Universität Regensburg

Johannes-Kepler-Forschungszentrum für Mathematik

Regensburg Conference 2010 September 28 – October 1

QUANTUM FIELD THEORY AND GRAVITY

Organizers:

Felix Finster, Olaf Müller, Marc Nardmann, Jürgen Tolksdorf (Regensburg)
Eberhard Zeidler (Max Planck Institute for Mathematics in the Sciences, Leipzig)

This is a joint conference of the University of Regensburg and the National Academy of Sciences Leopoldina.

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Time schedule:

Monday, September 27: *Arrival day.* **19:00**: Wine and Cheese (math building)

Tuesday, September 28: after **8:00** Registration (math building)

8:30 Opening (math building, lecture hall H31)

Official welcome:
Prof. Dr. Felix Finster,
Dekan der Fakultät für Mathematik,
Universität Regensburg

Opening address:
Prof. Dr. Thomas Strothotte,
Rektor der Universität Regensburg
Prof. Dr. Gunnar Berg,
Leopoldina, Halle

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Saturday, October 2: *Departure day*

Talks and abstracts:

Christian Bär (Potsdam):
CCR- versus CAR-quantization on curved spacetimes

Andreas Döring (Oxford):
Some new ideas about noncommutative spaces and space-time from the topos approach

By Gel'fand duality, each commutative C*-algebra corresponds to a locally compact Hausdorff space and vice versa. In quantum theory, noncommutative algebras play a central role, but for these a good notion of spectrum is still lacking. We show how the topos approach to quantum theory provides a new kind of noncommutative spectrum for unital C*-algebras and von Neumann algebras, providing some first steps towards noncommutative Gel'fand duality. In the second half of the talk, we will report on some very recent work with Rui Soares Barbosa on a new description of space and space-time suggested by the topos approach. Here, domain theory plays a central role.

Michael Dütsch (Göttingen)**:**
Massive quantum gauge models without Higgs mechanism

Constructing the S-matrix by causal perturbation theory we require (1) renormalizability and (2) causal gauge invariance. (2) can be motivated by invariance of the S-matrix with respect to the BRST-transformation of the asymptotic free fields. Stated differently, the physical motivation is that the full S-matrix (i.e. as an operator in the Fock space containing also unphysical states) induces a well defined operator on the physical subspace. We sketch that, given the asymptotic free fields of a model, (1) and (2) fix the interaction essentially uniquely. In particular the Lie algebraic structure and the need to add additional physical scalar fields (Higgs fields) in massive non-Abelian models are not to be put in; they follow from (1) and (2). We also clarify the connection of model building in this way to the usual model building by spontaneous symmetry breaking.

Thomas Elze (Pisa):
General linear dynamics: quantum, classical or hybrid

A path integral representation of classical Hamiltonian dynamics is presented. This allows a preliminary discussion of the coupling of quantum mechanical and classical objects and demonstrates perhaps surprising features of classical dynamics. These observations lead, in the second part of my talk, to the question "What is special about quantum dynamics?", viewed as a particularly constrained dynamics among general linear evolution laws. This is illustrated for the simplest case based on a two-dimensional state space.

Chris Fewster (York):
On the notion of "the same physics in all spacetimes"

Models of matter in curved spacetimes are often specified by a Lagrangian depending on the metric (and quantities derived from it) as well as the matter fields or variables. Exchanging one metric for another is normally understood to preserve the physics provided that the Lagrangian transforms covariantly under coordinate change. However, axiomatic approaches to quantum field theory do not assume a Lagrangian description as the starting point, which raises the issue of how it can be adapted from one spacetime to another while preserving the physics. I will describe work with R Verch that attempts to answer this question by refining the locally covariant framework of Brunetti, Fredenhagen and Verch. While the main focus is on quantum field theory, the ideas should apply to a wide range of physical theories.

Christian Fleischhack (Paderborn):
Loop Quantum Gravity: An Overview

Over the last two decades, loop quantum gravity has been established as a major approach to the quantization of general relativity. It is based on a reformulation of canonical general relativity as an $SU(2)$ gauge field theory with constraints which is canonically quantized a la Dirac. While the kinematical part is well understood, the dynamics of the quantum theory is still widely unknown. Nevertheless, some remarkable achievements have been obtained, e.g., the construction of geometric operators for area and volume, the derivation of black hole entropy and the transfer of the methods to cosmology. Here, results like the resolution of the big-bang singularity in highly symmetric models have been derived.
In this talk, we will present the foundations of loop quantum gravity and review selected results and open issues.

Klaus Fredenhagen (Hamburg)**:**
Local covariance and background independence

One of the many conceptual difficulties in the development of quantum gravity is the role of a background geometry for the structure of quantum field theory. To some extent the problem can be solved by the principle of local covariance. The principle of local covariance was originally imposed in order to restrict the renormalization freedom for quantum field theories on generic spacetimes. It turned out that it can also be used to implement the request of background independence. Locally covariant fields then arise as background independent entities

Domenico Giulini (Hannover):
'Down-to Earth' issues in atom interferometry

A recent and currently widely debated proposal (Nature 463 (2010) 926-929) to re-interpret some 10-year old experiments in atom interferometry would imply, if tenable, substantial improvements in measurements of gravitational redshift. This raises various compatibility issues concerning basic principles of General Relativity and Quantum Mechanics.

