Gravitation and Relativity Division
Fachverband Gravitation und Relativitätstheorie (GR)

Claus Lämmerzahl
ZARM, Universität Bremen
Am Fallturm
28359 Bremen
claus.laemmerzahl@zarm.uni-bremen.de

Dar Fachverband Gravitation und Relativtätstheorie hat sich für diese Tagung den thematischen Schwerpunkt **experimentelle Relativitätstheorie** gesetzt. Alle eingeladenen Hauptvorträge befassen sich mit diesem Thema und auch der von uns gestellte Plenarvortrag befasst sich mit praktischen Anwendungen und Test mittels neuer hochpräziser Uhren.

Zusammen mit dem Fachverband Quantenoptik und der Arbeitsgemeinschaft Philosophie bieten wir auch ein Symposium zum Thema *The Quantum-Classical Divide* an, in dem es ebenfalls um die experimentelle Explorierung dieser Fragestellung geht, aber auch um begriffliche Klärungen.

Darüber hinaus decken wir mit vielen Kurzvorträgen wieder die ganze Breite der Gravitationsphysik von grundlegenden Fragestellungen über Astrophysik und Schwarze Löcher bis hin zur Quantengravitation ab.

Overview of Invited Talks and Sessions

(Lecture rooms: SPA Kapelle and SR220; Posters: SPA Foyer)

Plenary Talks

PV I	Mon	8:30– 9:15	Audimax	**Meeting the Energy Challenge** — •Steve Chu
PV II	Mon	9:15–10:00	Audimax	**Reverse-engineering quantum theory: (anti-)matter waves, interferometry, and clocks** — •Holger Müller
PV III	Tue	8:30– 9:15	Audimax	**Research Data Infrastructures – Challenges, Desires, Incentives** — •Maik Thomas
PV IV	Tue	9:15–10:00	Audimax	**Isotopic Microprobe Mass Spectrometry** — •Michael J. Pellin
PV V	Tue	20:00–21:00	Audimax	**Das Higgs-Teilchen: Unsichtbares sichtbar und Unmögliches möglich machen** — •Felicitas Pauss
PV VI	Wed	8:30– 9:15	Audimax	**Sharp versions of Heisenberg's error-disturbance trade-off** — •Reinhard Werner
PV VII	Wed	9:15–10:00	Audimax	**Resolving and manipulating attosecond processes via strong-field light-matter interactions** — •Nirit Dudovich
PV VIII	Wed	12:10–12:55	Audimax	**Quantum Nano-Optics** — •Jelena Vuckovic
PV IX	Wed	20:00–21:00	Audimax	**Wege durch die Quantenwelt – neue Experimente zur Welle-Teilchen Dualität massiver Materie** — •Markus Arndt
PV X	Thu	8:30– 9:15	Audimax	**Atomic and Molecular Reactions in Slow-Motion: Time-Resolved Experiments with XUV and IR Laser Pulses** — •Robert Moshammer
PV XI	Thu	9:15–10:00	Audimax	**Relativistic Geodesy with Optical Clocks** — •Tanja E. Mehlstäubler
PV XII	Thu	20:00–21:00	Audimax	**The Scientists Go to War: Questions, Contexts and Consequences, 1914-1918** — •Roy MacLeod
PV XIII	Fri	8:30– 9:15	Audimax	**From Astrophysics to Life: The Making of Habitable Planets** — •Manuel Güdel
PV XIV	Fri	9:15–10:00	Audimax	**Quantum networks based on diamond spins: from long-distance teleportation to a loophole-free Bell test** — •Ronald Hanson

Invited Talks

GR 2.1	Mon	11:25–12:10	SPA Kapelle	**Modern tests of Special Relativity using cryogenic electromagnetic resonators** — •Achim Peters
GR 4.1	Mon	14:00–14:45	SPA SR220	**Fundamental Physics with Matter Waves** — •Ernst M. Rasel
GR 8.1	Tue	10:30–11:15	SPA SR220	**Measuring the frame-dragging effect with LAGEOS, LARES and other satellites** — •Rolf Koenig
GR 10.1	Tue	14:00–14:45	SPA SR220	**Gaia: the project, its status and scientific promises** — •Sergei Klioner
GR 20.1	Thu	14:00–14:45	SPA SR220	**Quantum & Gravitation** — •Hartmut Abele
GR 23.1	Thu	16:30–17:15	SPA SR220	**Schrödinger's Mirrors: confronting quantum physics with gravity** — •Markus Aspelmeyer

Invited talks of the joint symposium SYQC

See SYQC for the full program of the symposium.

SYQC 1.1	Thu	10:30–11:00	Audimax	**Experimental tests of quantum macroscopicity** — •Markus Arndt
SYQC 1.2	Thu	11:00–11:30	Audimax	**From classical instruments to quantum mechanics and back** — •Reinhard F. Werner
SYQC 1.3	Thu	11:30–12:00	Audimax	**Correlations and the quantum-classical border** — •Dagmar Bruss, Alexander Streltsov, Hermann Kampermann
SYQC 1.4	Thu	12:00–12:30	Audimax	**Why Physics Needs a Classical World...and How It Can Get One** — •Tim Maudlin

Sessions

GR 1.1–1.1	Mon	10:30–11:25	SPA Kapelle	**General discussion**
GR 2.1–2.1	Mon	11:25–12:10	SPA Kapelle	**Main talk: Experimental Gravitation**
GR 3.1–3.1	Mon	12:10–12:30	SPA Kapelle	**Experimental Gravitation I**
GR 4.1–4.1	Mon	14:00–14:45	SPA SR220	**Main talk: Experimental Gravitation**
GR 5.1–5.4	Mon	14:45–16:05	SPA SR220	**Experimental Gravitation II**
GR 6.1–6.3	Mon	16:30–17:30	SPA SR220	**Gravitational waves**
GR 7.1–7.4	Mon	17:30–18:50	SPA SR220	**Quantum Gravity and Quantum Cosmology I**
GR 8.1–8.1	Tue	10:30–11:15	SPA SR220	**Main talk: Experimental Gravitation**
GR 9.1–9.4	Tue	11:15–12:35	SPA SR220	**Classical theory of General Relativity I**
GR 10.1–10.1	Tue	14:00–14:45	SPA SR220	**Main talk: Experimental Gravitation**
GR 11.1–11.2	Tue	14:45–15:25	SPA SR220	**Relativistic Astrophysics**
GR 12.1–12.2	Tue	15:25–16:05	SPA SR220	**Classical theory of General Relativity II**
GR 13.1–13.3	Tue	16:30–17:30	SPA SR220	**Classical theory of General Relativity III**
GR 14.1–14.2	Tue	17:30–18:10	SPA SR220	**Alternative classical theories of gravitation I**
GR 15.1–15.2	Tue	18:10–18:50	SPA SR220	**Other topics**
GR 16.1–16.6	Wed	14:00–16:00	SPA SR220	**Black Holes I**
GR 17.1–17.3	Wed	16:30–17:30	SPA SR220	**Black Holes II**
GR 18.1–18.2	Wed	17:30–18:10	SPA SR220	**Fundamental problems and general formalism**
GR 19.1–19.1	Wed	18:10–18:30	SPA SR220	**Cosmology**
GR 20.1–20.1	Thu	14:00–14:45	SPA SR220	**Main talk: Experimental Gravitation**
GR 21.1–21.3	Thu	14:45–15:45	SPA SR220	**Experimental Gravitation III**
GR 22.1–22.1	Thu	15:45–16:05	SPA SR220	**Numerical Relativity I**
GR 23.1–23.1	Thu	16:30–17:15	SPA SR220	**Main talk: Experimental Gravitation**
GR 24.1–24.3	Thu	17:15–18:15	SPA SR220	**Numerical Relativity II**
GR 25.1–25.1	Fri	10:30–10:50	SPA SR220	**Classical theory of General Relativity IV**
GR 26.1–26.2	Fri	10:50–11:30	SPA SR220	**Alternative classical theories of gravitation II**
GR 27.1–27.2	Fri	11:30–12:10	SPA SR220	**Quantum Gravity and Quantum Cosmology II**
GR 28.1–28.6	Mon	8:30– 8:30	SPA Foyer	**Poster (permanent)**

Welcome evening

On Monday, 17th of March 2014, from 19.30 till 22.00 h, there will be an informal welcome evening with snacks and drinks (location: Mensa Nord, Hannoversche Strasse 7). All registered conference participants are cordially invited to take this opportunity of rekindling old contacts and making new ones.
Please wear your name tag for free entrance, which you will receive when registering.

Annual General Meeting of the Gravitation and Relativity Division

Donnerstag, 27. März 2014 18:20–19:30 Uhr SPA SR220

- Eröffnen und Festsetzen der engültigen Tagesordnung
- Bericht des Vorsitzenden
- Wahl des/der Vorsitzenden des FV
- Wahl des Beirates des FV
- Vergangene Aktivitäten
- Zukünftige Aktivitäten
- Koordinierte Forschung auf dem Gebiet der Gravitationsphysik in Deutschland
- Dissertationspreis
- Gründung der Sektion Materie und Kosmos SMuK
- Verschiedenes

GR 1: General discussion

Time: Monday 10:30–11:25 Location: SPA Kapelle

GR 1.1 Mon 10:30 SPA Kapelle

Discussion about the "Compton Clock" — •Claus Lämmerzahl — ZARM, Uni Bremen for the GR Section

Recently it has been suggested by S. Chu, A. Peters and H. Müller (see previous plenary talk, and Nature 463, 926 (2010)) that the Compton frequency of an atom constitues an ordinary clock, the "Compton clock" and that this clock can be used, e.g., for testing basic principles of General Relativity like the universality of the gravitational redshift. Based on an introductory statement by Domenico Giulini (Bremen and Hannover) a discussion aiming at better understanding of this concept will take place.

