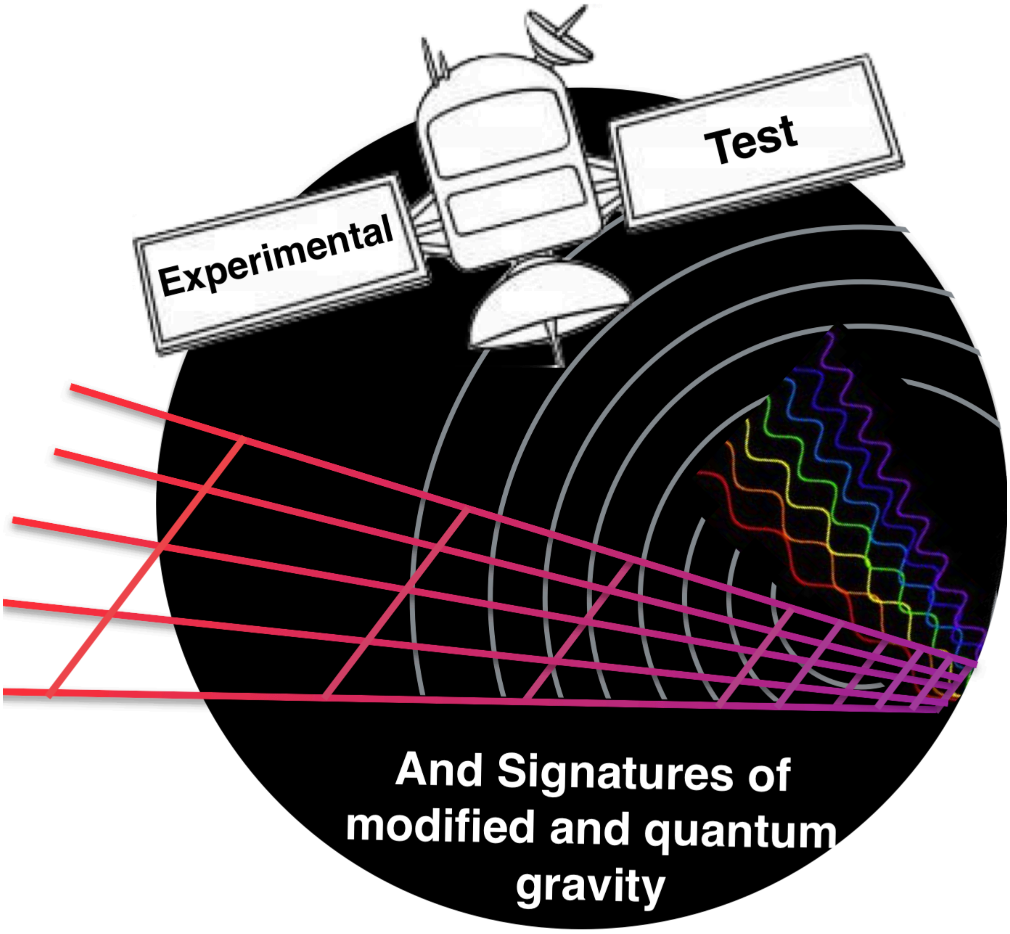

740. WE-Heraeus Seminar

1-5. Februar 2021
ONLINE

WILHELM UND ELSE
HERAEUS-STIFTUNG

Introduction

The Wilhelm und Else Heraeus-Stiftung is a private foundation that supports research and education in science with an emphasis on physics. It is recognized as Germany's most important private institution funding physics. Some of the activities of the foundation are carried out in close cooperation with the German Physical Society (Deutsche Physikalische Gesellschaft). For detailed information see https://www.we-heraeus-stiftung.de

Aims and scope of the 740. WE-Heraeus-Seminar:

Two major unsolved questions in fundamental physics are related to the gravity: What is the nature of Dark Matter and Dark Energy, and, what is the theory of quantum gravity? From the theoretical point of view these questions stimulated various fundamental approaches to a theory of quantum gravity, such as string theory, loop quantum gravity, canonical quantum gravity, noncommutative geometry, asymptotic safety and others as well as phenomenological models such as doubly or deformed special relativity and the relative locality framework. Moreover, numerous classical modifications of General Relativity have been suggested such as scalar-tensor theories, $f(R)$-theories, bi-metric gravity, tensor-vector-scalar gravity or metric affine gravity, Poincare gauge theory, telleparallel gravity, Finsler gravity and many more.

The viability of these alternative or extended theories of gravity has to be tested by comparison of predictions with experimental data. It is important that this comparison is done on all scales from the whole universe, i.e. on cosmological scales, via galaxy-clusters, galaxies, binary systems, black holes, the solar system, satellite experiments, down to laboratory experiments at micrometer and smallest scales, i.e. high energy scales looking for new elementary particles like axions or WIMPs.

This seminar aims for discussing predictions and their comparison with experiments of extended and modified classical and quantum theories of gravity, on all scales. The goal is to identify theories, which are consistent on all scales, and, to identify observables, in which deviations of general relativity or the quantum nature of gravity is most likely to manifest itself.

