

I was the Lord of Space, the one in three
Dimensions where you lived each mortal day,
Coordinates describing pointedly
A final resting place in graveyard clay.

> But that's to come; for now reserve your pity,
> Observe the longitude and latitude
> Of Dominick Street, the kingdom's second city,
> A multigravida in plenitude
>
> And my coy mistress, Time, deploys her power
> To act precisely on the midnight hour.
> (McGovern 2013, 19)

Although this sonnet is relatively understandable – the weak pun "squaw" for "square" notwithstanding – it was necessary to include brief explanatory notes with each of the remaining sonnets. As to the number of sonnets, these had to be a total of some power of four: four squared (sixteen) being too short and four to the fourth power (two hundred and fifty-six) too long – although there is an infamous *book* by Raymond Queneau containing ten to the power of fourteen (one hundred thousand billion) sonnets, but that's another story – I quickly settled on four cubed (sixty four).

Each part then has fourteen of what I call person-sonnets, sonnets in the voices of people who knew Hamilton and who tell some part of the story of his life. These include family members, scientific colleagues, poets, revolutionaries, clergymen, lovers and rivals. That leaves the four sonnets that close the four parts. These are in the voice of Death, an ironic voice, who tells us *inter alia* who has died in that part of Hamilton's life.

Part I is based on Hamilton's childhood, which is chiefly recalled by family members. A significant interloper is a near contemporary called Zerah Colburn, also known as *The Calculating Boy*. Colburn was an American with a gift for mental arithmetic, who came to Dublin on a performance tour; Hamilton competed with him – and lost – which may have piqued his interest in mathematics:

> ZERAH COLBURN (Performer)
>
> How many minutes since Christ went to Heaven?
> What are the two prime factors of, say, four,
> Two nine four, nine six seven, two nine seven?
> All ere the second's hand will mark a score.
>
> They billed me as *The Calculating Boy*:
> What cogs and wheels were whirring 'neath my crown
> To entertain street trader and Viceroy?
> I almost met my match in that drab town . . .
>
> I cared naught that I never understood
> Exactly how I did it, whereas he

Was interested less in magnitude
And more in finding methodology.

I see him living well into his pension,
Computing Christ's velocity of Ascension!
(McGovern 2013, 31)

Part II covers Hamilton's early career, beginning with his outstanding performance as an undergraduate student, winning major prizes in both Classics and Science, a performance that earned him the Professorship of Astronomy while still technically a student! In this regard he was much in debt to his College Tutor, Charles Boyton, who knowingly exaggerated his pupil's talent in star-gazing. But Hamilton's mathematical ability more than justified his appointment, as when five years later he predicted an optical effect known as *Conical Refraction*. This effect, in which a beam of light is transformed into a cone in certain crystals, is relatively easy to demonstrate with a modern laser source. The confirming demonstration by Hamilton's colleague Humphrey Lloyd using a beam of sunlight was itself a major achievement, as Lloyd might wish to complain:

DR HUMPHREY LLOYD (Colleague)

I'd read his tour de force, *System of Rays*
But unlike him had missed the satisfaction
Of proving a biaxial displays
The marvel that is conical refraction.

Immediately he's tugging at my sleeve
Demanding that I do the measurement:
These theorists mistakenly believe
That pen and paper makes experiment!

At first my sample of aragonite
Was much too thin for decent separation;
That it was 'macled' added to my plight
But Dollond's crystal saved the situation.

I did it, but it was a close-run thing
With Airy and some others on the wing.
(McGovern 2013, 50)

Although I have not attempted to explain the origins of conical refraction, there is still too much scientific terminology in that sonnet – "aragonite", "macled" and even "biaxial" cry out for explanation. And this raises a general issue around science in poetry or poetry in science, the glossary of uncommon terms.

Poetry relies on common language (even when it seeks to subvert that language) and the language of science is already cabalistic in its own right.

Still, Hamilton's friend and fellow poet, Aubrey de Vere could label conical refraction *The Radiant Stranger* and poetic interactions were also a significant feature of this part of Hamilton's life. Shortly after his appointment as Professor of Astronomy, Hamilton travelled in the Lake District of England, where he encountered the Romantic poet, William Wordsworth. They became lifelong friends and correspondents and poetry was not the sole basis of their conversation, as Science also featured. Indeed, given that Wordsworth's degree was in Mathematics, they had much in common. However, their shared poetic sense of Science was being challenged by the successful march of practical or engineering science and it is that *useful knowledge* which finally separates science from poetry. Hamilton was particularly incensed to learn that the Liverpool-Manchester railway was being touted as the highest manifestation of Science! Instead, the growth of experimental science and its partner engineering combined with the rise of Romanticism would cause divorce among Hamilton's quaternion of parents that would result in poetry leaving home!

