Gravitation and Relativity Division
Fachverband Gravitation und Relativitätstheorie (GR)

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Overview of Invited Talks and Sessions

(Lecture halls ZEU/0260, ZEU/0255, and HSZ/0401)

Plenary Talk of the Gravitation and Relativity Division

PV XVII	Fri	9:00– 9:45	HSZ/AUDI	**The Einstein Telescope** — •Harald Lück

Invited Talks

GR 3.1	Tue	11:00–11:45	HSZ/0401	**Scalaron-Higgs inflation** — •Christian Steinwachs
GR 6.1	Wed	11:00–11:45	ZEU/0260	**Geodesic motion in relativistic astrophysics** — •Eva Hackmann
GR 6.2	Wed	11:45–12:30	ZEU/0260	**Modelling the multi-messenger signals of gravitational wave sources** — •Stephan Rosswog
GR 11.1	Thu	11:00–11:45	ZEU/0260	**From quarks to black holes: micro- and macrophysics of neutron star mergers** — •Andreas Bauswein
GR 11.2	Thu	11:45–12:30	ZEU/0260	**Tracing beyond GR physics with gravitational waves** — •Daniela Doneva

Sessions

GR 1.1–1.5	Mon	16:30–18:10	ZEU/0260	**Black Holes**
GR 2.1–2.6	Mon	16:30–18:30	ZEU/0255	**Cosmology I**
GR 3.1–3.3	Tue	11:00–12:25	HSZ/0401	**Cosmology II**
GR 4.1–4.4	Tue	17:00–18:20	ZEU/0260	**Quantum Gravity**
GR 5.1–5.3	Tue	17:00–18:00	ZEU/0255	**Classical Relativity**
GR 6.1–6.2	Wed	11:00–12:30	ZEU/0260	**Relativistic Astrophysics**
GR 7.1–7.4	Wed	14:00–15:20	ZEU/0260	**Gravitational Waves I**
GR 8.1–8.4	Wed	14:00–15:20	ZEU/0255	**Foundations and Alternatives I**
GR 9.1–9.6	Wed	16:00–18:00	ZEU/0260	**Gravitational Waves and Astrophysics I**
GR 10.1–10.5	Wed	16:00–17:40	ZEU/0255	**Foundations and Alternatives II**
GR 11.1–11.2	Thu	11:00–12:30	ZEU/0260	**Gravitational Waves and Astrophysics II**
GR 12.1–12.4	Thu	14:00–15:20	ZEU/0260	**Relativistic Astrophysics and Scalar Fields**
GR 13.1–13.4	Thu	16:00–17:20	ZEU/0260	**Relativity and Data Analysis**
GR 14.1–14.5	Thu	16:00–17:40	ZEU/0255	**Gravitational Waves II**
GR 15	Thu	18:30–20:00	ZEU/0260	**Members' Assembly**
GR 16.1–16.5	Fri	11:00–12:40	HSZ/0401	**Experimental Tests**

Members' Assembly of the Gravitation and Relativity Division

Thursday 18:30–20:00 ZEU/0260

- Bericht
- Wahl
- Verschiedenes

GR 1: Black Holes

Time: Monday 16:30–18:10 Location: ZEU/0260

GR 1.1 Mon 16:30 ZEU/0260

Light propagation in a plasma on an axially symmetric and stationary spacetime: Separability of the Hamilton-Jacobi equation and shadow — Barbora Bezděková[1], •Volker Perlick[2], and Jiří Bičák[3] — [1]KIPAC, Stanford University, Stanford, CA 94305, USA — [2]ZARM, University of Bremen, Germany — [3]Institute of Physics, Charles University, Prague, Cech Republic

We study the effects of a non-magnetised, pressure-less plasma on light rays under the assumption of stationarity and axisymmetry. The necessary and sufficient conditions on the metric and on the plasma frequency are formulated, such that the rays can be analytically determined from a fully separated Hamilton-Jacobi equation. We demonstrate how these results allow to analytically calculate the photon region and the shadow, if they exist. As a special example, a rotating wormhole is considered. - For more details see J. Math. Phys. 63, 092501 (2022).

GR 1.2 Mon 16:50 ZEU/0260

Black holes at the Planck scale — •Piero Nicolini — Universität Triest, Triest, Italien — FIAS, Frankfurt am Main, Deutschland — Johann Wolfgang Goethe-Universiät Frankfurt am Main, Frankfurt am Main, Deutschland

Despite the difficulty in formulating a quantum theory of gravity, the good news is that the existing quantum gravity proposals seem to converge towards a unique scenario for the physics of black holes. In this talk, I will present an overview about the phenomenology of Planckian black holes and the possibility of detecting some effects in present and near future experiments. As a conclusion, I will comment about some of the existing open questions and future directions of investigation.

GR 1.3 Mon 17:10 ZEU/0260

Formulation Improvements for Critical Collapse Simulations — •Daniela Cors[1], Sarah Renkhoff[1], Hannes Rüter[2], David Hilditch[3], and Bernd Brügmann[1] — [1]Theoretisch-Physikalisches Institut, Friedrich-Schiller-Universität Jena — [2]CFisUC, Department of Physics, University of Coimbra — [3]CENTRA, Instituto Superior Técnico, University of Lisbon

We use our adapted pseudospectral code bamps, with its new hp adaptive mesh refinement, to tune close to the barrier between gravitational collapse and dispersed fields, in order to study the critical phenomena that emerges near that threshold. To achieve that goal and improve our previous results, we introduce adjustments to the generalised harmonic gauge formulation of General Relativity adapting it to the specific case of near collapse simulations. In particular, we adjust the constraint violations damping scheme, taking into account the collapse of the lapse that occurs in extreme spacetimes. We also prevent coordinate singularities by carefully choosing the gauge source function for collapsing spacetimes. As a result of these changes, we manage to improve our threshold estimation results. In spherical symmetry, we show critical phenomena of a massless scalar field minimally coupled to the Einstein field equations. In axisymmetry, we study gravitational waves in vacuum, revisiting our previous results.

GR 1.4 Mon 17:30 ZEU/0260

Wave optical image formation of exact scalar wave scattering in Kerr-de Sitter spacetime — •Felix Willenborg[1], Dennis Phillip[1,2], and Claus Lämmerzahl[1,2] — [1]Zentrum für angewandte Raumfahrt und Mikrogravitation (ZARM), University of Bremen, 28359 Bremen, Germany — [2]Gauss-Olbers Center, c/o ZARM, University of Bremen, 28359 Bremen, Germany

Linear perturbations of black holes have been discussed widely in many contexts. Of interest are properties such as differential cross-sections, quasi-normal modes, scattering or the intereference. A useful tool in this respect is the Newman-Penrose formalism and the resulting Teukolsky equations, giving seperated angular and radial differential equations. These were mostly evaluated by numerical means. However, the introduction of a cosmological constant allows the problem to be solved in an exact analytical manner by transforming the differential equations into the Heun differential equation, the most general second-order differential equation with four regular singularities.

We show for the Kerr-de Sitter spacetime that scattering of waves from a point source needs an additational discussion around the so-called Heuns function, which enables a then possible normalization of the angular solution, similarly to the case of spherical harmonics. We assume in the discussion and analysis a scalar source star of fixed frequency and solve the scattering problem by a partial wave sum. The observed wave optical image formation by means of Kirchhoff-Fresnel diffraction and the resulting shadow will be compared to the geodesic black hole shadow.

GR 1.5 Mon 17:50 ZEU/0260

Gravitational Lensing of Massive Particles in the NUT Spacetime — •Torben Frost — ZARM, University of Bremen, Bremen, Germany

Gravitational lensing of light is already a well-investigated question. Gravitational lensing of massive particles on the other hand did not receive much attention so far. This has mainly two reasons. First, appropriate particles, currently only neutrinos, are rare, hard to detect and their emission events short-lived. Second, particle detectors capable of detecting them only have a low angular resolution. However, considered in the framework of a multimessenger approach gravitational lensing of massive particles may provide us with supplementary information to gain a better understanding about their source and the lens. Therefore, in this talk we will discuss the potential of gravitational lensing of massive particles using the example of a NUT black hole acting as lens. We will first discuss and solve the equations of motion for timelike geodesics using elementary as well as elliptic functions and integrals. Then we will introduce latitude-longitude coordinates on the celestial sphere of an observer in the domain of outer communication and relate them to the constants of motion. Finally, we will derive the angular radius of the particle shadow, write down a lens equation, and calculate the travel time of the particles. We will also discuss differences with respect to lightlike geodesics.

GR 2: Cosmology I

Time: Monday 16:30–18:30 Location: ZEU/0255

GR 2.1 Mon 16:30 ZEU/0255

Anisotropies in the Cosmological Gravitational Wave Background — •Florian Schulze — Max-Planck-Institut für Kernphysik, Heidelberg, Germany

The cosmological stochastic gravitational wave background (CGWB) is expected to be detected by future gravitational wave (GW) interferometers. A map of angular fluctuations in the CGWB provides an independent measurement of cosmological parameters, similar to the cosmic microwave background (CMB). Furthermore, it contains information about the cosmological model and a multitude of possible CGWB sources, such as inflation, primordial black holes or phase transitions in the early universe.

