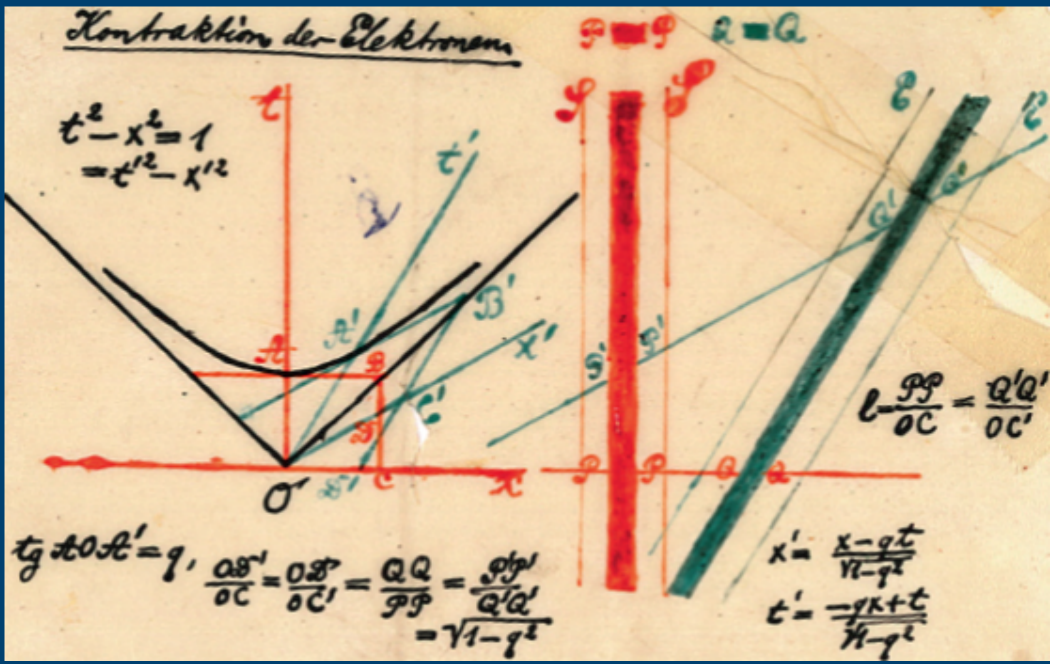
Reinoud Jan Slagter & Zoltán Keresztes (Editors)



SPACETIME

1909 - 2019

Selected peer-reviewed papers presented at the
Second Hermann Minkowski Meeting on the
Foundations of Spacetime Physics dedicated to
the 110th anniversary of the publication of
Minkowski's paper "Space and Time”
13-16 May 2019, Albena, Bulgaria

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This proceeding of the *Second Hermann Minkowski Meeting on the Foundations of Spacetime Physics*, held in 2019, is a continuation of the abundant tradition of the *Hermann Minkowski Institute for Foundational Studies*. Ontological and fundamental questions in theoretical physics are reviewed by three main categories, i. e., new aspects of black hole physics, fundamental aspects of spacetime and gravity from a different point of view. Firstly, this volume aims to provide some new insights in the fundamental difficulties one encounters in the description of the spinning black hole spacetime. In general, the final stage of a black hole is far from understood. It is believed that quantum effects will dominate the evaporation of the black hole by Hawing radiation. However, the maximally extended Penrose diagram of the black hole is not understood. Is there an inside of the black hole? One can modify gravity, alter the dimension of spacetime or add conformal invariance as a new symmetry in order to get new insights. Secondly, the conceptual aspects of the ontological state of the universe from first principles are considered. Issues in Minkowski spacetime like pure states, entangled states, Lorentz transformations and the notion of time are reconsidered. They interface with philosophy. In order to formulate the “laws of nature”, one needs unambiguity, simplicity, efficiency and finiteness. Other aspects, such as locality and spacetime slicing, are presented. Thirdly, this volume ends with some new ideas on quantization of spacetime and an application of transition state theory to spacetime flow. Conclusively, this volume will be of interest to researchers working in the field of conceptual aspect of spacetime and general relativity.