GR 2: Main talk: Experimental Gravitation

Time: Monday 11:25–12:10 Location: SPA Kapelle

Invited Talk GR 2.1 Mon 11:25 SPA Kapelle

Modern tests of Special Relativity using cryogenic electromagnetic resonators — •Achim Peters — Humboldt Universität zu Berlin, Institut für Physik, AG Optische Metrologie, Newtonstr. 15, 12489 Berlin, Germany

Ultra-stable electromagnetic resonators are an exquisite tool for performing precision tests of Lorentz invariance and Special Relativity.

In this talk I will first present results from a recently concluded Michelson-Morley type experiment using two orthogonally aligned cryogenic sapphire microwave oscillators (CSOs) actively rotated on a high-precision air-bearing turntable. After more than one year of almost continuous operation, the sensitivity of this setup to Lorentz invariance violations has now reached the 10^{-18} to 10^{-19} regime.

In the next version of this experiment these microwave oscillators will be combined with a new generation of ultra-stable cryogenic optical resonators (COREs). I will present first results from measurements utilizing these COREs and then discuss the prospects for using the new setup to investigate simultaneously a multitude of possible Lorentz invariance violations in the 10^{-20} to 10^{-21} regime.

GR 3: Experimental Gravitation I

Time: Monday 12:10–12:30 Location: SPA Kapelle

GR 3.1 Mon 12:10 SPA Kapelle

Michelson-Interferometrie zum Test nichtlinearer Vakuum-Elektrodynamiken — •Gerold Schellstede, Claus Lämmerzahl und Volker Perlick — ZARM, Universität Bremen

Wir diskutieren die theoretischen Grundlagen nichtlinearer Elektrodynamiken der Plebański-Klasse, um Vorhersagen dieser Theorien mithilfe der Michelson-Interferometrie experimentell überprüfen zu können. Bei der Plebański-Klasse handelt es sich um die Klasse aller Theorien, die sich aus einer Lagrange-Funktion herleiten lassen, die nur von den elektrodynamischen Feldinvarianten – $F = |\vec{E}|^2 - |\vec{B}|^2$ und $G = \vec{E} \cdot \vec{B}$ – abhängt. Die Born-Infeld-Theorie und die Heisenberg-Euler-Theorie werden hierbei als wichtigste Spezialfälle untersucht. Die Grundidee des vorgeschlagenen Michelson-Experiments besteht darin, die in der nichtlinearen Elektrodynamik vorhandene Abhängigkeit der Phasengeschwindigkeit des Lichts von der Stärke und der Richtung eines Hintergrundfelds auszunutzen. Dies sollte zu einer Änderung der Interferenzfigur führen, wenn man ein Michelson-Interferometer in einem Hintergrundfeld dreht respektive entlang der Arme des Interferometers ein Hintergrundfeld zu- oder wegschaltet.

GR 4: Main talk: Experimental Gravitation

Time: Monday 14:00–14:45 Location: SPA SR220

Invited Talk GR 4.1 Mon 14:00 SPA SR220

Fundamental Physics with Matter Waves — •Ernst M. Rasel — IQO, Leibniz Universität Hannover

Experimental tests of gravity with matter waves started as early as 1975 with neutrons. Today, atom interferometers offer new opportunities to probe the propagation of matter waves in gravity. The coherent evolution of quantum objects delocalized in space-time, the verification of the Einstein principle of equivalence with quantum objects and the detection of gravitational waves constitute only three of many timely quests motivating experiments with atom interfometers in extended free fall. The overarching aim is to enhance the sensitivity of these devices, which increases linearly with the momentum difference between the two matter waves emerging from a beam splitter and quadratically with the time of free fall as experienced in fountains, drop towers, parabolic flights and space. These scaling laws imply constraints with respect to the atomic source. Thanks to their slow spreading and their excellent mode properties, Bose-Einstein condensates represent a promising source for high-resolution interferometers. We will present experiments on ground and in microgravity aiming to test Einsteins principle of equivalence with matter waves.

The microgravity experiments are pursued by the QUANTUS cooperation comprising the group of K. Bongs (Univ. of Birmingham), C. Lämmerzahl (Univ. Bremen), A. Peters (Humboldt Univ. Berlin/Ferdinand Braun Institut), T. Hänsch/J.Reichel (MPQ/ENS), K. Sengstock/P. Windpassinger (Univ. Hamburg/Univ. Mainz), R. Walser (TU Darmstadt), and W.P. Schleich (Univ. Ulm). This project is supported by the German Space Agency Deutsches Zentrum für Luft- und Raumfahrt (DLR) with funds provided by the Federal Ministry of Economics and Technology (BMWI) under grant number DLR 50 WM 0346. We thank the German Research Foundation for funding the Cluster of Excellence QUEST Centre for Quantum Engineering and Space-Time Research

GR 5: Experimental Gravitation II

Time: Monday 14:45–16:05 Location: SPA SR220

GR 5.1 Mon 14:45 SPA SR220

Towards a test of the Universality of Free Fall of atoms in microgravity — •Christian Vogt, Sascha Kulas, Andreas Resch, and Sven Herrmann — ZARM, Universität Bremen, Am Fallturm, 28259 Bremen

Today matter wave interferometry is an established tool to perform precision measurements in fundamental physics. One of the main limiting factors in such experiments is the finite free evolution time available for matter waves in a laboratory setup. Thus, the extended free fall time which can be achieved in a space mission is expected to be of great benefit to future matter wave precision measurements. First promising results towards this have been achieved by the QUANTUS collaboration in experiments at the Bremen drop tower. Within the PRIMUS project we aim to further explore this potential in a dedicated drop tower experiment. This experiment will consist of a dual species interferomer to compare the free fall of 87Rb and 39K. Ultimately it shall provide the opportunity to study the potential sensitivity and systematic effects of a future space mission to test the Einstein Equivalence Principle with ultra-cold atoms at enhanced precision. Here, we present the current status of our experiment and discuss the perspectives and attainable sensitivity of such a free fall test in the Bremen drop tower. The PRIMUS project is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number DLR 50 WM 1142.

GR 5.2 Mon 15:05 SPA SR220

Quantum Weak Equivalence Principle — •Magdalena Zych[1,2] and Caslav Brukner[1,2] — [1]Faculty of Physics, University of Vienna, Vienna, Austria — [2]Institute for Quantum Optics and Quantum Information, Austrian Academy of Sciences, Vienna, Austria.

Equivalence between the gravitational and the inertial mass of a body, the Weak Equivalence Principle (WEP), lies at the heart of both Newton's and Einstein's theories of gravity and is a prerequisite for its understanding as a curvature of space-time. Beginning with Galileo's experiments WEP continues to be probed with ever increasing precision reaching nowadays the scale where quantum mechanics becomes relevant. Here we show that the classical formulation of the WEP does not apply in such a regime. The total mass of a test body includes contributions from the internal energy, which in quantum mechanics is given by a Hamiltonian operator describing the dynamics of internal degrees of freedom. We therefore introduce a quantum formulation of the WEP - equivalence between the inertial and gravitational internal energy operators. We show that the validity of the classical WEP does not imply the validity of the quantum WEP which thus requires independent experimental verification. We discuss how this goal can be achieved in quantum interference experiments with massive particles with internal structure.

GR 5.3 Mon 15:25 SPA SR220

A method to test Newton's law of gravity at micro- and submicrometre distances with parallel plates — •Helena Schmidt and Vladimir Nesterov — Physikalisch-Technische Bundesanstalt, 5.1 Oberflächenmesstechnik/Surface Metrology, Bundesallee 100, 38116 Braunschweig, Germany

We propose an experiment to test Newton's Law of Gravity at micro- and submicrometre length scale. Usually the correction to Newtonian gravity is parameterized through an additional Yukawa-type potential term: $V(r) = -G\frac{m_1 m_2}{r} \cdot \left[1 + \alpha \cdot e^{-r/\lambda}\right]$, α and λ are the parameters of the Yukawa-potential. The main idea is to measure the force variation between two parallel plates with periodically varying distances. The force variation is derived from the yukawa-part of the pontential. To minimize electrostatic parasitic forces a goldmembrane is placed between the plates. The membrane will be produced as a grid and included in one of the two plates. Therefore that plate is called Yukawa-Attraktor. The other plate is called detector, which is connected to the force sensor. The force sensor is the nanonewton force facility at the PTB (Physikalisch Technische Bundesanstalt). With this facility it is possible to measure up to a resolution of 10^{-14} N at a measuring time of $2 \cdot 10^5$ s. That resolution ables us to measure differences from Newton's Law of gravity up to 10^3 times better than current experiments.

GR 5.4 Mon 15:45 SPA SR220

Is it possible to measure the gravitomagnetic clock effect? — Eva Hackmann[1], •Claus Lämmerzahl[1], and Fritz Merkle[2] — [1]ZARM, University of Bremen, Germany — [2]OHB-Systems, Bremen, Germany

On the level of orbits of satellites the gravitomagnetic field of a rotating gravitating body like the Earth manifests itself in the precession of the orbital plane, which is known as the Lense-Thirring effect, or in the precession of the spin of a spinning top, known as the Schiff effect. Here we discuss the question whether and how this gravitomagnetic field can also be detected using clocks on orbiting satellites. Two clocks on counter rotating equatorial circular orbits around the Earth show a difference of about 10^{-7} s per revolution. However, the detectability of this effect depends on the accuracy and stability of the used clocks as well as on the precise knowledge of the satellites orbits. We show that with present technology it is possible in principle to measure this gravitomagnetic clock effect with satellites on arbitrary orbits. In particular, we analyze whether this gravitomagnetic clock effect has an impact on the clocks on the Galileo satellites. Such a measurement would constitute another important Solar System test of Einstein's General Relativity.