In this presentation, I will discuss anisotropies in the CGWB and introduce CLASS_GW, an extension of the Cosmological Linear Anisotropy Solving System (CLASS) to calculate CGWB anisotropies. Using CLASS_GW, I present forecasts for future GW experiments, showing their capabilities of testing the early universe physics and the cosmological model.

GR 2.2 Mon 16:50 ZEU/0255

Redshift Drift in Linear Perturbation Theory — Pedro Bessa, •Dennis Stock, and Ruth Durrer — Département de Physique Théorique, Université de Genève, Switzerland

The technical advance and continuously increasing precision of cosmological observations will make measurements of time variations of the redshift of a given source possible in the near future. This so-called redshift drift effect promises to be an exciting future cosmological probe of the Universe. In this talk, we derive its fully relativistic, gauge-invariant expression within linear perturbation theory and study in detail its angular power spectrum based on large scale structure observations.

GR 2.3 Mon 17:10 ZEU/0255

Lightcone invariant observables in cosmology — Bhuvan Agrawal[1], Markus Fröb[2], and •William Lima[2] — [1]Mathematisch-Naturwissenschaftliche Fakultät, Universität zu Köln, Köln, Germany — [2]Institut für Theoretisches Physik, Universität Leipzig, Leipzig, Germany

I will discuss a recent proposal by Brunetti et al. to construct gauge-invariant relational observables in gravity in the context of cosmological perturbation theory. I will report on new results showing how their method can be use to produce invariant observables adapted to measurements along the observer's past lightcone. These observables aim to model the experimental situation in cosmology, where virtually all experimental data is gathered via light-like signals. The lightcone observables are constructed using a field-dependent coordinate system, which I will take to be geodesic lightcone coordinates. As a concrete application, I will present a new computation of the correlator of an observable measuring the redshift produced by quantum-gravitational fluctuations on the de Sitter spacetime.

GR 2.4 Mon 17:30 ZEU/0255

Cosmological backgrounds and their pertubations in teleparallel gravity — •Manuel Hohmann — University of Tartu, Estonia

Within the framework of teleparallel gravity, a flat affine connection is used as a dynamical field in addition to the metric tensor. This general teleparallel connection may further be restricted by imposing either vanishing torsion, giving rise to symmetric teleparallel gravity, or vanishing nonmetricity, which then leads to metric teleparallel gravity. In the field of cosmology, a homogeneous and isotropic connection must been chosen alongside the homogeneous and isotropic metric. This presentation gives a complete classification of all homogeneous and isotropic teleparallel geometries (general, metric and symmetric), as well as their perturbations. For the latter, gauge transformations and gauge invariant quantities are presented.

GR 2.5 Mon 17:50 ZEU/0255

Torsional dark energy in quadratic gauge gravity — •Armin van de Venn[1], David Vasak[2], Johannes Kirsch[3], and Jürgen Struckmeier[4] — [1]Frankfurt Institute for Advanced Studies, Frankfurt am Main, Germany — [2]Frankfurt Institute for Advanced Studies, Frankfurt am Main, Germany — [3]Frankfurt Institute for Advanced Studies, Frankfurt am Main, Germany — [4]Frankfurt Institute for Advanced Studies, Frankfurt am Main, Germany

The Covariant Canonical Gauge theory of Gravity (CCGG) is a gauge field formulation of gravity which a priori includes non-metricity and torsion. It extends the Lagrangian of Einstein's theory of general relativity by terms at least quadratic in the Riemann-Cartan tensor. This work investigates the implications of metric compatible CCGG on cosmological scales. For a totally anti-symmetric torsion tensor we derive the resulting equations of motion in a Friedmann-Lemaître-Robertson-Walker (FLRW) Universe. In the limit of a vanishing quadratic Riemann-Cartan term, the arising modifications of the Friedmann equations are shown to be equivalent to spatial curvature. Furthermore, the modified Friedmann equations are investigated in detail in the early and late times of the Universe's history. It is demonstrated that in addition to the standard ΛCDM behaviour of the scale factor, there exist novel time dependencies, emerging due to the presence of torsion and the quadratic Riemann-Cartan term. Finally, at late times, we present how the accelerated expansion of the Universe can be understood as a geometric effect of spacetime through torsion.

GR 2.6 Mon 18:10 ZEU/0255

Consistent solution of Einstein-Cartan equations with torsion outside matter — •Klaus Morawetz — Münster University of Applied Sciences, Stegerwaldstrasse 39, 48565 Steinfurt, Germany — International Institute of Physics- UFRN, Campus Universitário Lagoa nova,59078-970 Natal, Brazil

The Einstein-Cartan equations in first-order action of torsion are considered. Inside matter the torsion is given by the spin which leads to an extended Oppenhaimer-Volkov equation. Outside matter a second solution is found besides the torsion-free Schwarzschild one with the torsion completely determined by the metric and vice-versa. This solution is shown to be of non-spherical origin and its uniqueness with respect to the consistence is demonstrated. Unusual properties are discussed in different coordinate systems where the cosmological constant assumes the role of the Friedman parameter in Friedman-Lamaître-Robertson-Walker cosmoses. Parameters are specified where wormholes are possible. Possible consequences on cosmological scenarios are discussed. [Class. Quantum Grav. 38 (2021) 205003]

GR 3: Cosmology II

Time: Tuesday 11:00–12:25 Location: HSZ/0401

Invited Talk GR 3.1 Tue 11:00 HSZ/0401

Scalaron-Higgs inflation — •Christian Steinwachs — University of Freiburg, Germany

After discussing various theoretical properties of scalar field theories in curved spacetime from an effective field theory point of view, I propose a concrete model that offers a unified description of inflationary cosmology, dark matter, and elementary particle physics at the electroweak scale. Except for a non-minimal coupling of the Standard Model Higgs boson to a modified gravitational sector, no new physics is required.

GR 3.2 Tue 11:45 HSZ/0401

Universality in cosmic structures — •Matthias Bartelmann — Institut für Theoretische Physik, Universität Heidelberg

Kinetic field theory allows describing cosmic structure formation analytically quite deeply into the non-linear regime of density fluctuations. We have used this theory to investigate several questions concerning the universality of cosmic structures. This talk will focus on three main results, partly obtained within a suitable mean-field approximation: (1) the universality of cosmic structures in the asymptotic small-scale limit; (2) generic effects of modified gravity theories on cosmic structure formation; and (3) possible imprints of the dark-matter model on small-scale cosmic structures.

GR 3.3 Tue 12:05 HSZ/0401

Inflation and its Discontents — •Marc Holman — Utrecht University, Utrecht, The Netherlands

Since their basic inception in the early 1980s, inflationary models have been shown to exhibit various physical and conceptual deficits. The main purpose of the present talk is to provide a systematic review of these deficits. One well-known issue, for instance, is that of initial conditions: originally invoked to address a very specific perceived fine-tuning in initial conditions, inflation inevitably seems to lead to fine-tuning problems of its own. Other problems include the transition to classicality, the spontaneous breaking of symmetry and crucially, as I will argue, the "multiverse" and the very rationale for inflation in the first place. A feature that is often claimed as a major success of inflationary models is their generic prediction of a (nearly) scale invariant, Gaussian spectrum of CMB density perturbations. As is less commonly emphasized however, effectively such a prediction was already made well before the entire notion of inflation even existed and, more importantly, is not unique to the specific inflationary mechanism of exponential primordial expansion. Time permitting, routes for viable alternatives to inflation are briefly discussed, emphasizing their key challenges.

GR 4: Quantum Gravity

Time: Tuesday 17:00–18:20 Location: ZEU/0260

GR 4.1 Tue 17:00 ZEU/0260

Quantum gravitational redshift — •David Edward Bruschi — Institute for Quantum Computing Analytics (PGI-12), Forschungszentrum Jülich, Germany

General relativity and quantum mechanics are the two frameworks through which we understand Nature. To date, they have remained valid to great extent in their respective domains. Regardless of the myriad of attempts to find a unified theory that can describe all of observable phenomena, the quest for unification continues.

One avenue for investigating the overlap of general relativity and quantum mechanics that is less ambitious but can still provide potentially observable and measurable predictions is that of quantum field theory in curved spacetime viewed through the lens of quantum information. In recent years, a great deal of attention has been given to this approach, which has provided novel and intriguing insights into phenomena that can be tested in the laboratory.

We present an investigation in the quantum nature of the gravitational redshift, seeking to understand which are the expected quantum dynamics that lead to the effective classical observable effect. We discuss the classical regime and show that more intriguing aspects are expected. We conclude discussing potential for detection in space-based experiments.

GR 4.2 Tue 17:20 ZEU/0260

A Rigorous Neutrino Oscillation Formula in Curved Spacetime — •Dominik Hellmann — TU Dortmund, 44227 Dortmund, Germany

In the light of upcoming experiments searching to detect neutrino signals from astrophysical sources, the question for a rigorously derived neutrino oscillation formula in curved spacetime from first principles seems to be well motivated.

Based on the theoretical foundations of quantum field theory in curved spacetime (cQFT), we generalize the well known external wave packet approach to neutrino oscillations from flat to curved spacetime.