Introduction

Scientific Organizers:

Dr. Christian Pfeifer	University of Bremen, ZARM, Bremen, Germany E-mail: christian.pfeifer@zarm.uni-bremen.de
Prof. Dr. Claus Laemmerzahl	University of Bremen, ZARM, Bremen, Germany E-mail: claus.laemmerzahl@zarm.uni-bremen.de

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Program

Program

Monday, 1 February 2021

08:45 – 09:00	Scientific organizers	**Welcome Words**

Session chair: Christian Pfeifer

09:00 – 09:45	Nick Mavromatos	**Gravitational Anomalies, Primordial Gravitational Waves and Spontaneous Lorentz-symmetry Violation: from Inflation to Matter-Antimatter Asymmetry**
09:45 – 10:30	Carlos Pérez de los Heros	**Searches for quantum gravity effects with IceCube**
10:30 – 10:45	Stefan Jorda	**About the Wilhelm and Else Heraeus Foundation**
10:45 – 11:15	*COFFEE BREAK*	
11:15 – 11:45	Uwe R. Fischer	**Phenomenological quantum "gravity" and cosmology via the many-body dynamics of ultracold gases**
11:45 – 12:15	Lucía Menéndez-Pidal	**Clock dependent features in quantum cosmology**
12:15 – 13:45	*LUNCH BREAK*	

Program

Monday, 1 February 2021

13:45 – 14:15	**Poster Flash A** (Posters 1 – 14)	
14:15 – 15:15	**Poster Session A** (Posters 1 – 14)	
15:15 – 15:45	*COFFEE BREAK*	

Session chair: Roy Barzel

15:45 – 16:30	Andre Grossardt	**Classically gravitating quantum systems: causality, entanglement, and experimental tests**
16:30 – 17:15	Domenico Giulini + Philip Schwartz	**The interface of classical gravity and quantum mechanics**

Program

Tuesday, 2 February 2021

Session chair: Claus Laemmerzahl

09:00 – 09:45	Vladimir M. Mostepanenko	**The theory of the Casimir effect**
09:45 – 10:30	Galina L. Klimchitskaya	**Constraints on modified gravity from Casimir force experiments**
10:30 – 11:00	*COFFEE BREAK*	
11:00 – 12:30	Dennis Rätzel	**Optimal estimation of time-dependent gravitational fields and constraints of modified gravity with non-linear quantum optomechanical sensors**
11:30 – 12:00	Jan-Willem van Holten	**The gravitational field of a light wave**
12:00 – 13:30	*LUNCH BREAK*	
13:30 – 14:00	**Poster Flash B** (Posters 15 – 28)	
14:00 – 15:00	**Poster Session B** (Posters 15 – 28)	
15:00 – 15:30	*COFFEE BREAK*	

Session chair: Dennis Philipp

15:30 – 16:15	Hendrik Ulbricht	**Probing new physics by levitated mechanical systems**
16:15 – 17:15	Clifford Will	**Zombie alert! Solar system tests of GR are still alive**

Program

Wednesday, 3 February 2021

Session chair: Sebastian Völkel

09:00 – 09:45	Lijing Shao	**Testing gravity with pulsars**
09:45 – 10:30	Eva Hackmann	**Infinite energies in near-horizon particle collisions**
10:30 – 11:00	*COFFEE BREAK*	
11:00 – 11:30	Yakov Shnir	**Boson Constellations**
11:30 – 12:00	Elisa Maggio	**How does a dark compact object ringdown?**
12:00 – 13:30	*LUNCH BREAK*	
13:30 – 14:00	**Poster Flash C** (Posters 29 – 40)	
14:00 – 15:00	**Poster Session C** (Posters 29 – 40)	
15:00 – 15:30	*COFFEE BREAK*	

Session chair: Michael Kopp

15:30 – 16:15	Jutta Kunz	**Compact objects in alternative theories of gravity**
16:15 – 17:00	Sven Herrmann	**Testing gravity with matter wave interferometry**

Program

Thursday, 4 February 2021

Session chair: Jose Manuel Carmona

09:00 – 09:45	Giulia Gubitosi	**Theoretical frameworks for quantum gravity phenomenology below the Planck scale**
09:45 – 10:30	Michele Arzano	**Decoherence and discrete symmetries in deformed relativistic kinematics**
10:30 – 11:00	*COFFEE BREAK*	
11:00 – 11:45	Tomislav Terzić	**Recent limits on Lorentz invariance violation using gamma rays**
11:45 – 12:15	José Javier Relancio Martínez	**Towards a geometrical interpretation of rainbow geometries for quantum gravity phenomenology**
12:15 – 13:45	*LUNCH BREAK*	

Session chair: Nicoleta Voicu

13:45 – 14:30	Jean-François Glicenstein	**Tests of quantum gravity models with gravitational lensing**
14:30 – 15:15	Volker Perlick	**Confronting Finsler spacetime theory with observations**
15:15 – 15:45	*COFFEE BREAK*	
15:45 – 16:15	Anupam Mazumdar	**Witnessing Quantum gravity in a laboratory via miniaturist quantum accelerator**
16:15 – 17:00	Frans R. Klinkhamer	**M-theory and the birth of the Universe**

Program

Friday, 5 February 2021

Session chair: Igor Pikovski

09:00 – 09:45	Ivette Fuentes	**Can quantum metrology solve some of the biggest questions in fundamental physics?**
09:45 – 10:30	Časlav Brukner	**Einstein's equivalence principle for quantum reference frames and spacetimes**
10:30 – 11:00	*COFFEE BREAK*	
11:00 – 11:45	Lavinia Heisenberg	**Born-Infeld inspired modifications of gravity (preliminary title)**
11:45 – 12:15	Lotte ter Haar	**Dynamics of Screening in Modified Gravity**
12:15 – 13:45	*LUNCH BREAK*	

Session chair: Aneta Wojnar

13:45 – 14:30	Yuri Obukhov	**Poincaré gauge gravity: Recent developments**
14:30 – 15:15	Manuel Hohmann	**Perturbative methods in modified gravity theories**
15:15 – 15:45	*COFFEE BREAK*	
15:45 – 16:30	Carlos Herdeiro	**Testing the Kerr hypothesis: the examples of synchronisation and scalarisation**
16:30 – 16:45	Scientific organizers	**Concluding Remarks + Poster awards**