Hamilton regularly sent his poems to Wordsworth and Wordsworth was forthright in his comments:

> You will have no pain to suffer from my sincerity. With a safe conscience I can assure you that, in my judgment, your verses are animated with true poetic spirit, as they are evidently the product of strong feeling [...] Now for the *per contra*. You will not, I am sure, be hurt, when I tell you that the workmanship (what else could be expected from so young a writer?) is not what it ought to be. (Graves 1882, 266–267)

Moreover, it was Wordsworth who told Hamilton that he would achieve more fame as a mathematician than as a poet, and that he should not try to be both! I have yet to receive like advice but I often wonder whether that is due to reticence, whether on the part of fellow poets or of fellow physicists. The physicists may enjoy having a poet as a colleague (if only to tease their friends in English Literature) but they wouldn't hesitate to fire me if all I did was write poetry! Certainly, I have never attached my creative bibliography to any application for science funding. Might these attitudes be changing, at least in Erlangen?

Part III finds Hamilton at the peak of his mathematical productivity. Key papers such as *On a General Method in Dynamics* and *Algebra as the Science of Pure Time* would be followed by the discovery of quaternion algebra. He was now married but there was a shadow on the marriage: while an undergraduate he had fallen in love with Catherine Disney, the sister of a fellow student. But Catherine was already promised elsewhere and the severance would affect both of their lives, most seriously in Catherine's attempt at suicide some years later.

Hamilton's wife was not unaware that her husband still had feelings for Catherine. Moreover, she was not esteemed by Hamilton's friends and colleagues, largely because she was almost invisible (by virtue of ill health and personality). So, Lady Hamilton sets out to claim her place, if only because she was there for the *Eureka Moment*.

LADY HELEN HAMILTON (Spouse)

A Lady, yes, but still without a carriage,
Long treks to Dublin at a walking pace
And there were always three souls in our marriage
Or four, if you count Missy Curraghchase!

I knew about the whispers behind-backs
That I was just a phantom of a wife,
My absences the focus of attacks;
As if my presence could enlarge his life?

But I was witness to his darker days,
A genius, yes, but still a child half-grown;
I weathered his precocious wants and ways
And gave him three strong children of his own

And I was midwife when, against the odds,
He brought forth his canal-bank set of quads.
(McGovern 2013, 61)

In the concluding Part IV Hamilton is beset by many issues. I have joked in the introductory paragraph that the title of this book might promise elements of spirituality, Freudian psychology and number theory; in fact, all of these feature to some degree. The Oxford Movement induced many Anglicans to convert to Roman Catholicism, including two of Hamilton's closest friends, the poet Aubrey de Vere and Viscount Adair (a former pupil). Hamilton suffered from depression and attempted to medicate his condition with alcohol; at one stage he took a pledge of abstinence but lapsed shortly after. But he continued to work, even overwork, on his mathematics, largely on quaternions. In 1853 he published a 700-page book *Lectures on Quaternions*, which sold very few copies; he then began work on what was meant to be a shorter primer *Elements of Quaternions*; this book was published posthumously and ran to 500 pages. Although the mathematician Peter Tait mounted a spirited defence, interest in quaternions waned after Hamilton's death.

However, Hamilton's other earlier work found their champion in the twentieth century; Erwin Schrödinger had received a thorough grounding in Hamiltonian dynamics from his professor, Hasenöhrl, who, in turn, was a student of

Sommerfeld. Schrödinger gave the Hamiltonian formulation a central role in his construction of wave mechanics. On that basis, Schrödinger is included in the list of sonnet-makers. The fledgling Dublin Institute of Advanced Studies, whose first head was Schrödinger, was quartered in buildings known as *Teach Hamilton* ("teach" is the Irish word for house):