In this framework, external particles are represented by wave packets, while the neutrino is described by its Feynman propagator and PMNS matrix elements. In addition to that, we incorporate nontrivial cQFT effects like the non-uniqueness of the vacuum and show how these modify the oscillation behavior. Finally, we derive the conditions under which a neutrino oscillation probability is well defined and show how it is calculated from cQFT amplitudes.

GR 4.3 Tue 17:40 ZEU/0260

Proton Stability and Quantum Gravity: Towards an asymptotically safe perspective — Astrid Eichhorn and •Shouryya Ray — CP3 Origins, Institut for Fysik, Kemi og Farmaci, Syddansk Universitet, Campusvej 55, 5230 Odense M, Denmark

The observed long lifetime ($\gtrsim 10^{34}$ yrs) of the proton can pose serious constraints on UV completions of the Standard Model. In those that include quantum gravity, fluctuations of the spacetime metric are often argued to break all effective global symmetries; baryon number conservation, which prevents proton decay, being one of them. Here, I shall present our computations concerning the proton lifetime within asymptotically safe quantum gravity. Time permitting, I shall speculate on how asymptotically safe metric fluctuations may in fact reconcile a significantly reduced quantum gravity scale with proton stability, and thereby possibly also stabilize the proton in certain GUT scenarios afflicted by excessive proton decay.

GR 4.4 Tue 18:00 ZEU/0260

Asymptotically nonlocal gravity — •Jens Boos and Christopher D Carone — William & Mary, Williamsburg, VA, USA

Asymptotically nonlocal field theories interpolate between Lee-Wick theories with multiple propagator poles, and ghost-free nonlocal theories. Previous work on asymptotically nonlocal scalar, Abelian, and non-Abelian gauge theories has demonstrated the existence of an emergent regulator scale that is hierarchically smaller than the lightest Lee-Wick partner, in a limit where the Lee-Wick spectrum becomes dense and decoupled. We generalize this construction to linearized gravity, and demonstrate the emergent regulator scale in three examples: by studying the resolution of the singularity (i) at the origin in the classical solution for the metric of a point particle, and (ii) in the nonrelativistic gravitational potential computed via a one-graviton exchange amplitude; (iii) we also show how this derived scale regulates the one-loop graviton contribution to the self energy of a real scalar field. We comment briefly on the generalization of our approach to the full, nonlinear theory of gravity.

GR 5: Classical Relativity

Time: Tuesday 17:00–18:00 Location: ZEU/0255

GR 5.1 Tue 17:00 ZEU/0255

Spinning light source orbiting a compact Schwarzschild object — •Jan-Menno Memmen and Volker Perlick — Zentrum für angewandte Raumfahrttechnik und Mikrogravitation, Bremen, Deutschland

In this talk, we determine the radiation of an extended, *spinning* light source in circular orbit in the symmetry plane of an stationary, axially symmetric spacetime. The light source is assumed to be a test particle, as to not interfere with the background spacetime. We derive the necessary transformations for a reference frame that is at rest on the surface of the rotating emitter, and link the emission angle on the surface of the emitter to the constants of motion of the light ray. Two emitter geometries are considered; a sphere and a Maclaurin spheroid that is flattened as a result of its spin. In particular, we investigate the influence of the emitter spin on the radiation in a Schwarzschild background. Specifically, the influnece of the spin on the redshift distribution and flux at an arbitrarily positioned observer is studied in detail.

GR 5.2 Tue 17:20 ZEU/0255

Gravitational field recovery via inter-satellite redshift measurements — •Jan P. Hackstein, Eva Hackmann, Dennis Philipp, and Claus Lämmerzahl — Center of Applied Space Technology and Microgravity, Bremen, Germany

Satellite gravimetry is a common technique to monitor global changes in the Earth system. High-precision atomic clocks are currently used in first experiments in terrestrial gravimetry to measure physical heights. In relativistic gravity, a clock comparison is sensitive to their positions in the gravity field and relative velocity. This makes clocks ideal tools to investigate the Earth's gravity field. Equipping Earth-orbiting satellites with clocks and comparing them to terrestrial ground stations allows for global and continuous measurements. However, one important obstacle for Earth-satellite chronometry is the low measurement accuracy of satellite velocity, which enters into the redshift via the Doppler effect. We present an alternative approach based on the framework of general relativity without velocity measurements from ground stations. Considering an idealised satellite setup in the Schwarzschild spacetime, pairwise redshift measurements between satellites equipped with clocks are used to recover the gravitational field's monopole moment. We investigate whether or not only relative observables between satellites suffice to recover the complete information about the gravitational field. This method promises higher accuracy for gravity field recovery by improving control of the Doppler effect. We compare the results and error estimates of this setup with conventional Earth-satellite measurements and conclude with future steps to generalise this approach.

GR 5.3 Tue 17:40 ZEU/0255

On the redshift and relativistic gravity potential determination in GR — •Dennis Philipp[1,2], Eva Hackmann[1,2], and Claus Laemmerzahl[1,2] — [1]ZARM, University of Bremen, 28359 Bremen, Germany — [2]Gauss-Olbers Center, c/o ZARM, University of Bremen, 28359 Bremen, Germany

We derive exact, formal expressions for the relativistic redshift and timing between observers in various configurations on stationary spacetimes for the purpose of chronometry, i.e., relativistic gravimetry based on clocks. These observers are assumed to transport standard clocks along their respective worldlines and may move in an arbitrary way - on geodesics, accelerated, or are simply stationary. It is shown how redshift observations can be used to infer the (mass) multipole moments of the underlying spacetime, i.e., a decomposition of the gravito-electric potential. In particular, an Earth-bound observer is considered that is meant to model a standard clock on the Earth's surface (or on the geoid). Its clock is continuously compared to a satellite's clock to determine a relativistic gravity potential from redshift measurements. Results shown here are in agreement with the Newtonian potential determination from the so-called energy approach. The framework is intended for applications within relativistic geodesy and is applied in different exact vacuum spacetimes for illustration.

GR 6: Relativistic Astrophysics

Time: Wednesday 11:00–12:30 Location: ZEU/0260

Invited Talk GR 6.1 Wed 11:00 ZEU/0260

Geodesic motion in relativistic astrophysics — •Eva Hackmann — ZARM, Universität Bremen

Astrophysical systems are usually composed of two major bodies. The throughout analysis of relativistic binary systems is therefore very important, but far from trivial due to the nonlinear nature of General Relativity. A limiting case, that can be handled analytically but is still informative for a wide range of systems, is the extreme mass ratio or one-body problem. In this presentation, we will first quickly review analytical solutions methods for this case, and then explore a range of applications in modern astrophysics, for example pulsar timing in extreme mass ratio systems.

Invited Talk GR 6.2 Wed 11:45 ZEU/0260

Modelling the multi-messenger signals of gravitational wave sources — •Stephan Rosswog — Sternwarte Hamburg, Gojenbergsweg 112, 21029 Hamburg

Compact binary systems that contain at least one neutron star are exiting sources of gravitational waves. Apart from relativistic gravity, their dynamics during a merger is governed by the microphysics of the neutron stars such as the nuclear matter equation of state or various neutrino processes. Observations of such mergers via gravitational and electromagnetic waves (and, ideally, also neutrinos) can provide many complementary facettes of the same event which can break degeneracies in the interpretation of observations.

While such multi-messenger approaches carry an enormous discovery potential, they come at the price of having to model very different physical processes (e.g. strong field gravity, nuclear matter, atomic opacities and radiative transfer) and very different length and time scales. These requirements also place high demands on the simulation methodology.

In my talk, I will review the physical and numerical challenges of such simulations, discuss a novel approach for relativistic hydrodynamics and show some first applications.

GR 7: Gravitational Waves I

Time: Wednesday 14:00–15:20 Location: ZEU/0260

GR 7.1 Wed 14:00 ZEU/0260

LISA Pathfinder — •Sarah Paczkowski for the LPF collaboration — Max Planck Institute for Gravitational Physics (Albert Einstein Institute), D-30167 Hannover, Germany — Leibniz Universität Hannover, D-30167 Hannover, Germany

The Laser Interferometer Space Antenna (LISA) is a satellite mission to observe gravitational waves in the frequency range from 0.1mHz to 1Hz. In this talk, I will give an overview of its technology demonstrator mission LISA Pathfinder (2015-2017), and how it is paving the way for LISA.

Conceptually, the idea of LISA Pathfinder was to mimic one arm of the triangular LISA constellation. The LISA Pathfinder satellite, therefore, hosted two free-falling test masses and their relative positions and orientations were measured using heterodyne laser interferometry. Combined with a drag-free attitude control system and micronewton thrusters in a quiet environment, a nearly perfect free-fall was achieved. The undesired remaining differential acceleration between the two test masses was only $(1.74 \pm 0.05)\,\mathrm{fms^{-2}}/\sqrt{\mathrm{Hz}}$ above 2 mHz. This was significantly below the requirements and exceeded expectations. Accordingly, LISA Pathfinder has demonstrated the ability to realise the low-frequency science potential of the LISA mission. The interferometric readout on LISA Pathfinder also worked immediately and reliably throughout the mission with a sensing noise of only $32.0^{+2.4}_{-1.7}\,\mathrm{fm}/\sqrt{\mathrm{Hz}}$. Since it will be similar to the local LISA interferometry, LISA Pathfinder has successfully proven this concept to work in space.