End of seminar

Posters

Posters

Poster Session A

Monday, Feb. 1 / 14:15 – 15:15 h
(14 Posters)

1	Thomas Agrenius	**Testing Universal Compton Clocks Using Clock Interferometry**
2	Mikhail Barabanov	**Probing of exotic quantum states in heavy ion collisions**
3	Roy Barzel	**Relativistic Effects on Continuous Variable Quantum Key Distribution**
4	Hristu Culetu	**Pattern for a star filled with imperfect fluid**
5	Pawan Kumar Gupta	**Relativistic effective action of dynamical gravitomagnetic tides for slowly rotating neutron stars**
6	Syed Naqvi	**Freely falling bodies in standing wave space-time**
7	Dennis Philipp	**Testing Relativistic Gravity: Geodesy, the Redshift, and Clock Effects**
8	*(cancelled at short notice)*	
9	Arman Tursunov	**Ultrahigh Energy Cosmic Rays from Supermassive Black Holes candidates**
10	Sebastian Ulbricht	**Impact of Earth's Gravity on the Frequency Stabilization of Optical Cavities**
11	Sebastian Völkel	**Metric Reconstruction with Gravitational Waves and Shadows**

Posters

12	Michael Werner	**Phase shifts of arbitrary matter wave interferometers in post-Newtonian spacetimes**
13	Aneta Wojnar	**Low-mass stars and tests of gravitational theories**
14	Saboura Sadat Zamani	**Gravitational lensing by a black hole in non-Riemannian spacetimes**

Posters

Poster Session B

Tuesday, Feb. 2 / 14:00 – 15:00 h
(14 Posters)

15	Asier Alonso-Bardaji	**Holonomy and inverse-triad corrections in spherical models coupled to matter**
16	Daniel Blixt	**Viability of teleparallel theories of gravity**
17	Ahmad Borzou	**Challenging general relativity using the temperature of galactic dark matter halos**
18	Alejandro Cárdenas-Avendaño	**Experimental gravity with electromagnetic and gravitational waves**
19	Marco de Cesare	**Modified gravity theories as effective descriptions of quantum gravity: lessons and cautionary tales**
20	Yurii Dumin	**The Cosmological Model Based on the Uncertainty-Mediated Dark Energy**
21	Praveer Gollapudi	**Quasi-Normal Modes and Tests of Modified Gravity**
22	Vesselin Gueorguiev	**The Scale Invariant Vacuum Theory as viable Cosmology Model**
23	Tanisha Joshi	**Can the viability of f(R) theory of gravity can explain the nature of dark energy?**
24	Sobhan Kazempour Ishka	**Cosmological Features of the Extended Quasi-Dilaton Massive Gravity Theory**

Posters

25	Michael Kopp	**Dark energy after GW170817 revisited: Gravitational wave propagation through inhomogeneities**
26	Tobias Mistele	**Superfluid dark matter: Beyond the modified gravity and dark matter dichotomy**
27	Bikash Chandra Paul	**A study of Traversable Wormholes in Modified Gravity and Non-linear Equation of State**
28	Paritosh Verma	**Probing gravitational waves from pulsars in Jordan-Brans-Dicke theory**

Posters

Poster Session C

Wednesday, Feb. 3 / 14:00 – 15:00 h
(12 Posters)

29	Pasquale Bosso	**Position in models of quantum mechanics with a minimal length**
30	Lennart Brocki + Josua Unger	**BMS algebras in 4 and 3 dimensions, their quantum deformations and duals**
31	Jan Chojnacki	**Multiverse in the asymptotically safe inflation**
32	Sara Fernández Uria	**Quantum approach to a Bianchi II singularity**
33	Sebastián Franchino-Viñas	**Big Bang Nucleosynthesis and running coupling constants**
34	Sjors Heefer	**Randers pp-waves**
35	Iarley Lobo	**Reaching Planck scale sensitivity with muon lifetimes from Finsler measures**
36	Yasmine M'hirsi	**Testing the sensitivity and limitations of a massive spin-2 boson model using the Contur approach**
37	Saeed Rastgoo	**Propagation of quantum gravity-modified gravitational waves on a classical FLRW spacetime**
38	Nicoleta Voicu	**The Geometry of Finsler spacetimes**
39	Fabian Wagner	**Asymptotic Extended Uncertainty Principle**
40	Ivan Zhogin	**Forth-order gravity in five-dimensional teleparallelism**

Abstracts of Lectures

(in alphabetical order)

Einstein's equivalence principle for quantum reference frames and spacetimes

Časlav Brukner

University of Vienna, Austria

The equivalence principle is at the core of general relativity, stating that all physical laws take their special-relativistic form in any local inertial frame. However, its formulation implicitly assumes reference frames as classical (i.e., constructed from classical rods and clocks), and that the background spacetime is well-defined. The questions then arise whether the principle also holds for "quantum reference frames" (QRF) (i.e., when quantum systems are taken as reference frames), and in a superposition of classical spacetimes. In my talk, I will address both questions by introducing the "quantum local inertial frame" attached to a free-falling quantum system in curved spacetime, or in a superposition of spacetimes. I will then show that from the perspective of such a QRF, the metric looks locally flat. Consequently, one cannot distinguish with a local measurement whether the spacetime is flat or curved, or whether it is in a superposition of such spacetimes. This result extends the equivalence principle to QRFs in a superposition of gravitational fields. The verification of this principle could pave the way to lay the conceptual foundations for a future theory of quantum gravity.