> ERWIN SCHRÖDINGER (Mathematical Physicist)
>
> *Teach Hamilton* – our happiest of days
> Among a people wonderfully odd,
> As when O'Nolan linked our first forays
> To write of "Two St Patricks and no God!"
>
> He is, perhaps, the ghost in the machine
> Of Quantum Physics, with his clanking chain
> Announcing the analogy between
> Mechanics and optics; first to distain
>
> Commutativity; re-formulation
> Of energy in systems large and small;
> He is the "H" in Schrödinger's Equation
> And hence the Doktorvater of us all.
>
> Teach Hamilton? As well the stars above
> Unless, perhaps, in Elements of Love.
> (McGovern 2013, 87)

The Schrödinger connection prompts some further thoughts on physics and poetry; in his book *Erwin Schrödinger and the Quantum Revolution* the popular science writer John Gribbin describes Schrödinger's poetry as

> a pastiche of the kind of poetry you would expect a physicist to write – it is technically correct, in terms of meter, rhyme and so on, but lacks the emotional impact of the work of a true poet. (Gribbin 2012, 217)

As regards "meter, rhyme and so on" I may be guilty as charged in *A Mystic Dream of 4*, but that is the nature of poetic biography. However, I do wonder what Gribbin might mean by "true" as in "a true poet"? Is that somehow different from a true physicist? This book aside, I hope that the reader of my other poetry would not so easily deduce my profession. As it happens, there is a tart companion piece from Schrödinger's fellow Nobel Prize-winner, Paul Dirac. Dirac is reported to have said to fellow theoretical physicist, Robert Oppenheimer:

> How can you do physics and poetry at the same time? The aim of science is to make difficult things understandable in a simple way; the aim of poetry is to state simple things in an incomprehensible way. The two are incompatible. (qtd. in Mehra 1972, 52)

At the very least these statements invite further discussion that ELINAS might investigate. But, on the question of physics and poetry *at the same time*, I find some comfort in remarks by Hamilton in a letter to Wordsworth:

> My dear Wordsworth
>
> As Keats exclaimed ‘O for ten years that I may overwhelm myself in Poesy,’ so you will perhaps exclaim ‘O for some Pause that Mr Hamilton may not overwhelm me with his verses! *Occiditque legendo!*’ What makes the matter worse, and your case more desperate, is that this is far from being my idlest time; on the contrary it is my busiest, and I am in the midst of a course of lectures, of which I am delivering *two* (a physical and a mathematical) every second day, in our university. The only hope is that I am rather perverse and often go by contraries, as soon as Science may leave me comparatively at leisure I may cease to versify too. (Graves 1882, 486)

Finally, it seems appropriate to finish with one of the four sonnets in the voice of Death. Although Hamilton was born over two centuries ago, many of his life experiences seem entirely modern. When he died he was almost bankrupt largely through supporting his eldest son’s enterprises, there were periods of his life where alcohol and depression combined to his detriment, and he suffered in his lifelong obsession with Catherine Disney. He also endured the antagonism of fellow Trinity Professor of Mathematics, James MacCullagh, who claimed priority with regard to much of Hamilton’s research. MacCullagh subsequently committed suicide, an event that also weighed heavily on Hamilton. Although Hamilton had been orphaned at the age of fourteen, he was fortunate in a succession of father-figures, including his Uncle James Hamilton who raised him, his cousin Arthur Hamilton who supported him financially in college, his Trinity College tutor Charles Boyton who ensured his appointment to the Chair of Astronomy and, of course, Wordsworth. These latter five individuals all died in the third quarter of Hamilton’s life, as recorded by the sonnet that closes Part III. That period also witnessed the disaster of the Great Famine in Ireland.

> DEATH
>
> A feast or famine? – famine *is* my feast!
> Who lives or dies is in the penny’s toss.
> He kept his head down at his sums; at least
> He sought no profit from another’s loss.
>
> He coined me five across the River Styx:
> First, Cousin Arthur, fountain of goodwill,
> Then Boyton, star of College politics
> And Uncle James, the lowly curate still.

He mourned these and moved on, as if by rote;
The fourth, though, haunts him like Old Marley's ghost:
The vision of MacCullagh's bloodied throat,
So much alike, affecting him the most.

And Wordsworth, in the poet's own words 'bound
Within the sonnet's scanty plot of ground.'
(McGovern 2013, 70)

POSTSCRIPT: see https://zenodo.org/record/3406824#.YTS4_Z5Kjos for Anne van Weerden's recent research on Helen Bayly and Catherine Disney.

Appendix

STONE

for ELINAS

place
motion
ensemble
eigenfunction
quantum mechanical states in Fock space.

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