GR 7.2 Wed 14:20 ZEU/0260

Potential of Gravitational Waves Detection with SCRF Cavities — •Gudrid Moortgat-Pick[1], Robin Löwenberg[1], Daniel Klein[1], Krisztian Peters[2], and Marc Wenskat[2] — [1]II. Inst. for Theoretical Physics, University of Hamburg, Luruper Chaussee 149, 22761 Bahrenfeld — [2]DESY, Notkestrasse 85, 22603 Hamburg

We study the physics potential of detecting gravitational waves via superconducting high-frequency cavities. The direct coupling of gravitational waves to electromagnetic fields is widely known as the (inverse) Gertsenshtein effect. We have described gravitational waves in the framework of linearized theory in general relativity. In this regard it is substantial to define the proper detector frame. We use a heterodyne cavity setup, extend the theoretical approach to calculate different scenarios in an unified and accurate way, including cavity perturbation theory and the effects of wall deformation.

GR 7.3 Wed 14:40 ZEU/0260

Gravitational wave induced perturbation of atomic levels — •Falk Adamietz[1,2], Friedemann Queisser[1,2], and Ralf Schützhold[1,2] — [1]Helmholz-Zentrum Dresden-Rossendorf — [2]Technische Universität Dresden

Motivated by partly controversial results in the literature and recent studies regarding the detection of gravitational waves with atoms instead of photons (as in LIGO), we study the response of atomic levels to gravitational waves. For slow gravitational waves, we may employ lowest-order stationary perturbation theory. We find that the perturbation Hamiltonian consists both of a kinetic and a potential correction term and explicitly evaluate their matrix elements.

GR 7.4 Wed 15:00 ZEU/0260

A Michelson interferometer as a demonstrator for gravitational wave detection in outreach activities — •David Koke and Alexander Kappes — Institut für Kernphysik der Westfälischen Wilhelms-Universität Münster, Deutschland

Gravitational waves are one of the most exciting phenomena in astrophysics and have given us new insights into our universe since their first direct detection in 2015. To easily demonstrate the basic principles of gravitational wave detection in outreach activities, a demonstration experiment based on a Michelson interferometer was created in the framework of a master thesis. Subject of this talk is the presentation of the results of the project with focus on the technical realization, as well as a live demonstration of the interferometer's features.

GR 8: Foundations and Alternatives I

Time: Wednesday 14:00–15:20 Location: ZEU/0255

GR 8.1 Wed 14:00 ZEU/0255

Der physikalische Hintergrund der dunklen Materie — •Albrecht Giese — Taxusweg 15, 22605 Hamburg

Dunkle Materie bedeutet einen Überschuss an Gravitation im Umfeld von Galaxien im Vergleich zur Physik Newtons.

Gegenwärtig werden zwei Theorien dazu diskutiert: Die Annahme von unentdeckten, schwach wechselwirkenden Teilchen und eine Modifikation der Gravitation Newtons (MOND). Jedoch erklären beide Theorien nur einen Teil der Beobachtungen und sind im Konflikt mit anderen. Das heißt, es gibt keine nutzbare Theorie in der heutigen Physik. Und die Suche nach neuen Teilchen ist völlig erfolglos geblieben.

Neuerliche intensivierte Beobachtungen haben jedoch eine verblüffende Eigenschaft der dunklen Materie geliefert: Sie hat eine Verteilung von 1/r^2 um das Zentrum der Galaxien. Damit ist die Verteilung identisch mit derjenigen der Photonen um diese Zentren. Das sieht zunächst aus wie eine Paarung zwischen dunkler Materie und Photonen. Auf dieser Basis präsentieren wir eine Erklärung, welche im Einklang mit allen Beobachtungen steht, und welche sogar *quantitativ* korrekte Ergebnisse liefert - ohne Adaptionen; dabei allerding von den Ansätzen Newtons und Einsteins abweicht bzgl. der Korrelation Gravitation zu Masse.

Wir können uns hier auch auf einen Ansatz der Gravitation berufen, dem Einstein selbst 1911 zunächst gefolgt ist. Wenn man diesen in geeigneter Weise weiter verfolgt, gelangt man ebenso zum obigen Ergebnis.

Weitere Info: www-ag-physics.org/gravity

GR 8.2 Wed 14:20 ZEU/0255

Geometrische Grundlagen der Nichtgleichgewichtsthermodynamik diskreter Systeme — •Marcus Hildebrandt — Uhlandstrasse 22a, 13158 Berlin

Aus thermodynamischer Sicht können kompakte Objekte wie Sterne und schwarze Löcher als diskrete Systeme behandelt werden, die sich im energetischen Austausch mit Ihrer Umgebung befinden (Schottky-Systeme). Zu einer konsistenten und erfolgreichen Beschreibung von solchen kompakten Objekten müssen die zentralen Feldtheorien der Physik, die Quantenmechanik, die Relativitätstheorie, die Elektrodynamik/Magnetohydrodynamik und die Thermodynamik zusammenspielen. Während alle Feldtheorien heutzutage in moderner geometrischer Formulierung auf Faserbündeln vorliegen, ist dies bisher in der Thermodynamik nur rudimentär der Fall. Der Autor zeigt, wie diese Struktur für diskrete Systeme aus einigen wenigen physikalischen Prinzipien abgeleitet werden kann und welche tiefe, geometrisch-physikalische Einsichten dies liefert. Zentrale Ergebnisse sind dabei: Relaxationsprozesse bleiben in den Fasern, in denen sie starten und enden auf einer Attraktormannigfaltigkeit, dem klassischen Gleichgewichtsteilraum der Thermostatik. Während in der Relativitätstheorie der Energie-Impulstensor die Geometrie des Raumes bestimmt, ist in der Thermodynamik die (1-Form der) Entropieproduktionsrate für das Entstehen einer geometrischen Struktur verantwortlich: Die Kontaktgeometrie.

GR 8.3 Wed 14:40 ZEU/0255

Mass & Charge — •Manfred Geilhaupt — Hochschule Niederrhein, Mönchengladbach, Germany

* General Relativity combined with Thermodynamic Principles reveals: Sommerfeld FSC: alpha=1/beta^2*1/g44*3/4*(1+1/beta*ln(W))^2 and W=1/3, Probability for each x, y, z- Direction.

* Elektron has a finite life span introduced into a Wave Function is the only chance to derive Sommerfeld FSC from a Principle Theory.

* Electron's restmass nature is inertial. Restmass and charge are effective (expectation) values from GR+TD to be compared with experimental values. Both mass and charge depend on the root of alpha.

Remark: If the superposition of two entangled Electrons collapses nevertheless mass (and charge) can not come out of nothing to exist as real. The collapse of a wave function also might come to existence when the metric g44 ("local observer") of space changes. This would be a natural brake down - based on GR.

https://www.youtube.com/watch?v=lxZ2Nu6_vC0

E=m(t)c^2+Q(t)=const=M*c^2 is the invariance within GR+TD.

GR 8.4 Wed 15:00 ZEU/0255

Was, wenn die Grundkraft "Gravitation" grundsätzlich abstoßend wirkt? — •Stefan Lahres — Aalen, Deutschland

Diese Hypothese nimmt an, dass Gravitation keine anziehende, sondern eine grundsätzlich abstoßende Wechselwirkung ist, und die anziehende Wirkung auf kosmologisch kleinen Maßstäben daher rührt, dass massebehaftete Strukturen die abstoßende Wirkung dämpfen.

Der Ansatz geht von einer isotropen, gravitativ vermittelten abstoßenden Kraftwirkung von allen Seiten auf jede Probemasse aus. Befindet sich nun in der Nähe einer Probemasse (z.B. Apfel) eine andere Masse (z.B. Erde), so schwächt die Erde als große Masse unter dem Apfel den "Druck" des Universums, der von unten auf den Apfel wirkt, ab. Die Kraft von oben ist also größer als die Kraft von unten. Der Apfel wird vom Universum mit einer zur Erde hin gerichteten Kraft nach unten gedrückt.

Eine lineare Näherung führt zum Newton'schen Gravitationsgesetz. Zwei mögliche Quellen der abstoßenden Wirkung werden vorgestellt:

1. Die sonstigen Massen des Universums
2. Eine gravitative kosmische Hintergrundstrahlung, die sich in einer frühen Phase des Universums von der Wechselwirkung mit anderen Energieformen abgekoppelt hat

Das Potenzial für Beiträge zur Beschreibung von Dunkler Energie, kosmischer Inflation und der Vermeidung von Singularitäten in der ART wird ebenso aufgezeigt wie Herausforderungen an die Beschreibung der physikalischen Mechanismen, die einer abstoßenden gravitativen Wechselwirkung zugrunde liegen könnten.

