Introduction

Does the universe have a beginning and does it have an end? What are the basic constituents of the universe? What determines the geometry of space and time? Classical and relativistic physics provide different answers to questions of this kind, thus constituting different scientific worldviews. How did the relativistic worldview emerge from the classical one? Which personal, cultural, and societal contexts played a role in this transition? How was this transition perceived by different communities? And what developments indicate that the worldview of physics keeps changing? These are some of the issues that are dealt with in the present volume.

The volume presents a collection of contributions to the seventh in a series of interdisciplinary conferences dedicated to the history and foundations of general relativity, which have been held since 1986 in locations alternating between the United States and Europe. One of the remarkable strengths of this series of conferences has been the dialogue it has fostered among historians, philosophers, and physicists, looking at the development and the foundations of general relativity from different perspectives. The seventh conference, jointly organized in La Orotava, Tenerife by the Fundación Canaria Orotava de Historia de la Ciencia, the Instituto Astrofisico de Canarias, and the Max Planck Institute for the History of Science, had a special character since it took place in 2005, marking both the centenary of Einstein's *annus mirabilis* and the fiftieth anniversary of his death.

The volume reviews conceptual conflicts at the foundations of physics now and in the past century. The focus is on the conditions and consequences of Einstein's pathbreaking achievements that sealed the decline of the classical notions of space, time, radiation, and matter. Particular attention is paid to the implications of conceptual conflicts for scientific views of the world at large, thus providing the basis for a comparison of the demise of the mechanical worldview around 1900 with the challenges presented by cosmology around 2000. In this regard, the present volume complements the four-volume series, *The Genesis of General Relativity* (Springer, 2007), which focuses on the emergence of Einstein's theory of gravitation from the knowledge of classical physics. As in the *Genesis* volumes, Einstein's contributions are not seen in isolation but rather are set into the wider intellectual context of dealing with the problem of gravitation in the twilight of classical physics. In the

spirit of these volumes, the investigation of the historical development is pursued with a number of epistemological questions in mind, concerning in particular the transformation process of knowledge associated with the changing worldviews of physics.

At the Limits of the Classical Worldview

While general relativity constitutes a break with fundamental notions of classical physics, such as the assumption that space and time form a rigid framework serving as a stage for physical interactions, it is deeply rooted in knowledge of classical physics that has accumulated since the time of Newton. Even ideas such as the deflection of light by gravitational attraction, the relativity of inertia and its connection with gravitation, as well as the role of non-Euclidean geometry for the large-scale structure of the universe, have been discussed within the context of classical physics. The contribution by Renn and Schemmel discusses the broad array of theories of gravitation that were being proposed prior to the advent of general relativity. These theories reveal the potential of classical physics to respond to the challenges of rethinking gravitation in light of the advances by around 1900 of field theory, observational astronomy, mathematics, mechanics, and philosophy. The paper by Eisenstaedt looks further back at the way in which the relation of light and gravitation was dealt with in early Newtonian physics, anticipating insights of the later relativistic treatment. In his contribution, Gereon Wolters discusses Mach's reaction to Einstein's relativity theory, which traditionally has been understood as an outright rejection of the theory by one of its most important intellectual predecessors. Wolters thus sheds light on how the relation between heuristic principles taken from classical physics and the unexpected outcomes of their elaboration was reflected in the personal realm.

Contexts of the Relativity Revolution

Was the relativity revolution the outcome of a general cultural turn away from absolutism in societal, artistic, and scientific values to their relativization? In view of the role of the long-term development of knowledge for the emergence of both special and general relativity, such a naive view seems hardly tenable. Nevertheless, the cultural and political contexts of Einstein and his contemporaries did play a role in shaping the formulation of their scientific work, as well as its interpretation and reception. Einstein's political views, for instance, became part of his self-image as a freethinking, independent intellectual unbound by societal commitments, an image that must have fostered his intellectual independence in science, too. Schulmann's contribution traces Einstein's political views back to their roots in the period that also was formative for his science: the Swiss years prior to his *annus mirabilis*. Sánchez-Ron's analysis offers insights into the philosophical reception of relativity in Britain. It reveals a surprising agility of the proponents of different philosophical viewpoints in turning Einstein's scientific theories into support for their views.