Phenomenological quantum "gravity" and cosmology via the many-body dynamics of ultracold gases

Uwe R. Fischer

Seoul National University, Physics and Astronomy, Seoul, South Korea

I will describe the curved space-times experienced by quasiparticle excitations in Bose-Einstein condensates, and how they can be used to elucidate certain kinematical aspects for quantum fields propagating on curved space-time, which are related to the form of the dispersion relations in the trans-Planckian sector.
Specifically I consider dipolar Bose-Einstein condensates with a deep "roton" minimum.
The effects of this minimum on the scale invariance of inflationary quantum cosmology will be elucidated. Furthermore, it will be shown that the dispersion minimum increases the degree of continuous variable entanglement generated by cosmological particle production to the level of steering.

Can quantum metrology solve some of the biggest questions in fundamental physics?

I. Fuentes
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The unification of quantum theory and general relativity remains one of the most important open issues in fundamental physics. A main problem is that we are missing experimental input at scales where quantum and relativistic effects coexist. Developing instruments sensitive at these scales might also help answer other big questions, such as the nature of dark energy and dark matter. In this talk, I will present a proposal to use quantum technologies to access new spacetime scales directly. The detection method uses quantum resonances and the sensitivity of collective quantum excitations (phonons) to gravitational fields. Applications include detecting gravitational waves at high frequencies [1], miniaturize devices to measure gravitational fields [2] and gradients [3] and set further constrains on dark energy/matter models [4].

References

[1] C. Sabín, J. Kohlrus, D. E. Bruschi, M. Ahmadi and I. Fuentes, New Journal of Physics **16**, 085003 (2014). C. Sabín, D. E. Bruschi, and I. Fuentes, EPJ Quantum Technology **3**, 8 (2016).
[2] T. Bravo, D. Rätzel, D. E. Bruschi, and I. Fuentes, UK patent application No. 1908538.0 (2019).
[3] T. Bravo, D. Rätzel, and I. Fuentes, arXiv:2001.10104v2, UK patent application No. 2000112.9 (2020).
[4] D. Hartley, C. Käding, R. Howl and I. Fuentes, arXiv:1909.02272, (2019).

The interface of classical gravity and quantum mechanics

Domenico Giulini and Philip Schwartz

Testing gravity with genuine quantum systems is on the agenda of many experimental groups worldwide. Such programmes presuppose a well defined scheme according to which the coupling of quantum matter to the classical gravitational field is determined. Such a scheme should be complete (i.e. account for all terms, say in a given PN-order) and generally applicable (i.e. without a priori restrictions on the quantum states the matter is assuming). But what are the hard principles on which such a scheme can be based?
In our talk we will dwell on that question and show that there exist schemes that allow to deduce the full Hamiltonian of an “atom” (electromagnetically bound system of two particles) in a static Eddington–Robertson parametrised post-Newtonian gravitational field to order (1/c)-squared.

Tests of quantum gravity models with gravitational lensing

J-F. Glicenstein
IRFU/CEA Paris-Saclay, Université Paris-Saclay

Abstract

Many astrophysical constraints on quantum gravity models are derived from the study energy-dependent photon propagation from distant sources, such as flaring AGNs and gamma-ray bursts. In this talk, an alternative astrophysical test of quantum gravity models, based on the study of high energy gravitational lensing systems, is explored. After a brief introduction to gravitational lensing, the energy-dependent time-delay between the lens images is derived in the framework of a LIV (Lorentz Invariance Violation) extension of the equations of motion of photons in the field of a massive object. The formalism is used to provide contraints from high energy lensing systems. The JVAS B0218+357 has been recently observed by high-energy (Fermi-LAT) and very high-energy (MAGIC) instruments. These observations will be used to illustrate the bounds achievable by future instruments and the systematics of these bounds.

Classically gravitating quantum systems: causality, entanglement, and experimental tests

A. Großardt[1]

[1]*Friedrich-Schiller-Universität Jena, Germany*

I will motivate the idea of quantum fields on a classical spacetime as a fundamental theory, giving rise to dynamics governed by the nonlinear Schrödinger-Newton equation in the nonrelativistic limit. I discuss the issue that arises from this nonlinear evolution regarding causality and how it may be avoided in a model that encompasses a mechanism for objective wave function collapse.

I will further discuss gravity-induced entanglement as a proxy for the quantisation of gravity, and argue that experimental tests of quantum versus semiclassical gravity through entanglement generation are strongly constrained by acceleration noise.

References

[1] Großardt, A. Classically Gravitating Quantum Systems. in Do Wave Functions Jump? Perspectives of the Work of GianCarlo Ghirardi (eds. Allori, V., Bassi, A., Dürr, D. & Zanghi, N.) 259–268 (Springer International Publishing, 2020).

[2] Großardt, A. Acceleration noise constraints on gravity-induced entanglement. Phys. Rev. A **102**, 040202(R) (2020).

Theoretical frameworks for quantum gravity phenomenology below the Planck scale

G. Gubitosi[1]

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The Planck energy is generally considered as the scale where quantum gravitational effects become important. Given that such scale is much larger than the energies that we can directly access in experiments, it has been thought for a long time that the possibility to find experimental clues of quantum gravity is hopeless. In this talk I will argue that this is not the case, since opportunities for experimental tests of quantum gravity arise in physical frameworks much below the Planck scale. In such frameworks the key is to identify some mechanism which amplifies the tiny residual quantum gravity signatures at low energies. I will provide a few examples of such "amplifiers". Motivated by the potential for the phenomenological applications just discussed, I will describe theoretical frameworks for quantum gravity that take a bottom-up approach. Instead of trying to build a full quantum gravity theory, these approaches are aimed at modelling possible quantum gravity features that are relevant for physics below the Planck scale. Notable examples are effective field theories, which model Lorentz symmetry breaking, and doubly special relativity models, which deform the Poincaré transformations linking inertial observers.