GR 9: Gravitational Waves and Astrophysics I

Time: Wednesday 16:00–18:00 Location: ZEU/0260

GR 9.1 Wed 16:00 ZEU/0260

Numerical-Relativity-Informed Effective-One-Body model for Black-Hole-Neutron-Star Mergers with Higher Modes and Spin Precession — •Alejandra Gonzalez[1], Rossella Gamba[1], Francesco Zappa[1], Gregorio Carullo[1], Sebastiano Bernuzzi[1], and Alessandro Nagar[2] — [1]Theoretisch-Physikalisches Institut, Friedrich-Schiller-Universität Jena, Fröbelstieg 1, 07743 Jena, Germany — [2]INFN Sezione di Torino, Via P. Giuria 1, 10125 Torino, Italy

We present the first effective-one-body (EOB) model for generic-spins quasi-circular black-hole - neutron-star (BHNS) inspiral-merger-ringdown gravitational waveforms (GWs). Our model is based on a new numerical-relativity (NR) informed expression of the BH remnant and its ringdown, it reproduces the NR (l, m) = (2, 2) waveform with typical phase agreement of about less than 0.5 rad (less than 1 rad) to merger (ringdown). The maximum (minimum) mismatch between the (2, 2) and the NR data is 4% (0.6%). Higher modes (HMs) (2, 1), (3, 2), (3, 3), (4, 4) and (5, 5) are included and their mismatch with the available NR waveforms are up to (down to) a 60% (1%) depending on the inclination. Phase comparison with a 16 orbit precessing simulation shows differences within the NR uncertainties. We demonstrate the applicability of the model in GW parameter estimation by perfoming the first BHNS Bayesian analysis with HMs (and non-precessing spins) of the events GW190814 and GW200105, together with a new (2, 2)-mode analysis of GW200115.

GR 9.2 Wed 16:20 ZEU/0260

To ring or not to ring, the tale of black hole quasi-normal modes — •Peter James Nee, Sebastian H. Völkel, and Harald Pfeiffer — Max Planck Institute for Gravitational Physics (Albert Einstein Institute), D-14476 Potsdam, Germany

The extraction of quasi-normal modes from compact binary mergers (also referred to as black hole spectroscopy) is one of the most promising pillars in current and future strong gravity tests. Recent works have sought to push current ringdown analysis into the non-linear merger part of the waveform via the inclusion of overtones, to better reproduce the waveform and ascertain the remnant black hole parameters. However it is well-believed that the presence of overtones is a non-trivial question, and as such caution is warranted. In this work we explore the potential pitfalls in both waveform reconstruction and parameter extraction in ringdown analysis. To this extent, we revisit the simpler problem of wave propagation in both Regge-Wheeler and Pöschl-Teller systems. We employ several modelling approaches to waveforms generated via a finite-difference evolution scheme, allowing for a varying number of overtones. The fitting is also performed over differently sized windows of the waveforms.

GR 9.3 Wed 16:40 ZEU/0260

Constraining modifications of black hole perturbation potentials near the light ring with quasinormal modes — •Sebastian Völkel[1,2,3], Nicola Franchini[1,2,4,5], Enrico Barausse[1,2], and Emanuele Berti[6] — [1]SISSA and INFN Sezione di Trieste, Trieste, Italy — [2]IFPU, Trieste, Italy — [3]Max Planck Institute for Gravitational Physics (Albert Einstein Institute), Potsdam, Germany — [4]Université Paris Cité, Paris, France — [5]CNRS-UCB International Research Laboratory, Berkeley, US — [6]Johns Hopkins University, Baltimore, USA

In modified theories of gravity, the potentials appearing in the Schrödinger-like equations that describe perturbations of non-rotating black holes are also modified. In this talk, we ask how such modifications can be constrained with future, high-precision measurements of quasi-normal modes. We use a perturbative framework that allows one to map modifications of the effective potential, in powers of M/R, to deviations in the quasi-normal mode spectrum. Using MCMC methods, we recover the coefficients in the M/r expansion in an “optimistic” scenario where we vary them one at a time, and in a “pessimistic” scenario where we vary them all simultaneously. In both cases, we find that the bounds on the individual parameters are not robust. However, inspired by WKB theory, we demonstrate that the value of the potential and its second derivative at the light ring can be robustly constrained. These constraints allow a more direct comparison between tests based on black hole spectroscopy and observations of black hole “shadows”.

GR 9.4 Wed 17:00 ZEU/0260

Packed Message delivered by Tides in Binary Neutron Star Mergers — •Hao-Jui Kuan[1] and Kostas Kokkotas[2] — [1]Albert-Einstein-Institut, Potsdam, Germany — [2]University of Tübingen, Tübingen, Germany

The morphology of gravitational waveforms depends on almost all source parameters, and thus encodes a bunch of information about the radiating objects. In particular, tidal parameters of neutron stars may stringently constrain the nuclear equation of state, thus their precise estimation is of fundamental importance. Emphasizing the tidal phase shift by aligned, rotating stars, we provide an accurate, yet economical, method to generate f-mode-involved, premerger waveforms. We find for slow-rotating stars that the dephasing effects of the dynamical tides can be uniquely, equation-of-state-independently determined by the direct observables. In addition, for binaries with fast rotating members, the dephasing due to f-mode is larger than that caused by equilibrium tides by a factor of $\sim$5, which may lead to a considerably overestimated tidal deformability if the dynamical tidal contribution is not accounted for. The influence of inclination angles of stellar spins will be discussed also, as well as the possibility of accompanying precursors flares associated with f-mode excitation.

GR 9.5 Wed 17:20 ZEU/0260

Binary neutron star merger simulations with neutrino transport and turbulent viscosity: impact of different schemes and grid resolution — •Francesco Zappa — Friedrich-Schiller-Universität Jena, Theoretisch-Physikalisches Institut, Jena, Germany

We present a systematic numerical relativity study of the impact of different treatment of microphysics and grid resolution in binary neutron star mergers.

We find that viscosity helps to stabilise the remnant against gravitational collapse but grid resolution has a larger impact than microphysics on the remnant's stability. The gravitational wave (GW) energy correlates with the maximum remnant density, that can be thus inferred from GW observations.

Simulations employing the M1 transport schemes show the emergence of a neutrino trapped gas that locally decreases the temperature a few percent when compared to the other simulation series. This out-of-equilibrium effect does not alter the GW emission at the typical resolutions considered for mergers.

Different microphysics treatments impact mass, geometry and composition of the remnant's disc and ejecta. Ejecta composition influences the nucleosynthesis yields, that are robust only if both neutrino emission and absorption are simulated. Synthetic kilonova light curves can be reliably predicted only including the various ejecta components.

We conclude that advanced microphysics in combination with resolutions higher than current standards appear essential for robust long-term evolutions and astrophysical predictions.

GR 9.6 Wed 17:40 ZEU/0260

GRMHD simulations with GR-Athena++ — •William Cook — Friedrich-Schiller-Universität Jena

We demonstrate the performance of the new code GR-Athena++ in evolving general relativistic magnetohydrodynamics (GRMHD) in a dynamically evolving spacetime. GR-Athena++ utilises the task-based parallelism and oct-tree based adaptive mesh refinement of the highly scaling Athena++ code, as well as its approach to solving GRMHD problems in stationary spacetimes; combined with new functionality to solve the Einstein equations in the Z4c formulation. We show the performance of this new code by simulating the evolution of Neutron Stars in a dynamical spacetime, presenting tests of our code, as well as strong and weak scaling tests.

GR 10: Foundations and Alternatives II

Time: Wednesday 16:00–17:40 Location: ZEU/0255

GR 10.1 Wed 16:00 ZEU/0255

The assumption of a continuous Lorentzian spacetime manifold in quantum gravity — •René Friedrich — Strasbourg

Spacetime is more and more often suspected of being at the origin of the problem of quantum gravity, and it is said that the concept of spacetime needs to be revised.

In this talk, we want to provide the concrete reason why the Lorentzian spacetime manifold is not compatible with quantum gravity, by showing that it is a man-made artefact: unlike the Euclidean metric, no Lorentzian pseudometric is able to span up a real-valued manifold. This is why - since its introduction with Minkowski's famous lecture ”Space and time” and until today - Lorentzian manifolds require always the addition of a second metric in order to override the appearance of negative squares and of imaginary values.

This artificial ”patchwork” of two opposite metrics is not only incompatible with quantum mechanics, it is even contradicting the very principles of general relativity.