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PREFACE

This volume is a selection of peer-reviewed contributions to the ***Second Herman Minkowski Meeting on the Foundation of Spacetime Physics***, which took place in Albena, Bulgaria, 13-16 May 2019. Contributing manuscripts have been classified into three main categories, i.e.,

I. ***New Aspects of Black Hole Physics and Modified Gravity***

II. ***Fundamental Aspects of Spacetime: Becoming, Passing Time and Locality***

III. ***Gravity from a different point of view***

Part I treats some aspects of black hole physics. It is now commonly believed that the general relativistic description of a black hole is not the complete picture of the physical aspects of the black hole. At our moment in time, we observe that in the centre of any galaxy there is a Kerr black hole, i. e., a rotating massive black hole. It is the final state of collapse of matter and therefore one of the most important analytical solutions of Einstein's general relativity theory. However, the features of the black hole in the early stages of our universe and the final fate of the black hole are far from understood. At the tiniest scales, quantum mechanical aspects should be incorporated. Further, the black hole will not live forever: it will evaporate by Hawking radiation. Spinning compact objects are of interest in general relativity, because there are only a very few of these objects which are asymptotically flat. Further, incorporation of spin implies that there is a connection with conformal field theory and holographic dualities and Maldacena's AdS/CFT correspondence. In these models, the 3-dimensional Banados-Teitelboim-Zanelli black hole solution plays a prominent role. The big advantage of studying lower dimensional solutions in general relativity, is the fact that quantum effect can be incorporated. Vacuum spacetime is locally flat in 3D. Often, one modifies gravity in order to get interesting black hole solutions, such as the Lifshitz black hole. Thermodynamical parameters will then be constraint in order to fulfil stability.

Zoltan Keresztes and **Balazs Mikoczi** consider the evolution of spinning bodies moving on zoom-whirl orbits. At the closest approach distance of the central rotating, singular/regular black hole, the body crossed the ergosphere. In the considered numerical simulations the initial values were chosen such that the relatively small mass body without spin would have moved in the equatorial plane. However since the initial spin was not aligned or anti-aligned with the rotation axis of the central black hole, the body moved out of the equatorial plane. They discuss also the signs of the different black hole spacetimes occurring in the spin precessional dynamics. Specifically, the spin precessional angular velocity depends on three parameters, i.e., the black hole rotation parameter, the charge parameter and the initial spin angle of the approaching body. Restrictions on these parameters are described.

Reinoud Slagter investigated conformally invariant gravity and find a new solution for the uplifted BTZ spacetime, without a cosmological constant. The solution shows some different features with respect to the standard BTZ solution. In the non-vacuum situation, where a scalar-gauge field is present, a numerical solution is presented on a spacetime where one writes the metric as $g_{\mu\nu} = \omega^2 \tilde{g}_{\mu\nu}$, with ω a dilaton field, to be treated on equal footing with the scalar field and $\tilde{g}_{\mu\nu}$ an "un-physical" spacetime. As soon as it ω is fixed (by the global spacetime after choosing the coordinate frame), the local observer experiences scales. The effect of ω on the behavior of the solution is evident. An outgoing wave-like initial value for the scalar field induces a wave-like response in the dilaton field and pushes the apparent horizon closer to $\rho = 0$. The solution depends critically on the shape of the potential. The solution can be used to investigate what happens with the spacetime of an evaporating black hole through Hawking radiation. In the vacuum situation in Eddington-Finkelstein coordinates, an exact solution is found for the (2+1)-dimensional case as well as for the uplifted situation. The "un-physical" $\tilde{g}_{\mu\nu}$ (BTZ) solution has a non-zero Ricci scalar, while is flat. There is possibly a link with the antipodal identification. Antipodal mapping is inevitable if one wants maintain unitarity during quantum mechanical calculations on the Hawking particles. The antipodal identification can be represented as a conformal transformation generated from the pseudo-orthogonal matrices of $O(3)$, i.e., the conformal group. Each conformal transformation in this group can be presented by a pair of antipodal matrices. The great advantage of the method is the avoiding of "the other side" of the black hole, i.e., the maximally extended Penrose diagram. Even an Einstein-Rosen bridge is not necessary ("ER=EPR"). In the antipodal approach there is no inside of a black hole.