Infinite energies in near-horizon particle collisions

E. Hackmann[1], H. Nandan[2,3] and P. Sheoran[4]

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[2] Department of Physics, Gurukul Kangri Vishwavidyalaya, Haridwar, India
[3]Center for Space Research, North-West University, Mafikeng, South Africa
[4] Instituto de Física y Matemáticas, Universidad Michoacana de San Nicolás de Hidalgo, Morelia, Michoacán, México

The occurence of infinite center of mass energies in particle collisions close to the horizon of an extremal Kerr black hole was first presented by Banados, Silk and West (BSW) in 2009. For their scenario, the rotation and the extremality of the black hole are key factors. Since their seminal paper, this phenomenon was studied for a large variety of spacetimes and for different particle setups. Here, we focus on static and spherically symmetric spacetimes and on a slightly different scenario than BSW. In particular, we discuss the physical feasability of infinite energies in our setup for both geodesic and spinning particles.

Testing the Kerr hypothesis: the examples of synchronisation and scalarisation

C. Herdeiro

[1]*Aveiro University and CIDMA, Aveiro, Portugal*

The Kerr hypothesis is that astrophysical black hole candidates are very special objects, with only two degrees of freedom and well described by the Kerr metric. Theoretically, this hypothesis is based on the uniqueness theorems for electro-vacuum. But in the presence of other types of matter or modified gravity are there any viable alternatives? In this talk I will illustrate some examples of black holes with "hair" that could co-exist with Kerr black holes, but emerge dynamically (and be preferred) at particular scales, either in General Relativity with ultralight bosonic matter or in modified gravity with higher curvature corrections, commenting on their theoretical and phenomenological differences (e.g. shadows) and on their phenomenological viability. In particular I will discuss some of the recent developments [1,2].

References

1. N. Sanchis-Gual, M. Zilhão, C. Herdeiro, F. Di Giovanni, J. A. Font and E. Radu, ``Synchronized gravitational atoms from mergers of bosonic stars'', Phys. Rev. D **102,**101504 (2020), [arXiv:2007.11584 [gr-qc]].
2. C. A. R. Herdeiro, E. Radu, H. O. Silva, T. P. Sotiriou and N. Yunes, ``Spin-induced scalarized black holes,'' Phys. Rev. Lett. (2020) in press [arXiv:2009.03904 [gr-qc]].

Testing gravity with matter wave interferometry

S. Herrmann[1], for the QUANTUS and PRIMUS teams

[1] *ZARM, University Bremen, Am Fallturm 2, 28359 Bremen, Germany*

Interferometry with cold atoms has seen a rapid technological progress in recent years. A lot of this work has been driven by the prospect to use such quantum sensors for practical purposes such as in Earth observation or navigation. But at the same time, addressing fundamental physics questions, in particular in new and improved precision tests of gravity, has been an important driver for these efforts as well.

In my talk I will present some of the recent progress in this field, with some focus on the work at the drop tower in Bremen, where we are implementing and testing concepts for matter wave interferometers in extended free fall and in space. Based on this, I will then address the question how such quantum sensors could help us to obtain new or improved tests of gravity.

Perturbative methods in modified gravity theories

Manuel Hohmann[1]

[1] *Laboratory of Theoretical Physics, Institute of Physics, University of Tartu, W. Ostwaldi 1, 50411 Tartu, Estonia*

A number of phenomenological studies of gravity are based on perturbation theory. Among the most commonly used frameworks are the post-Newtonian approximation in Solar system and binary dynamics, cosmological perturbation theory and quasinormal modes of black holes or other compact objects. In the context of general relativity, these approaches comprise of a perturbative expansion of the metric tensor, which mediates the gravitational interaction via the geometry of spacetime, around a known, usually highly symmetric background solution. Also in various modified gravity theories, in which additional scalar or higher rank tensor fields are employed in the description of gravity, this general scheme is retained.

More general theories of gravity, however, break with this paradigm of the metric tensor as the fundamental field mediating gravity (possibly aside other tensor fields): Metric-affine gravity theories [1] are based on an affine connection in addition to the metric, hence not a tensor field. Teleparallel theories of gravity [2] use flat affine connections, and may employ a tetrad instead of the metric as the fundamental gravitational field variable. Finally, gravity theories which model Lorentz violation and appear as effective models of quantum gravity make use of Finsler, Lagrange or Hamilton geometry on the tangent or cotangent bundle [3]. These more generalized geometric descriptions of gravity theories therefore also require an adapted perturbative treatment.

In my talk I will discuss different perturbative frameworks in the context of modified gravity theories, which use geometric descriptions beyond the metric paradigm. A particular emphasis will be on the post-Newtonian [4] and cosmological perturbation [5] methods, and on the teleparallel class of gravity theories.

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[2] J. B. Jiménez, L. Heisenberg and T. S. Koivisto, Universe **5** (2019) 173 [arXiv:1903.06830 [hep-th]].

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[4] M. Hohmann, Phys. Rev. D **101** (2020) 024061 [arXiv:1910.09245 [gr-qc]].