GR 10.2 Wed 16:20 ZEU/0255

A Physically Founded and Exact Model of Dark Energy — •Hans-Otto Carmesin — Gymn. Athenaeum, Harsefelder Str. 40, 21680 Stade — Studienseminar Stade, Bahnhofstr. 5, 21682 Stade — Universität Bremen, Fachbereich 1, Postfach 330440, 28334 Bremen

While Newton proposed static space, Einstein used his general relativity, GR, and derived a possible dynamic expansion of space [1]. Hubble observed it [2]. When Perlmutter [3] discovered the energy density u_Λ of cosmological vacuum, dark energy, an essential property of space beyond GR had been discovered. So, what is dark energy? Here, I present a physically founded model of the dark energy u_Λ [4,5]. I provide an exact solution of that model, and I derive the dark energy $u_{\Lambda,model}$. It is in precise accordance with the observed value $u_{\Lambda,obs}$. Thereby, I do not apply any fit parameter. Using that model, I explain the H_0-tension [6]. Lit.: [2] Hubble, E. (1929): A relation between distance and radial velocity among extra-galactic nebulae. Proc. of National Acad. of Sciences, 15, pp. 168-173. [3] Perlmutter, S. et al. (1998):

Discovery of a Supernova Explosion at Half the Age of the Universe. Nature, 391, pp. 51-54. [4] Carmesin, H.-O. (March 2021): Quanta of Spacetime Explain Observations, Dark Energy, Graviton and Nonlocality. Berlin: Verlag Dr. Köster. [5] Carmesin, H.-O. (December 2022): Unification of Spacetime, Gravity and Quanta. Berlin: Verlag Dr. Köster. [6] Riess, A. et al. (2022): A Comprehensive Measurement of the Local Value of the Hubble Constant with 1 km s^{-1} Mpc^{-1} Uncertainty from the Hubble Space Telescope and the SHOES Team. The Astrophys. J. Lett., 934:L7, pp. 1 - 52.

GR 10.3 Wed 16:40 ZEU/0255

Comparison of Models of Dark Energy — •Paul Sawitzki[1], Jannes Ruder[1], and Hans-Otto Carmesin[1,2,3] — [1]Gymn. Athenaeum, Harsefelder Str. 40, 21680 Stade — [2]Studienseminar Stade, Bahnhofstr. 5, 21682 Stade — [3]Universität Bremen, Fachbereich 1, Postfach 330440, 28334 Bremen

While Newton proposed a static and flat space, Einstein used his general relativity, GR, and derived a possible dynamic expansion of space [1]. Hubble observed that expansion [2]. When Perlmutter [3] discovered the energy density u_Λ of the cosmological vacuum, the dark energy, an essential property of space beyond GR had been discovered. Moreover, the dark energy amounts to 68 % of all energy in the universe. So, a basic question became relevant:
What is dark energy? Here, we summarize proposed models of dark energy, and we compare these models according to criteria of physics and epistemology [4,5]. [1] Einstein, A. (1917): Kosmologische Betrachtungen zur allgemeinen Relativitätstheorie. Sitzungsb. d. Königl. Preuß. Akad. d. Wiss., pp. 142-152. [2] Hubble, E. (1929): A relation between distance and radial velocity among extra-galactic nebulae. Proc. of National Acad. of Sciences, 15, pp. 168-173. [3] Perlmutter, S. et al. (1998): Discovery of a Supernova Explosion at Half the Age of the Universe. Nature, 391, pp. 51-54. [4] Humphreys, P. (2004): Scientific Knowledge. In: Niiniluoto, Ilkaa et al. (Eds.): Handbook of Epistemology. Dordrecht: Springer, pp. 549-569. [5] Styrman, A. (2020): Only a unified ontology can remedy disunification. Journal of Physics: Conference Series, 1466, pp. 1-25.

GR 10.4 Wed 17:00 ZEU/0255

Comparison of Models of the H_0 Tension — •Philipp Schöneberg[1], Phil Immanuel Gustke[1], and Hans-Otto Carmesin[1,2,3] — [1]Gymn. Athenaeum, Harsefelder Str. 40, 21680 Stade — [2]Studienseminar Stade, Bahnhofstr. 5, 21682 Stade — [3]Universität Bremen, Fachbereich 1, Postfach 330440, 28334 Bremen

While Newton proposed a static and flat space, Einstein used his general relativity, GR, and derived a possible dynamic expansion of space [1]. Hubble observed that expansion [2]. The dynamics of that expansion can be described by the Hubble parameter, and by its present-day limit H_0. However, the observed value at the early universe $H_{0,obs,early}$ differs from the observed value at the late universe $H_{0,obs,late}$ by five standard deviations [3]. So, what is the origin of that H_0 difference or H_0 tension? Here, we summarize proposed models of that H_0 difference, and we compare these models according to criteria of physics and epistemology [4].

[1] Einstein, A. (1917): Kosmologische Betrachtungen zur allgemeinen Relativitätstheorie. Sitzungsb. d. Königl. Preuß. Akad. d. Wiss., pp. 142-152. [2] Hubble, E. (1929): A relation between distance and radial velocity among extra-galactic nebulae. Proc. of National Acad. of Sciences, 15, pp. 168-173. [3] Riess, A. et al. (2022): A Comprehensive Measurement of the Local Value of the Hubble Constant with 1 km s^{-1} Mpc^{-1} Uncertainty from the Hubble Space Telescope and the SHOES Team. The Astrophys. J. Lett., 934:L7, pp. 1 - 52. [4] Humphreys, P. (2004): Scientific Knowledge. In: Niiniluoto, Ilkaa et al. (Eds.): Handbook of Epistemology. Dordrecht: Springer, pp. 549-569.

GR 10.5 Wed 17:20 ZEU/0255

Questionable predictions by EHT image of Sgr A* — •Jürgen Brandes — Karlsbad, Germany

The famous EHT image of Sgr A* predicts BH features in contradiction with observation: a*=0.9375 against a*=0.15; spin direction face-on against edge-on; accretion light variability arising with accretion disks against variability of accretion wind. And there is a theoretical shortcut by Broderick et al.: The missing UV bump agrees with *degenerate* supermassive objects being no BH. [1],[2]

[1] "*Observations questioning classical GRT ...*", chapter 13, homepage www.grt-li.de.

[2] J. Brandes, J. Czerniawski, L. Neidhart: *Spezielle und Allgemeine Relativitätstheorie für Physiker und Philosophen - Einstein- und Lorentz-Interpretation, Paradoxien, Raum und Zeit, Experimente*, 5th edition., VRI: 2022.

GR 11: Gravitational Waves and Astrophysics II

Time: Thursday 11:00–12:30 Location: ZEU/0260

Invited Talk GR 11.1 Thu 11:00 ZEU/0260

From quarks to black holes: micro- and macrophysics of neutron star mergers — •Andreas Bauswein — GSI Helmholtzzentrum fuer Schwerionenforschung, Darmstadt, Germany

Neutron stars are the densest stellar objects with densities exceeding those in atomic nuclei. Consequently, the collision of two neutron stars creates very extreme conditions and leads to a variety of different highly energetic and potentially observable phenomena: electromagnetic radiation from radio to gamma wavelengths, neutrinos and gravitational waves. Since the first unambiguous observation of a neutron star merger in 2017, a few more events have been detected, and increased instrumental sensitivity promises many more measurements in the future. We will provide an overview on which fundamental questions can be addressed by studying neutron star mergers. This includes the formation of black holes or the synthesis of heavy elements in the explosive outflows from these events. Moreover, mergers provide information on the properties of high-density matter including the prospect to identify the presence of a possible phase of deconfined quark matter in neutron stars.

Invited Talk GR 11.2 Thu 11:45 ZEU/0260

Tracing beyond GR physics with gravitational waves — •Daniela Doneva — Theoretical Astrophysics, University of Tübingen, 72076 Tübingen, Germany

Gravitational waves are among the ultimate tools to test fundamental physics and promise to answer the long-waiting question about the nature of gravity in the regime of strong fields. The degeneracies between different effects are a serious obstacle, though, to fulfilling this goal since modified gravity often leads to smaller cumulative changes. In the present talk we will focus on a few examples of interesting new effects we can observe in the gravitational wave spectrum that differ qualitatively from the standard picture in general relativity. This includes gravitational phase transition of neutron stars, jumps in the gravitational wave emission from merging black holes, and inverse chirp signal of extreme mass-ratio inspirals. Such effects are valuable because they are a smoking gun of beyond-GR physics that can be easily traced in observations.

GR 12: Relativistic Astrophysics and Scalar Fields

Time: Thursday 14:00–15:20 Location: ZEU/0260

GR 12.1 Thu 14:00 ZEU/0260

Testing scalar-tensor gravity with radio pulsars — •Alexander Batrakov[1], Huanchen Hu[1], Norbert Wex[1], Paulo Freire[1], Vivek Venkatraman Krishnan[1], and Michael Kramer[1,2] — [1]Max-Planck-Institut für Radioastronomie, Auf dem Hügel 69, 53121 Bonn, Germany — [2]Jodrell Bank Centre for Astrophysics, The University of Manchester, M13 9PL, United Kingdom

The talk will highlight some of the latest results in testing the strong-field aspects of scalar-tensor gravity (STG) with radio pulsars, which include spontaneous scalarization, dipolar radiation, and the violation of the universality of free fall by strongly self-gravitating bodies. Some of these results are based on a new timing model that provides a fully consistent analysis of pulsar timing data for certain classes of STG theories.

GR 12.2 Thu 14:20 ZEU/0260

Mergers of Dark Matter Admixed Neutron Stars — •Hannes Rüter[1], Violetta Sagun[1], Wolfgang Tichy[2], and Tim Dietrich[3] — [1]CFisUC, Department of Physics, University of Coimbra, 3004-516 Coimbra, Portugal — [2]Department of Physics, Florida Atlantic University, Boca Raton, FL 33431, USA — [3]Institut für Physik und Astronomie, Universität Potsdam, Haus 28, Karl-Liebknecht-Str. 24/25, Potsdam, Germany

We investigate mergers of neutron stars consisting of two non-interacting fluids minimally coupled to the gravitational field using the numerical relativity code BAM. The first fluid represents baryonic matter, whereas the second fluid models dark matter, which we describe using the equation of state of a degenerate Fermi gas.