GR 6: Gravitational waves

Time: Monday 16:30–17:30 Location: SPA SR220

GR 6.1 Mon 16:30 SPA SR220

LISA Pathfinder: A mission status — •Martin Hewitson — Albert Einstein Institute, Callinstr 38, Hannover, 30167

LISA Pathfinder (LPF) is a precursor and technology validation mission for LISA-like gravitational wave observatories in space. Some of the key technology needed for this kind of observatory, such as micro-Newton propulsion, space-based optical metrology, drag-free control, and inertial sensing, will be directly tested on LPF. With a scheduled launch date of July 2015, the mission is at an advanced stage of integration and testing. This talk will give an overview of the overall mission, giving the status of the various key components, a discussion on the key noise sources, and a brief introduction to the experiments that will be carried out during mission operations.

GR 6.2 Mon 16:50 SPA SR220

Birefringence Measurements of Laser Mirrors from Crystaline Silicon — •Christoph Krüger, Roman Schnabel, and Harald Lück — Albert-Einstein-Institut, Institut für Gravitationsphysik Leibniz Universität Hannover

Laser interferometric gravitational wave detectors (GWD) are using high light powers in order to achieve a high sensitivity of measurement. Future detectors of the so called 3rd generation - like the Einstein Telescope (ET) - will furthermore make use of optics cooled to cryogenic temperatures to improve the sensitivity. The current fused silica optics used at room temperature are not suited for operation at cryogenic temperatures, hence alternative optical materials have to be investigated. The baseline design of the Einstein Telescope foresees silicon as test-mass material.

The optical birefringence of a test-mass, however, may limit the GWD or cause additional optic losses. Transmitting light through a medium with birefringence can cause conversion of light from one polarization state into the other one and act as an undesired optical loss channel.

We developed a measurement technique with a sensitivity for birefringence $n_1 - n_2 = \Delta n$ as low as 10^{-8}. The talk presents the measurements of silicon birefringence obtained from different mono-crystalline silicon samples and its dependence on experimental parameters such as mechanical load, orientation and suspension of the crystals.

GR 6.3 Mon 17:10 SPA SR220

Gravitational wave constraints on the shape of neutron stars — •Nathan K. Johnson-McDaniel — Theoretisch-Physikalisches Institut, Friedrich-Schiller-Universität Jena

The gravitational wave observatories LIGO and Virgo have placed interesting upper bounds (below the limits from electromagnetic observations of the spin-down) on the gravitational radiation emitted by certain known pulsars, notably the Crab and Vela pulsars. We show how to convert these upper bounds into upper bounds on the $l = m = 2$ deformation of the star's surface, in full general relativity, to first order in the deformation. This relation only depends on the star's mass and radius, with reasonable assumptions about the matter at its surface. We then apply this relation to stars that have direct LIGO/Virgo bounds below the spin-down limit and compare with the expected surface deformation due to rotation. In particular, we find that the latest LIGO/Virgo observations have constrained the $l = m = 2$ deformation to be smaller than the rotational deformation for the Crab pulsar for all equations of state considered and for the Vela pulsar for the equations state with larger radii. These statements could not have been made using only the bounds on the $l = m = 2$ deformation from electromagnetic observations of the spin-down.

GR 7: Quantum Gravity and Quantum Cosmology I

Time: Monday 17:30–18:50 Location: SPA SR220

GR 7.1 Mon 17:30 SPA SR220

Resolution of type IV singularities in quantum cosmology — Mariam Bouhmadi-López[1], Claus Kiefer[2], and •Manuel Krämer[2] — [1]Department of Theoretical Physics, University of the Basque Country UPV/EHU, P.O. Box 644, 48080 Bilbao, Spain — [2]Institut für Theoretische Physik, Universität zu Köln, Zülpicher Straße 77, 50937 Köln, Germany

We discuss the fate of classical type IV singularities in quantum cosmology. As a framework we use Wheeler-DeWitt quantization applied to a homogeneous and isotropic universe with a perfect fluid described by a generalized Chaplygin gas. Such a fluid can be dynamically realized by a scalar field. We treat the cases of a standard scalar field with positive kinetic energy and of a scalar field with negative energy (phantom field). We are able to solve the Wheeler-DeWitt equation for these models analytically for a special case and to draw conclusions for the general case. Adopting the criterion that singularities are avoided if the wave function vanishes in the region of the classical singularity, we find that type IV singularities are avoided only for particular solutions of the Wheeler-DeWitt equation. We compare this result with earlier results found for other types of singularities.

GR 7.2 Mon 17:50 SPA SR220

On the relation between canonical and covariant Loop Quantum Gravity — •Antonia Zipfel — Instytut Fizyki Teoretycznej, Uniwersytet Warszawski, Poland

Loop quantum gravity is a background independent and non-perturbative approach towards a quantum theory of gravity that divides into a canonical and covariant (or spin foam) model. Heuristically, spin foams can be understood as the Feynman graphs of Quantum Gravity. Yet, summing over all 'histories' would lead to a projector on the physical Hilbert space of the canonical theory rather than to a true propagator due to the constraint nature of GR. Following this idea we construct a spin-foam operator acting on the kinematic Hilbert space and analyze its properties.

GR 7.3 Mon 18:10 SPA SR220

Loop quantum gravity in higher dimensions and black hole entropy — •Norbert Bodendorfer — IFT UW, Warschau, Polen

A reformulation of higher-dimensional gravity theories is discussed which allows for the application of the loop quantum gravity program. To this end, a Hamiltonian formulation of the gravity theory has to be given on a Yang-Mills phase space such that the Yang-Mills gauge group is compact, the Poisson brackets are canonical, the variables are real and the theory is only subject to first class constraints. The computation of black hole entropy is discussed as an application.

GR 7.4 Mon 18:30 SPA SR220

Lorentzian Regge Calculus and Spinfoam: an example with fixed Topology — •Dimitri Marinelli[1] and Giorgio Immirzi[2] — [1]Dipartimento di Fisica, Università degli Studi di Pavia, Pavia, Italy — [2]Colle Ballone, Montopoli di Sabina, Italy

Regge Calculus is the classical starting point for a bunch of different models of Quantum Gravity. I will present two different solutions of this classical model of gravity for a fixed topology. Some interesting aspects and open problems related to the Lorentzian structure of the discrete system will be analyzed. Moreover, I will present the first steps towards the implementation of the Spinfoam Quantization based on these classical solutions of the Regge Calculus.

GR 8: Main talk: Experimental Gravitation

Time: Tuesday 10:30–11:15 Location: SPA SR220

Invited Talk GR 8.1 Tue 10:30 SPA SR220

Measuring the frame-dragging effect with LAGEOS, LARES and other satellites — •Rolf Koenig — GFZ, Oberpfaffenhofen

During recent years quite some efforts are made to measure the frame-dragging effect by Earth's rotation or the Lense-Thirring effect by evaluating Satellite Laser Ranging (SLR) tracking data to the LAGEOS satellites and newly available gravity field models coming up with the GRACE mission. The accuracy of these attempts can be assessed at about 10 %, the new LARES mission is supposed to improve this to about 1 %. The technique of how this can be done and various error aspects of it are outlined and discussed. In particular the influence of the gravity field model, the solid Earth tides model, and the ocean tides model are illuminated. On the example of the GALILEO constellation the impact of radiation pressure mis-modelling is demonstrated. Also recent results based on up-to-date gravity field models are compared to earlier results.

GR 9: Classical theory of General Relativity I

Time: Tuesday 11:15–12:35 Location: SPA SR220

GR 9.1 Tue 11:15 SPA SR220

Analytic timing formula for a pulsar orbiting a Schwarzschild Black Hole — •Melanie Vogelsang, Eva Hackmann, and Claus Lämmerzahl — ZARM, Bremen, Deutschland

The timing formula of pulsars describe the pulse phase as a function of time with the goal to accurately predict the future pulse arrival times.

For the analytic calculation we consider pulsars around a supermassive black hole, whose gravitational field is described by the Schwarzschild metric. Therefore, the pulsars can be treated as test particles and their motion can be calculated analytically. The equation of motion of the light pulses can also be solved analytically, so that the time of arrival of a pulse can be calculated from its given time of emission. The crucial point in the calculation is to find the observed light ray, as the used pulsar model contains light emission in every direction.

The results of certain systems are compared to those of the post-Newtonian timing formula.

GR 9.2 Tue 11:35 SPA SR220

Test particle motion in a regular black hole spacetime — •Eva Hackmann — ZARM, Universität Bremen

We consider the motion of test particles in the regular black hole space-time given by Ayón-Beato and García in Phys. Rev. Lett. 80:5056 (1998). The complete set of orbits for neutral and weakly charged test particles is discussed, including for neutral particles the extreme and over-extreme metric. We also derive the analytical solutions for the equation of motion of neutral test particles in a parametric form.