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Constraints on modified gravity from Casimir force experiments

Galina L. Klimchitskaya

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The corrections to Newtonian gravity of Yukawa type at short separations are predicted from the exchange by light or massless elementary particles between atoms of two macrobodies and from the unification schemes with the low-energy compactification scale. In this lecture, we discuss the constraints on the Yukawa-type corrections to Newton's gravitational law and on the coupling constants of axionlike particles to nucleons following from the recently performed experiments of Casimir physics. It is shown that the most precise measurements of the Casimir force and its gradient lead to the strongest laboratory constraints on the Yukawa interaction for shorter than a few micrometers interaction range and on the axion-to-nucleon coupling in the interval of axion masses from 1 meV to a few eV. These constraints are compared with the other laboratory limits. Possible improvements due to minor modifications in the experimental setups are considered. The special attention is paid to the recently obtained strong constraints on both the Yukawa-type correction to Newtonian gravity and on the coupling constants of axionlike particles with nucleons which follow from measuring the Casimir force between a Au-coated microsphere and a silicon carbide plate performed at separations of about ten nanometers [1].

References

[1] G. L. Klimchitskaya, P. Kuusk, and V. M. Mostepanenko, Constraints on non-Newtonian gravity and axionlike particles from measuring the Casimir force in nanometer separation range, Phys. Rev. D vol. 101, 056013 (2020).

M-theory and the birth of the Universe

F. R. Klinkhamer[1]

[1]*Institute for Theoretical Physics, Karlsruhe Institute of Technology, Karlsruhe, Germany*

The IIB matrix model has been suggested as a a particular formulation of nonperturbative superstring theory (M-theory). It has now been realized that an emerging classical spacetime must reside in its large-N master field. The master field of the Lorentzian IIB matrix model can, in principle, give rise to the regularized-big-bang metric of general relativity. The length parameter of the regularized-big-bang metric is then calculated in terms of the IIB-matrix-model length scale.

Compact objects in alternative theories of gravity

J. Kunz

Institute of Physics, University of Oldenburg, Germany

Compact astrophysical objects such as black holes and neutron stars allow us to study the effects of strong gravity, providing tests of Einstein's General Relativity and alternative theories of gravity, when comparison with observations can be made, since alternative theories of gravity may predict distinctly different properties for black holes and neutron stars, like hair or spontaneous scalarization. Also quasi-normal mode analysis of such compact objects leads to distinct predictions for their ring-down to be scrutinized by future gravitational wave observations.

How does a dark compact object ringdown?

E. Maggio[1], L. Buoninfante[2], A. Mazumdar[3] and P. Pani[1]

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Gravitational waves from the coalescence of compact binaries provide a unique opportunity to test gravity in strong field regime. In particular, the postmerger phase of the gravitational signal is a proxy for the nature of the remnant.
This is of particular interest in view of some quantum-gravity models which predict the existence of horizonless compact objects that overcome the paradoxes associated to black holes. Such dark compact objects can emit a modified ringdown with respect to the black hole case and late-time gravitational wave echoes as characteristic fingerprints.
In this talk, I develop a generic framework to the study of the ringdown of dark compact objects and provide a gravitational-wave template for the echo signal. Finally, I assess the detectability of dark compact objects with current and future gravitational-wave detectors.

References

[1] E. Maggio, L. Buoninfante, A. Mazumdar, P. Pani, *Phys.Rev.D* **102** (2020) 6, 064053
[2] E. Maggio, A. Testa, S. Bhagwat, P. Pani, *Phys.Rev.D* **100** (2019) 6, 064056
[3] E. Maggio, V. Cardoso, S. Dolan, P. Pani, *Phys.Rev.D* **99** (2019) 6, 064007
[4] E. Maggio, P. Pani, V. Ferrari, *Phys.Rev.D* **96** (2017) 10, 104047

Gravitational Anomalies, Primordial Gravitational Waves and Spontaneous Lorentz-symmetry Violation: from Inflation to Matter-Antimatter Asymmetry

N.E. Mavromatos[1]

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I discuss the generation of primordial gravitational waves (GW), in a pre-inflationary era of a string-inspired model for the Universe, their condensation in the presence of Gravitational Anomalies (of Chern-Simons type) and the induction of a dynamical inflation, without external inflatons, of the type encountered in the so-called running-vacuum-model of cosmology. The GW condensate leads to backrounds for the axion field in the massless gravitational multiplet of the string, which violate spontaneously the Lorentz (and CPT) symmetry of the ground state. Such backgrounds remain undiluted at the exit of inflation, and lead to Lorentz-Violation-induced matter-antimatter asymmetry, via leptogenesis and subsequent baryogenesis during the radiation era in models that contain right-handed neutrinos. Some phenomenological consequences of this approach relevant for the current era of the Universe are briefly discussed.

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Title: Witnessing Quantum gravity in a laboratory via miniaturist quantum accelerator

Abstract: Unveiling the nature of spacetime remains one of the final frontiers of modern theoretical physics. I will discuss how to witness the quantum nature of gravity in a table-top experiment by creating the right witness involving the two neutral masses (spin embedded) undergoing through the Stern-Gerlach apparatus. I will discuss various challenges involved in pursuing the dream of witnessing graviton and the critical challenges. There are many challenges to be met and I will discuss the important ones:

1. To create a macroscopic quantum superposition of heavy masses via the Stern-Gerlach setup while controlling the stray gravitational acceleration and the gravity gradient noise.
2. Precise constraints on the magnetic field/current such that various electromagnetic interactions are under control.
3. Vacuum dominated Casimir effect which will create the main background for the experiment.
4. Constraints on vacuum and temperatures.
5. Feasibility of the experiment in a drop-tower.
6. The material properties and patch potentials.

I will briefly discuss time scales for realising such an accelerator which will witness for the first time the graviton in a terrestrial laboratory.