We consider two different scenarios for the distribution of the dark matter. In the first scenario the dark matter is confined to the core of the star, whereas in the second scenario the dark matter extends beyond the surface of the baryonic matter forming a halo around the baryonic star.

We show how the dark matter impacts the binary dynamics and merger waveforms.

GR 12.3 Thu 14:40 ZEU/0260

Boson star head-on collisions — •Florian Atteneder[1], Daniela Cors[1], Hannes Rüter[2], Roxana Rosca-Mead[1], David Hilditch[3], and Bernd Brügmann[1] — [1]Theoretisch-Physikalisches Institut, Friedrich-Schiller-Universität Jena — [2]CFisUC, Department of Physics, University of Coimbra — [3]CENTRA, Instituto Superior Tecnico, The University of Lisbon

Colliding boson stars (BS) can be regarded as one potential source for astrophysical gravitational wave signals. Templates for the detection of such signals are now being constructed, which makes accurate calculations of such more important. In contrast to fluid matter, BS solutions are smooth, which makes them, in some sense, an optimal domain for the application of pseudospectral numerical methods. Simulations so far have been limited due to the difficulty in building initial data containing two BSs. Most groups undergoing such studies either use a simple superposition of two boosted BSs or an improved version thereof. In this talk I will present first results of BS head-on collisions that start from constraint solved initial data.

GR 12.4 Thu 15:00 ZEU/0260

Image of the thin accretion disk in gravity with a minimally coupled scalar field — •Galin Gyulchev — Faculty of Physics, Sofia University, James Bourchier Boulevard, Sofia 1164, Bulgaria

We study possible observable images of a black hole and naked singularity described by rotating geometry in Einstein gravity, minimally coupled to a scalar field. We consider a Kerr-like (KL) alternative to the rotating Fisher-Janis-Newman-Winicour solution. Our study includes analytical and numerical calculations of equatorial circular orbits, shadow images, and radiation from thin accretion disks for various values of the object's angular momentum and scalar charge. The KL solution cannot be ruled out by the observations for small values of the scalar charge either. As the scalar charge increases, the optical properties change dramatically. The photon region does not hide the singularity, so it should be classified as a strong singularity. The shadow of the compact object can become multiply connected and strongly oblate. This new qualitative feature can be used to distinguish observationally black holes from naked singularities via the contemporary Very Long Baseline Interferometry experiments at short wavelengths.

GR 13: Relativity and Data Analysis

Time: Thursday 16:00–17:20 Location: ZEU/0260

GR 13.1 Thu 16:00 ZEU/0260

bajes-mma: Joint Bayesian Inference Framework for Multi-Messenger Astronomy with Binary Neutron Star Coalescences — •Ssohrab Borhanian[1], Matteo Breschi[1], Gregorio Carullo[2], Giacomo Ricigliano[3], Lukas Lippold[1], Albino Perego[4], and Sebastiano Bernuzzi[1] — [1]Friedrich-Schiller-University Jena, Jena, Germany — [2]Niels-Bohr-Institute, Copenhagen, Denmark — [3]Technical University of Darmstadt, Darmstadt, Germany — [4]University of Trento, Trento, Italy

The coincident observation of three events GW170817, GRB170817A, and AT2017gfo—a gravitational-wave signal with associated electromagnetic counterpart observed via a short gamma-ray burst, kilonova, and successive long-term afterglow emission—marked the onset of multi-messenger astronomy using gravitational and electromagnetic waves. In expectation of further multi-messenger events during upcoming observing runs by the LIGO, Virgo, and KAGRA observatories we developed a data analysis pipeline to jointly examine the observational data associated with a multi-messenger event. The pipeline is built on the Bayesian inference framework `bajes` and leverages its strength to incorporate any data channel, i.e. for binary neutron star mergers the gravitational waves signal and associated electromagnetic transients—including klionovae, short gamma-ray bursts, and synchrotron from the fast-tail of the ejecta. Using this pipeline we analyzed the events associated to GW170817 simultaneously to perform kilonova model selection, improve the parameter constraints of prior studies, and constrain the neutron star equation of state.

GR 13.2 Thu 16:20 ZEU/0260

Noise transients in machine-learning based gravitational-wave searches — •Ondřej Zelenka[1,2], Bernd Brügmann[1,2], and Frank Ohme[3,4] — [1]Friedrich-Schiller-Universität Jena, D-07743 Jena, Germany — [2]Michael Stifel Center Jena, D-07743 Jena, Germany — [3]Max-Planck-Institut für Gravitationsphysik, Albert-Einstein-Institut, D-30167 Hannover, Germany — [4]Leibniz Universität Hannover, D-30167 Hannover, Germany

In the recent past, machine-learning based approaches have been proposed as a solution to some problems in gravitational-wave data analysis. One of these are noise transients, which significantly complicate detection of gravitational waves. Contemporary matched-filtering based searches as well as unmodeled searches employ systems which flag likely noise transients and reject potential false alarms. It is possible that machine-learning based algorithms can learn to distinguish noise transients from signals with astrophysical sources.

In this contribution, we present a machine-learning based gravitational-wave detection algorithm focused on binary black holes, which has been submitted to the MLGWSC-1 mock data challenge. Furthermore, we describe an issue which arose when the model encountered non-Gaussian background noise, and present its solution. In doing so, we demonstrate that a machine-learning based algorithm with a suitable training method is capable of distinguishing false alarms due to transients from binary black hole injections.

GR 13.3 Thu 16:40 ZEU/0260

Finding Universal Relations using Statistical Data Analysis

— •Praveen Manoharan and Kostas D. Kokkotas — IAAT, University of Tübingen, 72076 Tübingen, Germany

We present applications of statistical data analysis methods from both bi- and multivariate statistics to find suitable sets of neutron star features that can be leveraged for accurate and EoS independent - or universal - relations. To this end, we investigate the ability of various correlation measures such as Distance Correlation and Mutual Information in identifying universally related pairs of neutron star features. We also evaluate relations produced by methods of multivariate statistics such as Principal Component Analysis to assess their suitability for producing universal relations with multiple independent variables.

As part of our analyses, we are able to put forward multiple entirely novel relations, including multivariate relations for the f-mode frequency of neutron stars with reduced error when compared to existing, bivariate relations.

GR 13.4 Thu 17:00 ZEU/0260

Ranging and Clock Synchronization in LISA Data Processing
— •Jan Niklas Reinhardt — Albert Einstein Institut, Hannover

The Laser Interferometer Space Antenna (LISA) is an ESA-led mission for gravitaional wave detection in space aiming for the frequency band between 1 mHz and 1 Hz after its launch in 2035. In order to extract the gravitational wave signals from the LISA data, various instrumental noise sources must be suppressed. The dominating noise source is by far the laser frequency noise, which must be reduced by more than 8 orders of magnitude to meet the LISA requirement of 1 pm. This can be achieved by time delay interferometry (TDI), which combines the various data streams with the correct delays to virtually form equal arm Michelson interferometers, in which laser frequency noise naturally cancels. This algorithm, as its name fortells, relies on knowledge about the delays (corresponding to the inter spacecraft distances), its classical execution additionally requires nano second synchronization of the three LISA timers. The estimation of the delays and the clock synchronization are the topic of this presentation.

GR 14: Gravitational Waves II

Time: Thursday 16:00–17:40 Location: ZEU/0255

GR 14.1 Thu 16:00 ZEU/0255

Implementation of a Stray Light Simulation for the Einstein Telescope
— •Hanna Marozava[1], Thomas Hebbeker[1], and Achim Stahl[2] — [1]III. Physikalisches Institut A, RWTH Aachen University — [2]III. Physikalisches Institut B, RWTH Aachen University

The Einstein Telescope (ET) will be the first gravitational wave detector of the third generation. Stray light is a severe problem for modern interferometers with high sensitivity, as another noise source contributing to the interferometer output. A simulation is required to tune detector settings to avoid undesirable light paths and to optimize the shape, number and position of baffles.

This talk will present the progress in developing a concept for the reduction of stray light in ET and first results.

GR 14.2 Thu 16:20 ZEU/0255

Test setup for cryogenic sensors and actuators working towards the Einstein Telescope
— •Robert Joppe[1], Thomas Hebbeker[2], Tim Kuhlbusch[1], Oliver Pooth[2], Achim Stahl[2], Timo Wittler[1], and Franz-Peter Zantis[1] — [1]III. Physikalisches Institut A, RWTH Aachen — [2]III. Physikalisches Institut B, RWTH Aachen

The Einstein Telescope will be the first gravitational wave detector of the third generation. The sensitivity goal, especially in the low frequency region, will be achieved among other improvements by cooling the main parts of the interferometer. The required electronic components, sensors and actuators needed for mirror alignment and active dampening of suspension resonances have to perform at cryogenic temperatures.