Andreas Grotz (Regensburg)**:**
A quantum space-time emerging from an action principle

We begin by introducing an action principle defined on a finite set of points. This action principle is causal in the sense that it generates a relation on pairs or points which distinguishes between spacelike and timelike separation. In this way, minimizing the action gives rise to a "discrete causal structure". We generalize our action principle to include continuum space-times and review existence results. We explain how for a given minimizer, one can introduce notions of parallel transport, curvature and spin connection, which generalize the classical notions and give rise to a proposal for "quantum geometry". In the second part of the talk, it is explained how the same action principle can be formulated in Minkowski space to obtain a formulation of quantum field theory. The differences to standard quantum field theory are explained in a simplified model where Dirac particles interact via an axial field.

Stefan Hollands (Cardiff):
Black holes in higher dimensions

I review the properties and classification results of higher dimension black hole spacetimes.

Claus Kiefer (Köln)**:**
Quantum gravity - Whence, whither

I shall give a general overview on the status of research in quantum gravity. After some historical remarks, I present arguments which can be invoked in favour of a quantization of gravity. I then discuss in some detail the direct quantization of general relativity in which I focus on quantum geometrodynamics, loop quantum gravity, and path-integral approaches. The main quantum gravitational aspects of string theory are briefly presented. The last part will be devoted to the major applications: black holes, cosmology, and the microscopic structure of space and time.

Michael Kiessling (Rutgers)**:**
On the motion of point defects in relativistic field theories

In the 1930s, Max Born inaugurated a quest for a divergence problem-free QED based on certain non-linear electromagnetic field equations (Maxwell-Born-Infeld field equations) in which the electric field of a point charge does not diverge but has a point defect. Curiously, higher-dimensional variants of these field equations have shown up a while ago in string theory because of their geometrical significance. In my talk I pick up on the four-dimensional approach. I show that while the Maxwell-Born-Infeld (MBI) equations get rid of the infinite self-energy of a point charge, the traditional proposals for how a classical point charge moves are not viable. I explain that a variant of Hamilton-Jacobi theory comes to the rescue. I also show that this classical theory can be deformed into a "first-quantized" theory in which the Hamilton-Jacobi law of motion is replaced by a de Broglie-Bohm law of motion. Spin will be incorporated as well. I also address the problem of coupling this theory to Einstein's theory of gravity. In my talk I also survey the current mathematical status of the classical MBI and EMBI field equations, without getting into technicalities.

Jerzy Kijowski (Warszawa)**:**
Field quantization via discrete approximations: problems and perspectives

A new approach to the idea of a Quantum Field Theory on a generic (possibly curved) spacetime is proposed. It is based on local, discrete approximations. For this purpose the relation between a quantum system and its subsystems is thoroughly discussed, with special emphasis to gauge invariance and renormalization. The present "state of art" in Quantum Gravity is discussed in the above context.

Renate Loll (Utrecht): tba

Dieter Lüst (München)**:**
The Landscape of Multiverses & Strings

Robert Oeckl (UNAM Morelia)**:**
Introduction to the general boundary formulation of quantum theory

I start by reviewing a main motivation for the general boundary formulation (GBF): Providing a formulation of quantum theory compatible with principles of general relativity. To this end I recall some of the inadequacies of the usual formulation in this respect, leading to the problem of time among others. In contrast, the GBF provides a framework for formulating quantum theory that is local and compatible with general covariance. Crucially, the physical interpretation of its ingredients does not require the introduction of a metric background. On the other hand, given a metric background the usual structure of quantum (field) theory together with its successful interpretation is recovered, meaning that the GBF also fully embraces quantum physics as we know it. I give an overview of the basic structures of the GBF, both mathematical and physical. In particular, I explain the notions of state space, amplitude, observable, probability interpretation and expectation value in the GBF and how they reduce to the standard notions in the presence of a metric background. I proceed to elaborate on the current status of the implementation of the GBF, mainly in quantum field theory. Finally, I consider existing and future quantization prescriptions that target the GBF, with an eye towards quantum gravity. If time permits I will also comment on the relation to the framework of algebraic quantum field theory.

Daniele Oriti (AEI Golm)**:**

The microscopic dynamics of quantum space as a group field theory

We give an introduction to the group field theory approach to quantum gravity. This is a generalization of matrix models for 2d gravity to higher dimensions, and a framework that brings together elements from other approaches like loop quantum gravity, non-commutative geometry and simplicial quantum gravity. We also report on some recent results obtained in this context, concerning both the mathematical definition and properties of group field theory models and possible avenues for extracting physical predictions from them.