Tsvetan Vetsov treats dark matter and dark energy phenomena in our Universe and the interesting correspondence between gravitational and quantum gauge theories in three and lower dimensions. A statistical approach towards the thermodynamics of gravitational models in three and four dimensions respectively is presented. He includes the 4D Deser-Sarioglu-Tekin higher-derivative gravity black hole solution and the 3-dimensional stationary Lifshitz black hole solution of massive gravity. Using the formalism of Thermodynamic Information Geometry , he obtains several non-trivial restrictions on the gravitational parameters in both models. When considering the 3D stationary Lifshitz solution of New Massive Gravity he finds that the simplest positive definite thermodynamic metric is given by the Hessian of the Gibbs free energy. Together with the Sylvester criterion of local and global thermodynamic stability, this approach leads to the restrictions on the parameters of the model. This in contrast to the DST black hole, where the positive definiteness of the TIG metric appeared in the unstable region. In the case of the Lifshitz solution one can go further to look at the regions where the thermodynamic curvature has different signs.

Ruben Arjona discusses in detail the effective fluid approach and perturbation theory in the context of modified gravity ($f(R)$) , dark matter and surviving classes of the Horndeski model. He demonstrates that the plethora of modified gravity and dark energy theories, where each model has its own structure, equations and parameters, are very difficult to analyse at a technical level in an Einstein Boltzmann solver code. He presents a modification of the "Cosmic Linear Anisotropy Solving System" (CLASS) and finds in a simple and straightforward way a less error-prone result. Only three variables are needed to compute and describe the fluid, i. e., an equation of state, the sound speed and the anisotropic stress. Experimental results on detected gravitational waves and gravitational lensing effects could deliver decisive answers on f(R) models and put restrictions on the involved parameters.

Part II of the volume treats the fundamental questions about the Minkowski spacetime, Lorentz transformations and the notion of time. These questions interface with philosophy. Any model in theoretical physics will be based on assumptions of "first principles". Particular, this demands unambiguity, simplicity, efficiency and finiteness. In general, Nature will choose out of different models, the simple one (Occam's rule). Quantum mechanics (QM) relies on locality, unitarity, causality, complementarity and Hilbert space controlled by operator equations. General relativity (GR) relies on the mathematical concept of curvature. In order to find a "grand unified theory", one tries to extend the Poincaré gauge group of spacetime with the Yang-Mills gauge group of particle physics. However, many problems are encountered. One of them is the initial state of the universe, because we live in an evolving universe controlled by GR (It is suggested that even QM should be an emergent feature of our universe).

The philosophical study of ontology, the concept of becoming, is still an actual subject in modern physics. Ontological states evolve into other ontological states. In QM, the information as to which quantum states form the ontological states, could be conserved in time. Mixed states then does not correspond to ontological states. Could this principle solve the well known EPR-Bell paradox? If the relation between the ontological basis and the conventional quantum state of a particle system is complex, one will encounter also quantum-entangled systems. An orthonormal transformation will turn ontological states into entangled states. However, problems like the "hidden variables" still remain. Conspiracy, i.e., miraculous correlations, take place at the ontological states at $t = 0$ and manifests itself in the distant future. The same problem is encountered for the black hole complementarity issue. Pure states evolve into mixed states (Hawking radiation). The problem in the black hole model is the maximally extended Penrose diagram. Is there an "inside" of the black hole? An Einstein-Rosen bridge (ER)? Famous is Maldacena's slogan "ER=EPR".

Vesselin Petkov treats the question: "Can there be becoming in spacetime"? He believes that the question of the reality of spacetime should come after Minkowski's arguments have been addressed and refuted. He believes that the way to reconcile the notions of becoming and time ow with spacetime physics, is by first recognizing the fact that these notions do not represent true features of the external world (since they are not based even on a single piece of experimental evidence) and then (following Eddington and Weyl) by seeking the origin of our perceptions of becoming and time flow in the very interaction of our sensory receptors with the external world, the processing of the obtained information by the brain and the way it is realized by the mind. He also involves Minkowski's viewpoints on four-dimensional spacetime, "local becoming" and eternalism (or block universe), i.e., the idea that present, past and future events are equally real.

Steven Savitt contribution deals with two notions of time. He explains the difference between the notions of "passing" and "succession"" related to spacetime slicing. He first explains that the notion of "time flows" is double-meaning. Secondly, he concludes that the notion of time contains a present or now, i.e., a universe wide hyperplane of simultaneous events happening everywhere. The passage of time is then the successive occurrence of sets of simultaneous events. Further, he discusses the ideas of Pooley and Dieks (et al.) about events that become "more past" and temporal passage in the bock universe model. He compares the philosophic notion of passage with the scientific view of time, starting with Einstein's special theory of relativity. Starting from Bergson's aphorism "time is succession", he tries to explain what we mean by "succession" in a post-1905 world.