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Clock dependent features in quantum cosmology

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We study the quantum cosmology of a flat FLRW universe filled with a (free) massless scalar field and a perfect fluid. With the appropriate change of variables, the theory has the same dynamics independently of the choice of perfect fluid; we choose a dark energy. We quantise the theory with respect to three different relational clocks: the coordinate conjugated to the cosmological constant, named *t*, the massless field, and a coordinate proportional to the logarithm of the scale factor cube, $\log a^3$. All theories have different dynamics and lead to different results regarding singularity resolution. The clock *t* theory achieves some sort of singularity resolution. Divergence from the classical theory is also observed in the field clock theory, however this theory is inequivalent to the previous. Unlike the two previous theories, the last theory contains semiclassical states that follow classical trajectories and evolve into the singularity without obstruction, thus showing no singularity resolution. We illustrate the properties and specificities of each theory, comparing them where possible. This model is a good illustration of the problem of time in quantum cosmology and clock changes.

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The theory of the Casimir effect

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The van der Waals and Casimir forces which arise between two closely spaced material bodies due to the zero-point and thermal fluctuations of the electromagnetic field are described by the Lifshitz theory. A lot of precise measurements of the Casimir force performed during the last two decades revealed a puzzle. The theoretical predictions have been found in agreement with the measurement data only under a condition that in computations one disregards the relaxation properties of conduction electrons for metals and the dc conductivity for dielectrics. On the theoretical side, it was found that if both these effects are included in computations, one arrives to contradictions of the Lifshitz theory with thermodynamics. Taking into account that the measure of agreement between theoretical predictions and the measurement data for the Casimir force is used for obtaining constraints on the hypothetical objects of quantum gravity, the resolution of this puzzle is of much importance. The lecture elucidates the present status of this problem including a very recent approach [1] which brings the Lifshitz theory to agreement with the measurement data of the Casimir interaction between metallic plates and with the requirements of thermodynamics taking due account of the relaxation properties of conduction electrons.

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Poincaré gauge gravity: Recent developments

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Poincaré gauge (PG) gravity theory offers a physically meaningful extension of Einstein's general relativity (GR) to the case when the spin of matter is consistently treated as a source of the gravitational field along with the mass of matter. The fundamental particles are classified by mass and spin in the representation theory of the Poincaré group which is a semidirect product of the translation group with the Lorentz group. In the framework of the Yang-Mills-Kibble-Utiyama field-theoretic approach, the Poincaré gauge gravitational potentials are identified with the coframe and the local Lorentz connection.

An overview of the recent developments in PG gravity is presented, with a special focus on the fundamental issues of the validity of the equivalence principle, Lorentz and parity symmetry. We demonstrate that GR can be consistently recovered in the PG approach. To probe the possible post-Riemannian deviations of the spacetime geometry one needs to use the test particles and bodies with spin. We analyse the spin dynamics in PG and discuss the present status and the prospects of the experimental testing of the Poincaré gauge gravity.

Confronting Finsler spacetime theory with observations

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Finsler geometry is a modification of pseudo-Riemannian geometry by which spatial isometry is being violated already ''in infinitesimally small regions'', i.e., on the tangent space. Some approaches to quantum gravity suggest a Finsler modification of spacetime theory. Moreover, the Ehlers-Pirani-Schild axiomatic approach to spacetime theory gives additional strong motivations for considering such a modification: If one just relaxes a differentiability condition in one of the axioms one arrives at a Finsler spacetime. In the first part of this talk I discuss the axiomatic foundation of Finsler spacetime theory, in the second part I give an overview on the bounds that can be placed on Finsler deviations from standard (general) relativity on the basis of observations and experiments. The strongest bounds come from laboratory experiments, e.g. from atom spectroscopy; much weaker bounds are found from Solar system tests and from cosmology.

Optimal estimation of time-dependent gravitational fields and constraints of modified gravity with non-linear quantum optomechanical sensors

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We study the fundamental sensitivity that can be achieved with an ideal optomechanical system in the nonlinear regime for measurements of time-dependent gravitational fields. Using recently developed methods to solve the dynamics of a nonlinear optomechanical system with a time-dependent Hamiltonian, we compute the quantum Fisher information for linear displacements of the mechanical element due to gravity. We demonstrate that the sensitivity can not only be further enhanced by injecting squeezed states of the cavity field, but also by modulating the light–matter coupling of the optomechanical system. We specifically apply our results to the measurement of gravitational fields from small oscillating masses, where we show that, in principle, the gravitational field of an oscillating nano-gram mass can be detected based on experimental parameters that will likely be accessible in the near-term future. Furthermore, we examine the parameter regime of a Yukawa-like modification to Newtonian gravity that can be excluded with quantum optomechanical sensors in the non-linear regime.

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Towards a geometrical interpretation of rainbow geometries for quantum gravity phenomenology

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In this talk, I will consider a deformed kinematics that goes beyond special relativity as a way to account for possible low-energy effects of a quantum gravity theory that could lead to some experimental evidences. This can be done while keeping a relativity principle, an approach which is usually known as doubly (or deformed) special relativity. In this context, I will give a simple geometric interpretation of the deformed kinematics and explain how it can be related to a metric in maximally symmetric curved momentum space [1]. Moreover, this metric can be extended to the whole phase space, leading to a notion of spacetime [2]. Also, this geometrical formalism can be generalized in order to take into account a space-time curvature, leading to a momentum deformation of general relativity [2]. I will explain theoretical aspects [3] and possible phenomenological consequences [4] of such deformation.

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Testing gravity with pulsars

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Einstein's general relativity has passed enormous tests with flying colours, ranging from the Solar System, binary pulsars, gravitational waves, to cosmology. Binary pulsars, being in a strong-field regime with quasi-stationary orbital motion, are excellent testbeds for multiple aspects of gravitation. I will introduce the pulsar-timing techniques that have enabled the various tests, and highlight a few cases where binary pulsars have played an essential role, in particular where strong gravity has significantly impacted the inner structure of neutron stars. Even when assuming a perturbative approach, we can still use binary pulsars to probe quite a few unique aspects, which will be revealed in an effective-field-theoretic framework.