Gerd Rudolph (Leipzig)**:**

Lattice Gauge Models: Singular Reduction and Quantization

The models under consideration arise from lattice approximation of nonabelian gauge theories. First, we formulate them on the classical level as Hamiltonian systems, endowed with a gauge symmetry and with a natural momentum mapping. We discuss singular Marsden- Weinstein reduction, which yields the stratified reduced phase space, for simple examples [2]. Next, we shortly recall previous results [1] on the structure of the field and observable algebras of these models. For implementing the stratified structure on quantum level [3] we use the generalized Bargmann-Segal transform for compact Lie groups as developed by B. C. Hall and the concept of a costratified Hilbert space as proposed by J. Huebschmann. Finally, we discuss a simple, exactly solvable example [3], [4].

References

[1] J. Kijowski, G. Rudolph, J. Math. Phys. Vol. 46, 032303 (2005)

[2] E. Fischer, G. Rudolph and M. Schmidt, J. Geom. Phys. 57 (2007) 1193-1213

[3] J. Huebschmann, G. Rudolph and M. Schmidt, Commun. Math. Phys. 286, 459-494 (2009)

[4] G. Rudolph, M. Schmidt, J. Math. Phys. 50, 052102 (2009)

Miguel Sánchez (Granada)**:**

Causal boundary of spacetimes: revision and applications to AdS-CFT correspondence

Stimulated by the holography of plane waves, the classical notion of "causal boundary" of a spacetime has been revised recently. A new redefinition turns out consistent with the conformal boundary, and it is connected with other known boundaries, as the Gromov or Cauchy ones for Riemannian and Finslerian manifolds. In most pp-waves, it is computable explicitly.

A review on this topic with prospective applications will be carried out.

Blake Temple (UC Davis)**:**

General Relativistic self-similar waves that induce an Anomalous Acceleration into the Standard Model of Cosmology

In 1927, the American astronomer Edwin Hubble showed that the Universe is expanding: distant galaxies are receding from each other. This confirmed the so-called *Standard Model of Cosmology*, that the universe, on the largest scale, is evolving according to a uniform k=0 Friedmann-Robertson-Walker (FRW) spacetime. But in 1998, more accurate measurements of the recessional velocity of distant galaxies based on Type 1a supernova data, showed that the Universe is actually accelerating relative to the Standard Model. This is referred to as the *Anomalous Acceleration* of the galaxies, and its explanation is one of the great problems of physics. To preserve the FRW framework, cosmologists have proposed modifying the Einstein equations by adding a controversial correction term called the Cosmological Constant. *Dark Energy*, the physical interpretation of the Cosmological Constant, is then an unknown source of anti-gravitation that, for the model to be correct, must account for some 70 percent of the energy density of the universe. In this talk I discuss a new one-parameter family of General Relativistic (GR) self-similar expansion waves, such that the Standard Model of Cosmology during the radiation phase of the expansion corresponds to one member of the family (with J. Smoller, PNAS August 2009, and arXiv 2010). By adjustment of the *acceleration parameter*, waves in the family speed up or slow down the expansion rate relative to the Standard Model without Dark Energy. Moreover, all of the self-similar spacetimes in the family are distinct from the non-critical k≠0 FRW spacetimes, thereby *characterizing* k=0 FRW as the unique spacetime lying at the intersection of these two one-parameter families. Since self-similar expansion waves represent possible time-asymptotic wave patterns for the highly nonlinear conservation laws associated with the radiation phase of the Big Bang, we propose that these waves could perturb a uniform FRW background something like the self-similar waves that emerge when a rock is thrown into a still pond. I present these GR expansion waves, and explore the possibility that they could account for the Anomalous Acceleration of the galaxies within classical General Relativity, without Dark Energy or the Cosmological Constant.

Rainer Verch (Leipzig)**:**

Quantum fields and cosmology: Particle production and local thermal equilibrium

In this talk, we report on recent progress in quantum field theory in cosmological spacetimes. First, we review H. Olbermann's concept of states of low energy, which permit a particle concept localized in time, and we present a calculation of cosmological particle production tied to that concept. Secondly, we present a generalization of the concept of local thermal equilibrium states in quantum field theory, developed by D. Buchholz et al., to curved spacetime. We report on interesting new results, based on that concept, on the temperature behaviour of quantized matter in cosmology. There will also be some comments on recent developments regarding the generalized Einstein (backreaction) equations in semiclassical gravity.

Mu-Tao Wang (Columbia University):
On the notion of quasilocal mass in general relativity

There have been many attempts to define quasilocal mass for a spacelike 2-surface in spacetime by the Hamilton-Jacobi method. The essential difficulty in this approach is the subtle choice of the background configuration to be subtracted from the physical Hamiltonian. The quasilocal mass should be positive for a large class of surfaces, but on the other hand should be zero for surfaces in the flat spacetime. In this talk, I shall discribe how to use isometric embeddings into the Minkowski space to overcome this difficulty and propose a new definition of quasi-local energy (and mass) that has the desired properties, in addition to other natural requirements.
This talk is based on a joint work with Shing-Tung Yau at Harvard.