Rein Saar and **Stefan Groot**e present a historical overview of the group structure for massless particles. The subgroups of the Lorentz and Poincaré group are treated, i. e., the $SO(3)$ and Borel group. They formulate some theorems on the subgroup structure of the Lorentz group. Further, they treat the representations of Lie groups and algebras in relation to spacetime degrees of freedom and internal forms acting on charge-like degrees of freedom. They also give some examples from particle physics. Special attention is given to the neutrino in the helicity representation (Weinberg-ansatz).

Jan Pilotti explains superluminal Lorentz transformations in six dimensions and the possibility that Minkowski already has the notion of this possibility. He also wonders if this model is just a mathematic trick or could be connected with real new physics. His treatment consists of 6 paragraphs, i. e., experimental search, history of superluminal systems, mathematical interludes, derivations of the Lorentz transformation missing $v > c$ and the possibility of new physics from six dimensional spacetime. He explains the ideas of Weyl and Petkov in connection with 4D block universe and the notion of consciousness and relativity. He ends with a mathematical conjecture that "a N-dimensional structure can in no sense create (produce or emerge) a $(N+1)$ dimensional structure".

Joseph Cosgrove reviews “simultaneity without cosmology”. He starts with Aristotle’s Physics: “actuality qua potential” and sees potential as becoming. Then he treats the subjects: clock synchrony, preferred cosmological frames, and frame-relativity and gravity. He ends with some notes on Smolin’s treatment on global time and preferred cosmological rest frames. To his opinion, Smolin fails to break through the psychological barrier of taking arguments for reality of time seriously. There is no basis for the assumption that global time requires preferred cosmological rest frames. He suggest that global simultaneity relation is real apart from cosmological considerations.

Part III consists of two contributions, i.e., a different approach to quantization of general relativity and modelling spacetime using transition state theory.

Tom McClain presents an overview of the polysymplectic approach to covariant Hamiltonian field theory and the geometric quantization of classical particle theories. He conclude that no difficulties arise when the extended Kostant-Souriau quantization map is applied to general relativity. There are, however, some problems left. For example, the Legendre transformation fails in the covariant Hamiltonian analysis. But this problem also exists in all covariant Hamiltonian field theories. A second problem is the global time coordinate, which is a physical problem, rather than a mathematical one.

Bruce M. Boman considers the flow of spacetime as a spontaneous flow by extrapolating from progressive chemistry processes. Using the “transition state theory”, he is able to design a mathematical model to describe the flow of spacetime. Quasi-equilibrium then exists between future events and now events. In this quasi-equilibrium , an event will exist in both the future and the now, which established a superposition state. There must be enough entropy and energy during the transition state to progress to a past event.

The editors, R. J. Slagter and Z. Keresztes, September, 2020

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8 How Minkowski Could Have Discovered Superluminal Lorentz Transformations and Six Dimensional Spacetime

Jan Pilotti

Abstract The history and rationale for the discovery of superluminal Lorentz transformations is given. The analyses of how Einstein, Minkowski, Cunningham, Born, Pauli and three more didn't find the possibility of $v > c$, at least show that we must be cautious in our interpretation of the principle of relativity and symmetry and how we mathematically describe "rotation" in the non-Euclidean Minkowski spacetime, not to implicitly exclude $v > c$. It is also shown how Minkowski already 1908 could have discovered a six dimensional spacetime, with three space and three "timelike" dimensions, which allows superluminal LT. Is this just a mathematical possibility? Or can it be related to the apparently insurmountable contradictions, between block universe in the theory of relativity and our everyday experience of change and the flow of time, and between determinism and indeterminism in relativity vs. quantum theory and to the relation between consciousness and physical reality?

8.1 Introduction

Before Einstein scholars studied superluminal particles, as e.g. Sommerfeld who published a paper "Ueber Lichtgeschwindigkeits und Ueber-Lichtgeschwindigkeits-Elektronen" [1], just a couple of months before Einstein's seminal paper 1905. As is well known from two basic postulates
PI: *The laws of physics are the same in all inertial reference frames,*
PII: *The velocity of light in vacuum c is the same in all inertial frames,*

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