GR 9.3 Tue 11:55 SPA SR220

Non-perfect-fluid space-times in thermodynamic equilibrium and generalized Friedmann equations — •Konrad Schatz, Horst-Heino von Borzeszkowski, and Thoralf Chrobok — Institut für Theoretische Physik, TU-Berlin, Germany

Assuming homogeneous and parallax-free space-times, in the case of thermodynamic equilibrium, we construct the energy-momentum tensor of non-perfect fluids. To this end, first, we integrate the propagation equations for the matter functions, i.e., for energy density, isotropic and anisotropic pressures, and heat-flux. This provides these functions in terms of the structure constants of the three-dimensional isometry group of homogeneity and, espectively, of the kinematical quantities, expansion, rotation and acceleration. Second, the matter functions are combined to the energy-momentum tensor. Using Einstein's equations, the constants of integration can be determined such that one gets bounds on the kinematical quantities and finds a generalized form of the Friedmann equations. Finally, it is shown that, for a perfect fluid, the Friedmann and Gödel models can be recovered. All this is derived without assuming any equations of state or other specific thermodynamic conditions.

GR 9.4 Tue 12:15 SPA SR220

Rotating Wormholes — •Burkhard Kleihaus — Universität Oldenburg

Wormholes are solutions of the Einstein equations discribing space-times with two asymptotically flat regions connected by a throat. A textbook example is the Ellis wormhole supported by a scalar phantom field. In the static case this solution is known since long a time.

Here we present the stationary rotating generalizations of the Ellis wormhole in four and five dimensions and discuss their physical properties. These solutions are asymptotically flat and free of sigularities. For a fixed size of the throat the angular momentum is bounded from above. The domain of existence is bounded by the extremal black hole solutions. We derive a Smarr-like relation between mass and angular momentum. Also astrophysical implications are considered in the four dimensional case. We address the question of stability and argue that wormholes might be stabilized by rotation.

GR 10: Main talk: Experimental Gravitation

Time: Tuesday 14:00–14:45 Location: SPA SR220

Invited Talk GR 10.1 Tue 14:00 SPA SR220

Gaia: the project, its status and scientific promises — •Sergei Klioner — Lohrmann Observatorium, TU Dresden

The launch of the ESA Cornerstone mission Gaia has marked a new era in astrometry: the era of microarcsecond accuracies. In addition to astrometric data Gaia will provide a homogeneous photometric and spectrophotometric survey of about one billion celestial sources. Gaia is expected to deliver revolutionary data and discoveries in many fields of astronomy: from the solar system science to the physics of quasars. An overview of the mission and its scientific promises will be given with a special emphasis on the planned tests of fundamental physics. Unprecedented angular accuracy of Gaia will allow to perform a series of tests relation to the gravitational deflection of light, a test of Local Lorenz Invariance as well as measure the mass of some black hole candidates in some compact binary systems with optically visible components. Gaia data can also be used to estimate the energy flux of the gravity waves in certain frequency ranges.

GR 11: Relativistic Astrophysics

Time: Tuesday 14:45–15:25 Location: SPA SR220

GR 11.1 Tue 14:45 SPA SR220

Rapidly rotating neutron stars in Einstein-Gauss-Bonnet-dilaton theory — Burkhard Kleihaus, Jutta Kunz, and •Sindy Mojica — University of Oldenburg

Compact astrophysical objects like neutron stars are good natural laboratories for testing general relativity. Here we consider neutron stars in Einstein-Gauss-Bonnet-dilaton theory, which is a generalized model of gravity, motivated by String Theory. Similar to studies of black holes in this theory, our goal is to identify observable corrections to the properties of neutron stars. We here present our results for rapidly rotating neutron stars, and discuss the dependence of obervables like mass, angular momentum, moment of inertia and energy density on the angular velocity. We find that the mass and energy density decrease in Einstein-Gauss-Bonnet-dilaton theory.

GR 11.2 Tue 15:05 SPA SR220

The I-Q relation for rapidly rotating neutron stars — •Norman Gürlebeck[1], Sayan Chakrabarti[2], Térence Delsate[3], and Jan Steinhoff[4] — [1]ZARM, University of Bremen, Am Fallturm, 28359 Bremen, Germany — [2]Department of Physics, Indian Institute of Technology Guwahati, North Guwahati, 781039, Assam, India — [3]Université de Mons, Place du Parc 20, 7000 Mons, Belgium — [4]CENTRA, Departamento de Física, Instituto Superior Técnico, Universidade de Lisboa, Avenida Rovisco Pais 1, 1049-001 Lisboa, Portugal

We discuss universal relations between the moment of inertia and the quadrupole moment of arbitrarily fast rotating neutron stars. These relations are independent of the equation of state and they were first discussed in a slow rotation approximation. However, recent studies suggested that these relations break down for fast rotations. Nonetheless, we consider the dependence of the relation on different dimensionless parameters characterizing the magnitude of rotation, thereby, restoring their universality among various suggested equations of state.

GR 12: Classical theory of General Relativity II

Time: Tuesday 15:25–16:05 Location: SPA SR220

GR 12.1 Tue 15:25 SPA SR220

Dynamics of spinning particles in curved geometry — •Daniela Kunst[1], Volker Perlick[1], and Claus Lämmerzahl[1,2] — [1]Center of Applied Space Technology and Microgravity (ZARM), University Bremen, Bremen, Germany — [2]University of Oldenburg, Oldenburg, Germany

Based on a recently developed Hamiltonian approach [1] we consider the dynamics of spinning particles in curved geometry, in particular in Schwarzschild and Kerr spacetime. The chosen framework is linearised in the spin of the particle and uses the Newton-Wigner supplementary condition to close the system of differential equations. When Schwarzschild spacetime is considered in spherical coordinates some peculiar coordinate effects arise which can be eliminated by changing to isotropic coordinates. Thus, when we look at Kerr there is a probability that it inherits these coordinate effects. For this reason, we aim to rewrite the Hamiltonian into the Kerr-Schild cartesian coordinates to compare the results with the ones obtained in Boyer-Lindquist coordinates.

Additionally, we intend to investigate and characterise the dynamics of spinning particles employing methods of KAM and chaos theory. These results can then be compared to studies of such systems with different assumptions, e.g. with other spin supplementary conditions.

[1] E. Barausse, E. Racine, and A. Buonanno, Phys. Rev. D 80, 104025 (2009)

GR 12.2 Tue 15:45 SPA SR220

Thermodynamics of self-gravitating distributions of matter — •Tanja Schlemm, Horst-Heino von Borzeszkowski, and Thoralf Chrobok — Technische Universität Berlin, Berlin, Germany

Relativistic thermodynamics has been applied to self-gravitating spherical distributions of fluid matter, where only reversible processes have been considered. From the condition that no entropy is produced follows that the temperature vector $\xi_\mu = u_\mu/T$ must be Killing or conform Killing.

Applied to exact solutions of static star models given in the literature this approach leads to a mostly homogeneous temperature throughout the star, because the assumed equations of state have no explicit dependence on the temperature. Applied to a time dependent spherical metric and a fluid with heat flux an expanding and a contracting solution were obtained.

GR 13: Classical theory of General Relativity III

Time: Tuesday 16:30–17:30 Location: SPA SR220

GR 13.1 Tue 16:30 SPA SR220

The covariant description of spinning fluids in non-linear electrodynamics — •Benjamin Regler, Horst-Heino von Borzeszkowski, and Thoralf Chrobok — Technische Universität Berlin, Berlin, Germany

Spinning fluids are continuous media with intrinsic spin. In this work these fluids are coupled to the most widely known type of non-linear electrodynamics, the Born-Infeld theory.

With particular reference to the charged spinning Weyssenhoff fluid, the equations of motion in curved spacetime are studied and a generalized Lorentz force is derived. Moreover, an interpretation of each term is given and the features of such a charged spinning Born-Infeld Weyssenhoff fluid are highlighted.

GR 13.2 Tue 16:50 SPA SR220

An exact static two-mass solution using Nariai spacetime — •Michael Fennen and Domenico Giulini — ZARM, University of Bremen

If we try to construct a globally static, spherically symmetric, closed spacetime with two identical masses and the topology of a 3-sphere, it is known not to be possible by gluing together two Schwarzschild-De Sitter spacetimes without a separating horizon between the masses or non-static regions. However, in this talk we show that we can construct an exact two-mass solution by embedding two identical stars of constant density into Nariai spacetime. The resulting spacetime has all the desired properties and does not contain a horizon. A generalization to charged stars is possible, at least for low charges.

GR 13.3 Tue 17:10 SPA SR220

Boson stars with wormholes at their cores — •Christian Hoffmann, Burkhard Kleihaus, and Jutta Kunz — University of Oldenburg, Oldenburg, Germany

We consider a new type of configurations in Einstein gravity coupled to a phantom field. They represent boson stars with wormholes at their cores. These configurations are obtained with an ordinary complex scalar field, whose self-interaction includes a quartic and a sextic term. The phantom field allows for the non-trivial topology of the configurations. We study the dependence of the global charges like the mass and the particle number on the frequency of the scalar field, and on the throat size of the wormholes.

GR 14: Alternative classical theories of gravitation I

Time: Tuesday 17:30–18:10 Location: SPA SR220

GR 14.1 Tue 17:30 SPA SR220

On a Finsler-type modification of the Coulomb law — Yakov Itin[1], Claus Lämmerzahl[2], and •Volker Perlick[2] — [1]Institute of Mathematics, The Hebrew University of Jerusalem, Israel — [2]ZARM, Universitaet Bremen

We demonstrate that a Finslerian modification of the spacetime metric leads to modified Maxwell equations which are no longer differential equations but rather pseudo-differential equation. The corrections to the Coulomb potential and to the hydrogen energy levels are computed. We find that the Finsler modification of the metric yields a splitting of the energy levels. We calculate the bounds on the Finsler parameters from experimental data.