In South America, the early reception of relativity also took place in the context of different philosophical frameworks and was triggered, in particular, by Einstein's visit to South America in 1925, as Tolmasquim points out in his reconstruction of the trip. But the relativity revolution had an impact not only on science and philosophy but also on literature and the arts, a theme that is taken up with a skeptical tone in the contribution of Hubert Goenner. As Goenner makes clear, it was ultimately Einstein's fascinating personality rather than the actual content of his scientific work that appealed to artists and writers.

The Emergence of the Relativistic Worldview

The emergence of a relativistic worldview was not a sudden event and was far from being completed when Einstein published his general theory of relativity in 1915. Important conceptual implications of the theory for the understanding of physical reality continue to be discussed even today. The contributions in this section present foundational issues, their contexts, and some of the protagonists in the profound conceptual development of general relativity since 1915. Brading and Ryckman return once more to the much-debated question of Hilbert's impact on this process, claiming that Hilbert's work on general relativity in the year 1915 was motivated by the concern to resolve the alleged tension between the requirement of general covariance and that of causality, which Einstein thought he had identified with the hole argument. Kennefick's contribution challenges the historical myth that the first observational confirmation of general relativity was due to an intellectual bias of Eddington and offers a new analysis of the question of the reliability of the results of the 1919 solar eclipse expedition. In their respective contributions, Goenner and Salisbury review the lives and works of two of the most influential scientists to shape the development of general relativity in the generation after Einstein: Peter Havas and Peter Bergmann. Their technical achievements in general relativity were closely associated with a deep philosophical, historical, and political awareness of Einstein's intellectual legacy. The paper by Schutz offers a broad survey of the conceptual revolution created by the development of general relativity, culminating in the equally surprising and profound claim that general relativity did not become a theory of physics until the 1970s, when a set of heuristic concepts emerged that was suited to communicate the results of the theory, connecting the results with insights achieved in other parts of physics, in particular astrophysics.

A New Worldview in the Making

The last section of the volume deals with a number of current issues. Recent developments confirm the impression that we are witnessing the emergence of a new worldview, triggered by new empirical findings as well as by theoretical achievements transcending the framework of general relativity. The section begins with a survey by John Beckman of the history and present state of observational tests of general relativity showing the solidity of Einstein's theory even in view of the

most refined observational techniques currently available. Yet, the richness and complexity of recent observational data, as well as the expected yield from ongoing or planned observational projects and space-bound missions, indicate that the established understanding of the early universe and its development may be challenged. An example, discussed in the contribution by Battaner and Florido, is provided by primordial magnetic fields and their impact on the properties of the cosmic microwave background that may be detected by the forthcoming Planck space mission. But the established picture is also being challenged on the theoretical side. It is, for instance, remarkable to consider the extent to which even the mathematical elaboration of general relativity and the physical interpretation of its solutions, in particular of their properties such as singularities, are still under discussion, as the contribution by Senovilla reminds us. It is equally astonishing to see that, in spite of the many open issues still hampering the synthesis of general relativity and quantum theory, it is nevertheless possible to attain rather firm insights with regard to certain conditions that a future synthesis must satisfy. As in other cases in the history of physics, such progress could be achieved by exploiting an intermediate territory between the two theoretical frameworks to be integrated. The contribution by Wald offers an impressive review of the theoretical treatment of quantum fields in a curved spacetime, arguing that this treatment offers important hints for a future unification. The contribution by Dray addresses the borderline problems between relativity and quantum theory from a different perspective, focusing on the role of spinors in several approaches to the unification of quantum field theory and general relativity. In the final contribution to this volume, Ashtekar draws our attention to the fact that a unification of quantum field theory and general relativity might also force us to fundamentally revise our ideas about the beginning of the universe, conventionally understood according to the big bang model.

Taken together, the contributions to this volume make it evident that the dynamics of knowledge development driving the emergence of relativity theory, and involving both the integration of different knowledge resources as well as their conceptual transformation, is still at work in current research with the potential to again fundamentally change our physical worldview.

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