The talk presents the progress on the development of electronics, optics and mechanics within the E-TEST project. Furthermore the performance of our cryogenic UHV test setup and the characterization of light emitting diodes at low temperatures will be explicated.

GR 14.3 Thu 16:40 ZEU/0255

A Cryogenic Displacement Sensor and Actuator for the Einstein Telescope
— Thomas Hebbeker[1], Robert Joppe[1], •Tim Kuhlbusch[2], Oliver Pooth[2], Purnalingam Revathi[2], Achim Stahl[2], Timo Wittler[1], and Franz-Peter Zantis[1] — [1]III. Physikalisches Institut A, RWTH Aachen — [2]III. Physikalisches Institut B, RWTH Aachen

The Einstein Telescope will be the first third-generation gravitational wave detector. In achieving an increase in sensitivity of more than one order of magnitude at low frequencies compared to current detectors, mitigating thermal noises is essential. Thus cooling the mirrors of the interferometer to cryogenic temperatures is required. Consequently parts of the vibration isolation systems of the mirrors need to be working at these low temperatures.

This talk will present the developement of an actuator with an integrated absolute displacement sensor operating below 20 K. Sensitivity of the sensor, forces of the actuator and thermal design will be discussed. This includes the effects of cryogenic temperatures on diodes of the sensor and the electromagnet of the actuator.

GR 14.4 Thu 17:00 ZEU/0255

Wireless power transfer for cryogenic sensors and actuators in the Einstein Telescope
— •santosh mutum[1], christian grewing[1], andre zambanini[1], and stefan van waasen[1,2] — [1]Central Institute of Engineering, Electronics and Analytics, Electronic Systems, Forschungszentrum Jülich, Germany — [2]Faculty of Engineering, Communication Systems, University of Duisburg-Essen, Germany

Gravitational wave detectors have to be extremely sensitive by nature. Hence, a significant effort is required to investigate in optimizing the hardware setup to reduce noise impacts as much as possible. For the upcoming Einstein Telescope, an optical power and information transfer is proposed and investigated to limit the mechanical coupling of cables. Additionally, in order to achieve more sensitivity in the proposed third generation gravitational wave detector, the main optics and consequently the electronics of the interferometer need to be cooled down to cryogenic temperatures.

This talk will address the wireless power transfer for the sensor-actuator system. The concept of a wireless power transfer in cryogenic using laser and solar cell will be discussed as well as first measurements and estimations for the expected performance.

GR 14.5 Thu 17:20 ZEU/0255

Development and Testing of Composite Vacuum Tubes for the Einstein Telescope
— •Purnalingam Revathi[1], Ralf Schleichert[2], Tim Kuhlbusch[1], Robert Joppe[1], Thomas Hebbeker[1], Oliver Pooth[1], and Achim Stahl[1] — [1]III. Physikalisches Institut B, RWTH Aachen — [2]Institut für Kernphysik, Forschungszentrum Jülich

The Einstein Telescope, a proposed third-generation gravitational wave detector, requires about a 120 km long set of vacuum tubes with diameters of up to 1 m. Due to the vacuum requirements and mechanical integrity, stainless steel tubes are the standard for ultra high vacuum applications. But even with higher material costs, composite tubes may be a promising alternative to reduce the overall costs and to open possibilities for an on site production. This talk presents the details of the development and testing of prototypes made of Glass Fiber Reinforced Plastic wound around a stainless steel liner. Vacuum pressure stability and overpressure tests have been performed. Finite element simulations were done to optimize the material choice and thicknesses. The possibility of integrating sensors to measure temperature and pressure will be discussed.

GR 15: Members' Assembly

Time: Thursday 18:30–20:00 Location: ZEU/0260

All members of the Gravitation and Relativity Division are invited to participate.

GR 16: Experimental Tests

Time: Friday 11:00–12:40 Location: HSZ/0401

GR 16.1 Fri 11:00 HSZ/0401

New search for differences in active and passive gravitational masses using Lunar Laser Ranging — •Claus Lämmerzahl[1], Vishwa V. Singh[2], Liliane Biskupek[2], Jürgen Müller[2], and Eva Hackmann[1] — [1]ZARM, University of Bremen — [2]IfE, Leibniz Universität Hannover

Each body possesses three masses: inertial mass, passive gravitational mass (weight), and active gravitating mass. With MICROSCOPE the equality of inertial and passive gravitational mass has been confirmed at the order 10^{-15}. Laboratory test confirmed the equality of active and passive mass at the order 10^{-5}. Using Lunar Laser Ranging (LLR) data from 1970 to 2022, we obtained a new limit of 3.9×10^{-14} that improves the previous LLR-based result by two orders of magnitude. We also propose a new laboratory experiment for the search of a difference between active and passive masses, and present a new orbital analysis for stellar binary systems made of different masses. Finally, we add some remarks on active and passive charges.

GR 16.2 Fri 11:20 HSZ/0401

A concept for testing the gravitomagnetic clock effect with GNSS satellites — •Jan Scheumann[1,2], Dennis Philipp[1,2], Eva Hackmann[1,2], Sven Herrmann[1,2], Benny Rievers[1,2], and Claus Lämmerzahl[1,2] — [1]ZARM, University of Bremen, 28359 Bremen, Germany — [2]Gauss-Olbers Space Technology Transfer Center, Bremen, Germany

General Relativity (GR) predicts that the rotation of a central body influences the trajectory of an orbiting mass in a non-Newtonian way. One of the predicted effects was first described by Cohen and Mashhoon, concerning the proper time difference of two counter-revolving clocks in an orbit around a rotating mass, which is yet to be verified experimentally. After the accuracy of the tests of the gravitational redshift could be improved using two Galileo satellites on eccentric orbits, other possibilities to use GNSS satellites for tests of GR are under investigation. This work presents a concept to test the gravitomagnetic clock effect (GMCE) with GNSS satellites and looks into the technical requirements for such a test.

The introduced theoretical framework yields an incrementally defined observable, that is accesible e.g. via orbit and clock products. Some usage of the framework is presented, taking advantage of state-of-the-art orbit simulations as an a-priori data source.

A comparison of a dedicated mission's technical requirements with the state-of-the-art in SLR and modelling of gravitational and non-gravitational perturbations yields that a measurement is highly demanding, but might just be within reach of current technology.

GR 16.3 Fri 11:40 HSZ/0401

Taking gravity tests with the Double Pulsar to higher orders — •Huanchen Hu[1], Michael Kramer[1,2], Norbert Wex[1], and David J. Champion[1] — [1]Max-Planck-Institut für Radioastronomie, Auf dem Hügel 69, 53121 Bonn, Germany — [2]Jodrell Bank Centre for Astrophysics, The University of Manchester, Oxford Road, Manchester M13 9PL, UK

Relativistic binary pulsars are excellent testbeds for probing strong-field aspects of gravity. In particular, the Double Pulsar system PSR J0737-3039A/B offers a wealth of relativistic effects that can be studied in depth. Pulsar timing observations with MeerKAT and the future Square Kilometre Array (SKA) can bring the accuracy of these gravity tests to an unprecedented level, as well as enable precision tests of next-to-leading order (NLO) effects in the orbital motion and signal propagation. In this talk, I will present the timing results of PSR J0737-3039A based on 3-yr MeerKAT observations with a focus on the NLO signal propagation effects. These include the retardation effect due to the movement of pulsar B and the deflection of the signal of A by the gravitational field of B. Moreover, future observations with MeerKAT and the SKA are expected to provide one of the first measurements of the moment of inertia of a neutron star, hence an important complementary constraint on the equation of state at ultranuclear density. Finally, other prospects from future observations will be also demonstrated.

GR 16.4 Fri 12:00 HSZ/0401

Measurement of Gravitational Coupling of Planck Mass-sized Object — •Hans Hepach[1], Mathias Dragosits[2], and Jeremias Pfaff[2] — [1]IQOQI Vienna, OeAW, Austria — [2]University of Vienna, Austria

Gravity is the weakest of all known fundamental forces and continues to pose some of the most outstanding open problems to modern physics: it remains resistant to unification within the standard model of physics and its underlying concepts appear to be fundamentally disconnected from quantum theory. Testing gravity on all scales is therefore an important experimental endeavour. Thus far, these tests involve mainly macroscopic masses on the kg-scale and beyond. Here we show gravitational coupling between a gold sphere of 1mm radius and a Planck mass sized object. Periodic modulation of the source mass position allows us to perform a spatial mapping of the gravitational force. The current measurement improves upon our previous result by a reduction of the source mass by three orders of magnitude and opens the way to a yet unexplored frontier of microscopic source masses. This enables new searches of fundamental interactions and provides a natural path towards exploring the quantum nature of gravity.

GR 16.5 Fri 12:20 HSZ/0401

Measuring the gravitational field using quantum imaging — •Marian Cepok — ZARM, University of Bremen, 28359 Bremen, Germany

Quantum Imaging is a method which can be used to image an object using photons which have not interacted with the object. This scheme uses an entangled pair of photons, one of the photons interacts with the object while it is only the other photon which is being measured. Here a setup similar to quantum imaging is proposed which images the gravitational field instead of an object.