GR 14.2 Tue 17:50 SPA SR220

Parameterized post-Newtonian formalism for multimetric gravity — •Manuel Hohmann — Tartu University, Estonia

We discuss the post-Newtonian limit of multimetric gravity theories with $N \geq 2$ metric tensors and a corresponding number of standard model copies, and construct an extension of the parameterized post-Newtonian (PPN) formalism. This extended formalism allows a characterization of multimetric gravity theories by a set of constant parameters. The multimetric PPN parameters are in close correspondence to the standard PPN parameters, which have been measured using high-precision experiments in the solar system. We apply our formalism to a class of theories which we previously discussed in the context of cosmology and gravitational waves, and which feature an accelerating expansion of the universe. A comparison between our results and the measured PPN parameters shows that multimetric gravity is fully compatible with solar system observations.

GR 15: Other topics

Time: Tuesday 18:10–18:50 Location: SPA SR220

GR 15.1 Tue 18:10 SPA SR220

Spinning gauged boson stars in anti-de Sitter spacetime — •Olga Kichakova, Eugen Radu, and Jutta Kunz — University of Oldenburg, Oldenburg, Germany

We study axially symmetric solutions of the Einstein-Maxwell-Klein-Gordon equations describing spinning gauged boson stars in a 3+1 dimensional asymptotically AdS spacetime. These smooth horizonless solutions possess an electric charge and a magnetic dipole moment, their angular momentum being proportional to the electric charge.A special class of solutions with a self-interacting scalar field, corresponding to static axially symmetric solitons with a nonzero magnetic dipole moment, is also investigated.

GR 15.2 Tue 18:30 SPA SR220

Hairy Wormholes and Bartnik-McKinnon Solutions — •Olga Hauser[1], Rustam Ibadov[2], Burkhard Kleihaus[1], and Jutta Kunz[1] — [1]University of Oldenburg — [2]Samarkand State University

We consider Lorentzian wormholes supported by a phantom field and threaded by non-trivial Yang-Mills fields, which may be regarded as hair on the Ellis wormhole. Like the Bartnik-McKinnon solutions and their associated hairy black holes, these hairy wormholes form infinite sequences, labeled by the node number k of their gauge field function. We discuss the throat geometry of these wormholes, showing that odd-k solutions may exhibit a double-throat, and evaluate their global charges. We analyze the limiting behavior exhibited by wormhole solutions as the gravitational coupling becomes large. The even-k solutions approach smoothly the Bartnik-McKinnon solutions with $k/2$ nodes, while the odd-k solutions develop a singular behavior at the throat in the limit of large coupling. In the limit of large k, on the other hand, an embedded Abelian wormhole solution is approached, when the throat is large. For smaller throats the extremal Reissner-Nordström solution plays a fundamental role in the limit.

GR 16: Black Holes I

Time: Wednesday 14:00–16:00 Location: SPA SR220

GR 16.1 Wed 14:00 SPA SR220

XMM-Newton's impact on Relativistic Astrophysics — •Norbert Schartel — XMM-Newton SOC, ESA, illanueva de la Cañada, Spain

With about 300 refereed papers published each year, XMM-Newton is one of the most successful scientific missions of ESA ever.

Observations of compact objects, where relativistic effects have to be accounted for, play a major role in XMM-Newton's observing program: Neutron stars and Galactic black holes as well as supermassive black holes in the centre of active and non-active galaxies. The main focus of the talk will be the discussion of scientific highlight results based on XMM-Newton observations of compact, relativistic objects during the last years. X-ray observations provide a unique opportunity to study the vicinity of compact objects, i.e. the region where the strong gravitational field acts and allows the determination of black hole spin.

GR 16.2 Wed 14:20 SPA SR220

Sequences of extremal radially excited rotating black holes — Jose Luis Blazquez-Salcedo[1], •Jutta Kunz[2], Francisco Navarro-Lerida[1], and Eugen Radu[2] — [1]Universidad Complutense de Madrid — [2]Universität Oldenburg

In 5-dimensional Einstein-Maxwell-Chern-Simons theory with Chern-Simons coefficient λ the solutions are only known in closed form, when $\lambda = 1$. For $\lambda \neq 1$ the charged rotating black hole solutions are obtained numerically. Beyond $\lambda = 1$ counterrotating black holes appear. Moreover, for $\lambda > 2$ uniqueness is lost. Here the extremal Reissner-Nordström solution is no longer the single extremal solution with vanishing angular momentum. Instead a whole sequence of rotating extremal $J = 0$ solutions arises, which can be labeled by the node number of the magnetic U(1) potential. These global black hole solutions thus represent a sequence of radially excited extremal solutions. They are associated with the same near horizon solution, and their mass converges to the mass of the extremal Reissner-Nordström solution. On the other hand, not all near horizon solutions are also realized as global solutions.

GR 16.3 Wed 14:40 SPA SR220

Balanced black holes with $S^2 \times S^{2k+1}$ horizon topology as higher dimensional counterparts of $d = 5$ black rings — Burkhard Kleihaus[1], Jutta Kunz[1], and •Eugen Radu[2] — [1]Institut für Physik, Universität Oldenburg, Postfach 2503 D-26111 Oldenburg, Germany — [2]Departamento de Fisica da Universidade de Aveiro and I3N, Campus de Santiago, 3810-183 Aveiro, Portugal

We present numerical evidence for the existence of a new type of black hole solutions with a nonspherical event horizon topology in $d > 5$ spacetime dimensions. These asymptotically flat configurations are found for a specific metric Ansatz by directly solving the Einstein equations with suitable boundary conditions. The new black holes are regular on and outside an event horizon of $S^2 \times S^{2k+1}$ horizon topology, being supported against collapse by rotation. Numerical solutions are constructed in a systematic way for $d = 7$. We point out that the basic properties of the new solutions are very similar to those of the $d = 5$ black rings. In particular, one finds two branches of solutions, which branch off from a cusp. Moreover, for a range of the parameters, there are three different solutions with the same global charges –two black holes with $S^2 \times S^{2k+1}$ horizon topology and one Myers-Perry black hole.

GR 16.4 Wed 15:00 SPA SR220

Black hole remnants due to Planck-length deformed QFT — •Alain Dirkes[1], Michael Maziashvili[2], and Zurab Silagadze[3] — [1]Frankfurt Institute for Advanced Studies (FIAS) & Goethe Universität, Frankfurt am Main, Germany — [2]Particle Physics & Cosmology Group, Ilia State University, Tiblisi, Georgia — [3]Budker Institute of Nuclear Physics SB RAS, Novosibirsk State University, Novosibirsk, Russia

It was shown in a number of papers that the gravitational potential calculated by using the propagator, that follows from the minimum-length deformed QFT, implies the existence of black hole remnants of the order of the Planck-mass.

Here we examine the behaviour of the potential that follows from Planck-length deformed QFT, which in general does not entail the concept of the minimum length.

We analyse whether the existence of black holes remnants is intimately related to the concept of the minimum length or not.

The key ideas of the above mentioned investigations are summarized in a preprint on the arXiv: 1309.7427v1 [gr-qc].

We intend to further generalize our analysis to a range of physically viable Non Local Field Theories.

GR 16.5 Wed 15:20 SPA SR220

Dynamical Black Holes in 2+1 Dimensions — •Mario Flory[1] and Ivo Sachs[2] — [1]Max-Planck-Institut für Physik, München — [2]Arnold Sommerfeld Center, Ludwig-Maximilians-Universität München

In this talk, the global structure of a recently discovered simple, exact, non-stationary solution of certain higher curvature theories in 2+1 dimensions will be discussed. We establish the existence of a time-like singularity in the causal structure of the spacetime as well as the presence of time dependent trapping and event horizons, making the spacetime at hand an exactly known dynamical vacuum black hole. We will in particular compare this dynamical black hole to the related stationary BTZ black holes.

GR 16.6 Wed 15:40 SPA SR220

Dynamics of test particles in the five-dimensional Myers-Perry-spacetime — Valeria Diemer[1], Jutta Kunz[1], Claus

Lämmerzahl[1,2], and •Stephan Reimers[1] — [1]Carl von Ossietzky Universität Oldenburg — [2]ZARM, Universität Bremen

We present the complete set of analytical solutions of the geodesic equation in the five-dimensional Myers-Perry-spacetime with unequal rotation parameters. The solutions are given in terms of the Weierstrass $\wp$-, ζ- and σ-functions. We visualize the trajectories of test particles and discuss their properties. We show that observables can be presented in a closed form in terms of the periods of the Weierstrass functions.

GR 17: Black Holes II

Time: Wednesday 16:30–17:30 Location: SPA SR220

GR 17.1 Wed 16:30 SPA SR220

Orbits in rotating dyonic extremal Kaluza-Klein black hole spacetimes — Valeria Diemer, •Matthias Kruse, and Jutta Kunz — University of Oldenburg

The analytic solution of the geodesic equation obtained in rotating dyonic extremal Kaluza-Klein black hole spacetimes is presented. The possible orbits for massive and massless test particles in these spacetimes are investigated and classified. The equations of motion are solved analytically by means of elliptic functions, leading to an exact description of the orbits.

GR 17.2 Wed 16:50 SPA SR220

Shadows and Photon Regions of Black Holes — •Arne Grenzebach, Claus Lämmerzahl, and Volker Perlick — ZARM, Universität Bremen, 28359 Bremen

I my talk I start with a short general definition of the concept of the *shadow* of black holes and describe how the shadow of a Kerr-Newman-NUT black hole with a cosmological constant can be determined. Here, the crucial point is the existence of (unstable) spherical light rays in a region $\mathcal{K}$ which determine the boundary of the shadow. This region $\mathcal{K}$ shrinks to the well known photon sphere in the Reissner-Nordström case. After transformation to celestial coordinates on the observer's sky, the shadow can be viewed via stereographic projection.

GR 17.3 Wed 17:10 SPA SR220

Dilatonic Black Saturn — •Saskia Grunau and Jutta Kunz — Universität Oldenburg

We construct the charged rotating black saturn in Einstein-Maxwell-dilaton theory in five dimensions. The black saturn solution of Elvang and Figueras is embedded in six dimensions and boosted with respect to the time coordinate and the added sixth dimension. Then the charged solution is obtained by a Kaluza-Klein reduction.

If the parameters of the solution satisfy certain conditions, the dilatonic black saturn is in mechanical and thermodynamical equilibrium at the same time.

We study the influence of the dilaton on the black saturn spacetime by analysing the physical properties and the phase diagram.

GR 18: Fundamental problems and general formalism

Time: Wednesday 17:30–18:10 Location: SPA SR220

GR 18.1 Wed 17:30 SPA SR220

Probing the gravitational field with test bodies — •Dirk Puetzfeld — ZARM, U Bremen, Germany

We discuss some techniques for the detection of the gravitational field by means of test bodies. In particular we highlight how measurement methods depend on assumptions made within the underlying relativistic approximation schemes.

GR 18.2 Wed 17:50 SPA SR220

On *Dirac*'s covariant quantization of non-linear electrodynamics — •Rico Berner, Horst-Heino von Borzeszkowski, and Thoralf Chrobok — Technische Universität Berlin, Berlin, Germany

This talk's aim is to give an alternative view on the quantization procedure of *Dirac*'s paper (Proc. R. Soc. Lond. A 1960 257, 23–43) concerning the Born-Infeld electrodynamics. An extension of *Dirac*'s approach is introduced for the determination of the constraints of non-linear electrodynamics. Furthermore, the application of the extended approach to various theories is presented and compared to the results of Dirac, especially with regard to the theory of Born and Infeld.

GR 19: Cosmology

Time: Wednesday 18:10–18:30 Location: SPA SR220

GR 19.1 Wed 18:10 SPA SR220

Beyond single stream with the Schrödinger method - Closing the Vlasov hierarchy — •Cora Uhlemann, Michael Kopp, and Thomas Haugg — Arnold Sommerfeld Center for Theoretical Physics, Ludwig-Maximilians-University, Theresienstr. 37, D-80333 Munich

We investigate large scale structure formation of dark matter in the phase-space description based on the Vlasov equation whose nonlinearity is induced by gravitational interaction according to the Poisson equation. Determining the time-evolution of density and peculiar velocity demands solving the full Vlasov hierarchy for the moments of the phase-space distribution function. In the presence of long-range interaction no consistent truncation of the hierarchy is known apart from the pressureless fluid (dust) model which is incapable of describing virialization due to the occurrence of shell-crossing singularities and the inability to generate higher cumulants like vorticity and velocity dispersion. Our goal is to find a phase-space distribution function that is able to describe regions of multi-streaming and therefore can serve as theoretical N-body double. We use the coarse-grained Wigner probability distribution obtained from a wavefunction fulfilling the Schrödinger equation and show that its evolution equation bears strong resemblance to the Vlasov equation but cures the shell-crossing singularities. This feature was already employed in cosmological simulations of large-scale structure formation by Widrow & Kaiser '93. We are able to show that the coarse-grained Wigner ansatz automatically closes the corresponding hierarchy while incorporating nonzero higher cumulants which are determined self-consistently from density and velocity.

GR 20: Main talk: Experimental Gravitation

Time: Thursday 14:00–14:45 Location: SPA SR220

Invited Talk GR 20.1 Thu 14:00 SPA SR220
Quantum & Gravitation — •Hartmut Abele — Atominstitut - TU Wien, Stadionallee 2, 1020 Wien, Österreich

Gravitation: Newton's Law of Gravity is considered valid from sub-millimetre distances up to inter-galactic space. Nevertheless it fails to describe important features of cosmology like the accelerating expansion component of our universe. While the most straightforward candidate for such a component is Einstein's cosmological constant, a plausible alternative is dynamical vacuum energy, or 'quintessence', changing over time. So far, distinguishing between these two explanations has eluded experimental tests. Here, we present a novel search strategy using a quantum interference technique with neutrons to differentiate between Einstein's cosmological constant and quintessence, see below.

Quantum: Ultra-cold neutrons are falling in the gravity potential of the earth and are retroreflected by a neutron mirror. The quantum nature allows them to be manipulated in novel ways, which are being used to create new instruments for gravity research. We are now developing a gravity resonance spectroscopy technique by vibrating the mirror underneath thus providing a coupling between different energy levels. The sensitivity for deviations on Newton's gravity law right now is E = 10^{-14} eV, providing severe restrictions on any possible new interactions on that level of accuracy. If some undiscovered dark matter or dark energy particles interact with a neutron, this should result in a measurable energy shift of the observed quantum states.

GR 21: Experimental Gravitation III

Time: Thursday 14:45–15:45 Location: SPA SR220

GR 21.1 Thu 14:45 SPA SR220
Gravity resonance spectroscopy constrains dark energy and dark matter scenarios — •Tobias Jenke[1], Gunther Cronenberg[1], Hanno Filter[1], Peter Geltenbort[2], Andrei N. Ivanov[1], Thorsten Lauer[3], Tobias Lins[1], Heiko Saul[1], Ulrich Schmidt[4], and Hartmut Abele[1] — [1]Atominstitut, TU Wien, Wien, Austria — [2]Institut Laue-Langevin, Grenoble, France — [3]FRM II, TU München, Garching — [4]Physikalisches Institut, Universität Heidelberg, Heidelberg

Modern astronomical observations clearly point to the existence of dark energy and dark matter. Their true nature and content remain a mystery however. The two most obvious candidates for dark energy are either Einstein's cosmological constant or quintessence theories. In particular the idea that chameleon scenarios, a realization of quintessence with a coupling to matter, may exist, is attracting high interest of a growing community.

Here, we present results from the qBounce measurements using ultracold neutrons. Our observation technique is based on Rabi-spectroscopy of bound quantum states in the gravity potential of the earth, devoid of electromagnetic perturbations. As yet undiscovered particles of dark matter or dark energy would introduce a measurable energy shift, the result delivers severe restrictions on any gravity-like interaction. The present accuracy indicates that gravity is understood at the level of $\Delta E = 10^{-14}$ eV. Hence, we can present experimental limits for dark-energy chameleons fields and the pseudo-scalar interaction of an axion, a prominent dark matter particle.

GR 21.2 Thu 15:05 SPA SR220
Preparing a Measurement of the Charge of the free Neutron within qBounce — Gunther Cronenberg[1], •Hanno Filter[1], Peter Geltenbort[2], Martin Thalhammer[1], Tobias Jenke[1], and Hartmut Abele[1] — [1]Atominstitut, Technische Universität Wien, Stadionallee 2, 1020 Wien, Austria — [2]Institut Laue-Langevin, 6 rue Jules Horowitz, 38042 Grenoble Cedex 9, France

With a new Gravity Resonance Spectroscopy technique we plan to probe the electric neutrality of the neutron. This is possible by expanding our existing qBounce setup. Through adding two regions to our current three regions setup, we would basically implement Ramsey*s Method of separated oscillating fields with a beam of ultracold neutrons [1]. The approach has the potential to improve the 25 years old existing limit on the electric neutrality of the neutron [2] [3]. Our project is related to the question of the quantisation of the electric charge, which is a well established experimental observation. Charge quantisation in the Standard Model of Particle Physics can be introduced by many fundamentally different extensions. Hence a measurement of the charge is a promising way to refine the theoretical framework with far reaching consequences for various topics i.e. neutron-antineutron oscillations, magnetic monopoles, or the search for a Grand Unified Theory [2].

GR 21.3 Thu 15:25 SPA SR220
qBounce: Frequency's view on Newton's Law — •Gunther Cronenberg[1], Thomas Bittner[1], Hanno Filter[1], Peter Geltenbort[2], Tobias Jenke[1], Martin Thalhammer[1], and Hartmut Abele[1] — [1]Atominstitut, Technische Universität Wien, Stadionallee 2, 1020 Wien, Austria — [2]Institut Laue-Langevin, BP 156, 6 rue Jules Horowitz, 38042 Grenoble Cedex 9, France

In the frame of the qBounce experiment, resonant transitions between several of the lowest quantum states of gravitationally bound neutrons are observed for the first time. The coupling between the states is provided by well-defined mechanical oscillations of the confining neutron mirrors boundary conditions. The Rabi- like setup in the latest generation is improved by renouncing the upper confining mirror. The presented spectroscopy method enables a frequency's view on Newton's Inverse Square Law of Gravity, which has been put under scrutiny by theoretical extensions of the Standard Model. The method allows testing the weak equivalence principle (WEP) for a quantum system in the sub-millimetre regime of space-time. The weak equivalence principle is a corner stone of our understanding of gravitation, which is being challenged by emerging theories.

GR 22: Numerical Relativity I

Time: Thursday 15:45–16:05 Location: SPA SR220

GR 22.1 Thu 15:45 SPA SR220
Initial data for eccentric neutron star binaries — •Niclas Moldenhauer[1], Charalampos Markakis[1], Nathan Johnson-McDaniel[1], Wolfgang Tichy[2], and Bernd Brügmann[1] — [1]Friedrich-Schiller Universität Jena, 07743 Jena, Deutschland — [2]Florida Atlantic University, Boca Raton, FL 33431 USA

Various groups have been recently evolving neutron-star binaries on eccentric orbits, but either in Newtonian gravity or with constraint violating initial data. On circular orbits, which are stationary in a rotating frame, helical symmetry can be exploited for constructing equilibrium solutions. However, due to lack of helical symmetry, no such method exists for eccentric orbits. Thus, the numerical relativity community has often resorted to unsolved initial data based on superimposed spherical stars. Because such configurations lack tidal deformation and are not stationary in the correct frame, they give rise to unphysically large oscillations in the subsequent evolution. We consider configurations which are approximately stationary in physically relevant frame. We utilize the resulting approximate first integral of the Euler equation in a self-consistent iteration of the Einstein constraints in the extended conformal thin-sandwich approach, to construct initial data for eccentric binaries. We compare the constraint violations and stellar oscillations in simulations based on various data sets, and find that simulations based on the new data compare favorably to earlier ones in the eccentric case.

GR 23: Main talk: Experimental Gravitation

Time: Thursday 16:30–17:15 Location: SPA SR220

Invited Talk GR 23.1 Thu 16:30 SPA SR220
Schrödinger's Mirrors: confronting quantum physics with gravity — •Markus Aspelmeyer — University of Vienna, Faculty of Physics, Vienna Center for Quantum Science and Technology (VCQ), Vienna, Austria

Quantum optics provides a high-precision toolbox to enter and to control the quantum regime of the motion of massive mechanical objects. This opens the door to a hitherto untested parameter regime of macroscopic quantum physics. Due to the large available mass range – from picograms in nanomechanical waveguides to kilograms in mirrors for gravitational wave detection – it becomes possible to explore the fascinating interface between quantum physics and gravity in table-top quantum optics experiments.

GR 24: Numerical Relativity II

Time: Thursday 17:15–18:15 Location: SPA SR220

GR 24.1 Thu 17:15 SPA SR220
Mergers of binary neutron stars with realistic spin — •Tim Dietrich[1], Sebastiano Bernuzzi[1], Wolfgang Tichy[2], and Bernd Brügmann[1] — [1]Theoretical Physics Institute, University of Jena, 07743 Jena, Germany — [2]Department of Physics, Florida Atlantic University, Boca Raton, FL 33431 USA

Binary neutron star mergers are a primary source of gravitational waves. We present the first, fully nonlinear general relativistic dynamical evolutions of the last three orbits for constraint satisfying initial data of spinning neutron star binaries. The dynamics of the systems is analyzed in terms of gauge-invariant binding energy vs. orbital angular momentum curves. By comparing to a binary black hole configuration we can estimate the different tidal and spin contributions to the binding energy for the first time. Additionally, a frequency shift in the main emission mode of the hyper massive neutron star is observed. Our results suggest that a detailed modeling of merger waveforms requires the inclusion of spin, even for the moderate magnitudes observed in binary neutron star systems.

GR 24.2 Thu 17:35 SPA SR220
Einstein-matter dynamics with a hyperboloidal evolution code — •Oliver Rinne — Albert-Einstein-Institut, Potsdam

In hyperboloidal evolution, spacetime is foliated by spacelike hypersurfaces approaching future null infinity, thereby avoiding any problems arising from an artificial timelike boundary. With V. Moncrief we developed a conformal constrained 3+1 formulation of the Einstein equations on such a foliation. In this talk I will present some new numerical results on evolutions of Yang-Mills and/or massive scalar fields coupled to the Einstein equations, focusing on the dynamical role played by nontrivial static solutions.

GR 24.3 Thu 17:55 SPA SR220
An axisymmetric formulation in spherical coordinates — Oliver Rinne and •Christian Schell — Max Planck-Institute for Gravitational Physics, Golm

In this talk we present a new formulation for a non-rotating axisymmetric spacetime in vacuum. The majority of formulations for this situation uses cylindrical coordinates. In contrast to those we introduce spherical coordinates. A general problem for both choices of coordinate systems in axisymmetry is the occurrence of a coordinate singularity at the axis of symmetry. Spherical harmonics are manifestly regular at the axis and hence take care of that issue automatically. Therefore we express all our variables in the corresponding harmonics. We also address the question of an appropriate gauge choice.

GR 25: Classical theory of General Relativity IV

Time: Friday 10:30–10:50 Location: SPA SR220

GR 25.1 Fri 10:30 SPA SR220
Fireballs of GRBs derived from Lorentz-Interpretation (LI) of GRT — •Jürgen Brandes — Karlsbad, Germany

LI of GRT expands GRT [1]. Counterarguments [2]. Main differences with GRT though using the same formulas: (a) Free falling particles decrease their rest mass, loose it when reaching the event horizon and because of that become a wave, s. formula $E = mc^2\sqrt{(1-2GM/c^2r)}$ of [2]. This means: While Higgsfields *give* elementary particles a rest mass, gravitational fields *take* rest mass *away.* (b) Gravitational fields only exist if there are particles with rest mass $\neq 0$.

Assume a collapsing dust star reaching the event horizon. Then, using (a) and (b) all the particles loose their rest mass, become waves and all together form an expanding fireball with zero rest mass at $t = 0$. This is the (over)simplified idea of fireballs of GRBs seen by LI and needs more explanation in the talk. Some details s. [2].

[1] J. Brandes, J. Czerniawski: *Spezielle und Allgemeine Relativitätstheorie für Physiker und Philosophen - Einstein- und Lorentz-Interpretation, Paradoxien, Raum und Zeit, Experimente*, 4. Aufl. 2010 p. 316 ff, [2] Website www.grt-li.de

GR 26: Alternative classical theories of gravitation II

Time: Friday 10:50–11:30 Location: SPA SR220

GR 26.1 Fri 10:50 SPA SR220
Relativity without Space-Time — •Albrecht Giese — Taxusweg 15, 22605 Hamburg

Einstein developed relativity on the basis that the speed of light c is a true constant in any system, and he deliberately abstained from assuming the existence of an ether. Einstein paid a high price for this as he had to introduce (curved) 4-dimensional space-time to overcome logical conflicts.

Relativity (SRT and GRT) can be developed by assuming a fixed reference system (as an abstraction of an ether) and using known physical causes of contraction, dilation, the - measured - constancy of 'c' and the curvature of light rays. The resulting mathematical theory produces exactly the same results as Einstein. However, it only needs standard mathematics and is thus easy enough to be taught at school.

In addition, unresolved problems like dark energy and quantum gravity can be solved.

There is a common misconception about the origin of relativity. This is the erroneous assumption that the Michelson-Morley experiment disproved the existence of an ether. Even Einstein did not draw this conclusion. It was Einstein's relation to the philosophy of positivism in his early years that made him dispense with an ether as a non-visible phenomenon (ref. Karl Popper).

For further info: www.ag-physics.org

GR 26.2 Fri 11:10 SPA SR220

Die Bedeutung der Entdeckung des Higgs-Bosoms für die Relativitätstheorie — •Kai-Olaf Henkel — Doverkamp 10 22335 Hamburg

Einleitung: Die Relativitätstheorie geht von einer Krümmung des Raumes durch den Einfluß von Gravitationsfelder aus. Die Entdeckung des Higgs-Bosoms steht im Widerspruch zu dieser allgemein anerkannten Beobachtung. Denn das Higgs-Teilchen ist als Elementarteilchen kein Bestandteil der Raumkonfiguration. These: Der Raum selbst ist deshalb ohne Masse und unterliegt entsprechend dem 2. newtonschen Gravitationsgesetz nicht dem Einfluß schwerer Massen. Damit existiert keine gravitationsabhängige Krümmung des Raumes. Erklärung: Die beobachteten Effekte, wie z.B. Ablenkung eines Lichtstrahls im Schwerefeld der Sonne leiten sich aus einer Verlangsamung des Zeitzablaufs im Gravitationsfeld der Sonne ab. Schlussfolgerung: Der Verlauf der Zeit ist nicht konstant. Er ist in Bereichen geringerer Gravitation beschleunigt. Beweis: Die Abflachung der Rotationsgeschwindigkeit von Galaxien zum Rand hin ist ein Beleg für diese Schlussfolgerung. Da die Verteilung der Masse in einer Galaxie zum Rand hin abnimmt, beschleunigt sich der Verlauf der Zeit. Unter der Annahme eines uniquitären konstantanten Zeitverlaufs ergibt sich damit die Diskrepanz zwischen berechneter und beobachteter Umlaufgeschwindigkeit von Objekten am Rand der Galaxie.

GR 27: Quantum Gravity and Quantum Cosmology II

Time: Friday 11:30–12:10 Location: SPA SR220

GR 27.1 Fri 11:30 SPA SR220

Die Gravitation, die Entropie und die dunkle Materie — •Norbert Sadler — Wasserburger Str, 25a ; 85540 Haar

Die Gravitation kann als die Entropie des makroskopischen, linearen Energiedichte-Zustandes, E(1kg/1m x c**2), verstanden werden. Die mikroskopischen Energiedichte-Zustände der mittleren, linearen Materiedichte des Universums, E(4/9Prot/1m x c**2),sind als die gravitativen Feldquanten des Universums zu betrachten.

Durch lineare, spontane Spiegelungen der mikroskopischen Feldquanten über den Radius des Universums bzw. an dem 57 dimensionalen Objekt der E8-Gruppe wird die Entropie des makroskopischen Energiedichte-Zustandes identifiziert, und ist in der Größe emergent zu den 23.9% dunkler Materie.

Die gravitativen-,entropischen Energie-Zustände des Universums:
Allgemein: Betrag R(Univ.)x(1Proton/1m)=(0.239)x(1kg/1m)
Die E8-Grp.: 57x((e**57)x4/9Prot./1mxc**2)=(0.239)x(1kg/1mxc**2)
PL-Metrik:248x((57)**3x(m(Pl./1m)/xc**2)=(0.239)x(1kg/1mxc**2)
Dunkle Materie: (0.239)=(e**0.0458)x57/248
Dunkle Energie: (0.705)x1GeV=(e**-0.288)x(1Prot.0.938GeV)
alfa(vereinheitl.)=(32x4/3)x Betrag (Pl.-Zeit)=2.29x10**-42
Weitere Information: www.cosmology-harmonices-mundi.com

GR 27.2 Fri 11:50 SPA SR220

Is Our Universe Finite? New Physics by Dark Matter. On Hike through Black, White, and Worm Holes — •Claus Birkholz — D-10117 Berlin, Seydelstr. 7

Quantum Gravity (QG) allows finite-dimensional representations for its particles without getting into the traditional trouble with probability conservation. As in QG a particle and a universe are described by identical equations, our universe is expected to be finite, as well.

Within a finite universe, not only space-time is limited, but there also must exist upper bounds for energy-momentum: A particle cannot be accelerated up to arbitrary energy.

By erasing major inconsistencies in quantum field theories, their current types are proved to systematically destroying structure of our universe, which, thus, must be much greater than officially assumed. The key is traced back to Dark Matter.

Black Holes are argued to be "particle vertices" with respect to our universe, while "White Holes", here, are not yet identified. The intermediary exchange state between such a related pair, by GR is represented as a "Worm Hole".

For more information on QG and GUT see www.q-grav.com

GR 28: Poster (permanent)

Time: Monday 8:30–8:30 Location: SPA Foyer

GR 28.1 Mon 8:30 SPA Foyer

Book: Special and general theory of relativity — •Jürgen Brandes — Karlsbad, Germany

Exact and comprehensible are discussed [1]: The experimental proofs of relativity theory, the solutions of the paradoxies, the theses of the four-dimensional space-time-continuum of special relativity as well as the theses of curved, expanding and closed spacetime of general relativity. Included are the general relavistic solution variant of the twin paradox and the paradoxies of Bell, Ehrenfest and Sagnac.

The so-called Lorentz-interpretation (LI) was initiated by Lorentz, Poincaré, Bell, Sexl and many others. It connects Einstein's principle of relativity with the concept of a three-dimensional space and a one-dimensional time

An important point in [1] concerns energy conservation. Within Newton's theory there is a negative gravitational potential, on account of the famous relation $E = mc^2$ this means negative masses. Negative masses don't exist. Lorentz-interpretation gives a clear, experimentally verifiable answer to this problem.

Additionally, the poster presents details of the DPG talks "GRT - well proven and also incomplete" and "Fireballs of GRBs derived from Lorentz-interpretation (LI) of GRT". The full talks become part of [2].

[1] J. Brandes, J. Czerniawski:*Spezielle und Allgemeine Relativitätstheorie für Physiker und Philosophen - Einstein- und Lorentz-Interpretation, Paradoxien, Raum und Zeit, Experimente*, 2010, [2] Website www.grt-li.de

GR 28.2 Mon 8:30 SPA Foyer

Einsteins Traum — •Claus Birkholz — D-10117 Berlin, Seydelstr. 7

Die konsistente Vereinigung von Einsteins Allgemeiner Relativitätstheorie mit Plancks Quantentheorie und Gell-Manns Quarks wird Wirklichkeit. Ein erkenntnis-theoretischer Schub bahnt sich seinen Weg.

Die Quantengravitation führt über ihre voll quantisierte Raum-Zeit automatisch zu einer Ebene von "Quanten" weit unterhalb der Ebene von Quarks. Ihre Einbeziehung von Nicht-Valenz-Strukturen fehlt im "Standardmodell", das ja nur fittet, aber nichts erklärt. Dies aber war der Schlüssel zur erfolgreichen Einbeziehung auch der Gravitation in die konsistente Vereinigung aller Kräfte der Natur.

Erst die Quantengravitation erklärt den Aufbau der Leptonen, die Hadron- und Lepton-Flavour, die Neutrino-Physik, das Quark Confinement - ganz zu schweigen vom Aufbau der kosmologischen Konstante, der Dunklen Materie, der Erklärung virtueller Zustände, der Dunklen Energie, der kosmischen Inflation, der Physik vor dem Urknall usw.

Die ganze Wunschpalette der String-Modelle - die QG liefert sie, realiter und konsistent, und noch vieles mehr. Im Einklang mit dem Experiment.

GR 28.3 Mon 8:30 SPA Foyer

Algebra und Geometrie des kosmologischen Standard-Modells — •Norbert Sadler — Wasserburger Str. 25a: Haar

Das Universum ist nach geometrischen Prinzipien aufgebaut und kann in seiner Struktur algebraisch berechnet und verstanden werden. Das Standard-Modell benötigt zur Berechnung und Darstellung vier essentiellen Größen:

Die Kreis-Zahl (Pi), die Euler-Zahl (e), die Elemente und die Trägermatrix der Exzeptionellen E8-Gruppe (wie die 248 Freiheitsgrade in der Drehung eines 57 dimensionalen Objektes), und den Wert der direkten CP-Verletzung.

Die kosmischen Größen/Parameter des Standard-Modells:
Der Hubble Parameter: H=c/(4/9x57xe**57x1m)=64.5km/Mpcs.
Reynolds-Zahl d. Univ.:Re=861=2Pi/alfa(QED)=e/(0.0458x0.24x0.288)
Baryon. Energiedichte:(0.0458)=(CP-Verl.0.0028)x57x(0.288)
Dunkle Materie: (0.24)=2x(CP-Verl.0.0028)x57x(e**-0.288)
Dunkle Energie: (0.705)x1GeV=(e**-0.288)x(1Prot.0.938GeV)
Zu den Ergebnissen der "Planck-Mission":
Das Schwerefeld der Erde beeinflusst die Planck-Ergebnisse:
H(Pl.)=67,5km/Mpcs=(e**0.0458)xH(kosm.=64.5 km/Mpcs)
Dunkle Mat.(Pl.)=(0.263)=(e**4Pi alfa(QED))xDunkl.Mat(0.24)
Weitere Information: www.cosmology-harmonices-mundi.com

GR 28.4 Mon 8:30 SPA Foyer

The Question of Dark Energy — •Albrecht Giese — Taxusweg 15, 22605 Hamburg

Dark energy is considered to be one of the great mysteries in present-day physics. From measurements of the motion of supernovae type Ia, it is deduced that the universe is undergoing accelerated expansion. To explain this acceleration, it is assumed that the universe is filled with some type of ('dark') energy.

However, there are 2 very unspectacular explanations for the measurement.

Solution 1: The speed of light 'c' was higher in early times. This inserted into the Doppler equation for the determination of early speeds from red-shift yields higher speeds for early stars. So there is no acceleration.

Solution 2: From the cosmological concept of inflation it follows that space was smaller in early times. This has caused (at constant 'c') higher frequencies for the eigenstates of the atoms, which in turn caused the frequency of spectral lines to be positioned towards 'blue' compared to 'now'. So the resulting red-shift is higher than presently assumed, and early stars have in fact been faster. No acceleration.

Further info: www.ag-physics.org/darkenergy

GR 28.5 Mon 8:30 SPA Foyer

Is the Speed of Light 'c' a True Constant? — •Albrecht Giese — Taxusweg 15, 22605 Hamburg

The Michelson-Morley experiment has at the first glance given the impression that 'c' is a constant in relation to any system. However, at the second glance this constancy turns out to be pure measurement result.

H. Lorentz had pointed out that this apparent constancy is the result of well understood field behaviour. Einstein accepted this as a working explanation, but he disliked it as it made an ether necessary, which he didn't want. He insisted in a theory with a constant 'c' with respect to any system. To achieve this, he had to assume a variation of space and time depending on the actual conditions of motion.

Einstein extended this principle about 'c' to gravitational fields. Even though it can be directly measured that 'c' is reduced there, Einstein again stated its constancy and explained the measurement result as a change of space-time (which is not directly measurable).

It is logically possible to transform Einstein's equations based on a constancy of 'c' and a variable space-time into a model, where space and time are fixed as always assumed but 'c' variable. This results in a much simpler understanding of physics with predominantly similar results as with Einstein.

Further information: www.ag-physics.org/gravity

GR 28.6 Mon 8:30 SPA Foyer

Sektormodelle gekrümmter Räume — •Corvin Zahn und Ute Kraus — Universität Hildesheim

Die Allgemeine Relativitätstheorie beschreibt die Welt als vierdimensionale Lorentz-Mannigfaltigkeit. In vielen Fällen sind zwei- oder dreidimensionale Unterräume von Interesse, beispielsweise Räume zu konstanter Koordinatenzeit.

Zur anschaulichen Darstellung solcher Unterräume, deren Geometrie i. A. nicht euklidisch ist, haben wir Anschauungsmodelle entwickelt. Sie basieren auf der im Regge-Kalkül verwendeten koordinatenfreien, nur auf messbaren Abständen beruhenden Beschreibung der Raumzeit.

In diesem Beitrag werden Beispiele solcher Sektormodelle vorgestellt, u. a. Räume konstanter positiver und negativer Krümmung sowie die Umgebung eines schwarzschildschen Schwarzen Lochs.