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Boson Constellations

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We study new families of stationary rotating soliton stars in a complex scalar field theory minimally coupled to Einstein gravity. We show, by explicitly constructing the solutions of fully non-linear Einstein-Klein-Gordon model in three spatial dimensions, that boson stars, composed of a single complex scalar field, can have a non-trivial multipolar structure, yielding the same morphologies for their energy density as those that elementary hydrogen atomic orbitals have for their probability density. The multipolar boson stars can be interpreted as individual bosonic lumps in equilibrium without any continuous symmetries.

Dynamics of Screening in Modified Gravity

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Gravitational theories differing from General Relativity may explain the accelerated expansion of the Universe without a cosmological constant. However, their viability crucially depends on a "screening mechanism" needed to suppress, on small scales, the fifth force driving the cosmological acceleration. I will discuss a scalar-tensor theory with first-order derivative self-interactions exhibiting such a mechanism, and present screened solutions in this theory for both non-relativistic and relativistic stars. Then, I will discuss the stability of these solutions and present our results from numerically evolving them in the strong-field, highly dynamical regime.

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Recent limits on Lorentz invariance violation using gamma rays

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Certain candidates for the theory of quantum gravity allow violation or deformation of the Lorentz symmetry. This phenomenon, usually referred to as Lorentz invariance violation (LIV), is often modelled by introducing energy-dependent corrections to the standard photon dispersion relation. Modifying terms are expected to be significant at the scale of the Planck energy, and affect photon propagation and interaction. Unfortunately, these effects are vastly below sensitivities of present-day laboratories. However, gamma rays of very high energies, commonly emitted from astrophysical sources, cover astronomical distances on their way to Earth. During this time, the minuscule effects of LIV could sufficiently accumulate to be measured in gamma-ray observatories.

In this talk, possible effects of LIV on gamma rays will be reviewed, as well as recent attempts at measuring them. The usual methods of data analysis for tests of LIV will be presented. We will compare and comment on the most prominent results.

Probing new physics by levitated mechanical systems

Hendrik Ulbricht

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I will report on our recent progress with levitated experiments, especially with Meissner levitated ferromagnets above a type-1 superconductor. We find a system with ultralow mechanical damping showing great potential for sensing tiny forces [1] and, interestingly, independent from the standard quantum limit - which holds promise to detect record low magnetic fields and we discuss ideas for a ferromagnetic gyroscope [2], where the precession motional degree of freedom is used to sense tiny magnetic fields. We also discuss how other rotational degrees of freedom can be used for inertial and force detection. We apply force noise measurements to bound collapse models to test the quantum superposition principle in the macroscopic domain of large mass systems [3, 4]. We illustrate ideas to used levitated mechanical systems to probe into gravity interactions leading toward the experimental exploration of the interplay between quantum mechanics and gravity [5]. We also mention ideas to probe into the physics of quantum field theory effects in non-inertial reference frames based on spinning micro-particles [6, 7].

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Supersymmetric Quantum Cosmology

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Supersymmetric extensions of the Friedmann equation with additional bosonic and fermionic degrees of freedom admit a Dirac-like square root. This equation can be solved in specific non-trivial backgrounds.

Zombie alert! Solar system tests of GR are still alive

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We have entered an era of testing general relativity in the strong-field, dynamical regime, using gravitational wave detections, direct observations of neutron stars and black holes, and cosmological observations. Yet, like the zombies of cinema, solar system tests continue to trudge along, adding new and interesting constraints on gravitational theories, while fortunately not devouring everything in their wakes. In this talk, we review some recent results, including tests of the equivalence principle using the MICROSCOPE and Galileo satellites, a test of light bending performed by an amateur astronomer, new bounds on frame dragging from the LAGEOS/LARES satellites, and a bound on the graviton mass from solar system ephemeris data. We also describe future tests that could come from the BepiColombo Mercury orbiters, the ACES clock experiment on the Space Station, and from the GAIA astrometry satellite.

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Abstracts of Posters

(in alphabetical order)

Testing Universal Compton Clocks Using Clock Interferometry

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It is believed that internal energy superposition states of massive particles contribute which-way information in gravitational interferometry experiments. The reason is that the internal states act as clocks, and desynchronize due to gravitational time dilation between the interferometer paths [1, 2]. We apply this proposal to an extreme case, where the frequency of the internal clock matches the particle's Compton frequency $\omega_{\mathrm{C}} = mc^2/\hbar$. We show that such clocks would produce interference patterns inconsistent with experimental data such as [3]. This demonstrates the ability of gravitational interferometry experiments to restrict the existence of mass superposition states generally, and gives interesting new perspectives on quantum clocks, the clock interferometry effect, and mass-energy equivalence in quantum mechanics.

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Holonomy and inverse-triad corrections in spherical models coupled to matter

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One of the main aspects a quantum theory of gravity must face is that regarding the singularities of general relativity. The discrete nature of spacetime predicted by loop quantum gravity may provide an answer to this problem. This theory introduces two characteristic modifications in the classical constraints of general relativity: holonomy and inverse-triad corrections. Following [1], a systematic construction of anomaly-free effective constraints encoding such corrections is developed for spherically symmetric spacetimes. As the starting point of the analysis, we take a generic Hamiltonian constraint where free functions of the triad and curvature components as well as non-minimal couplings between geometric and matter degrees of freedom are considered. Then, the requirement of anomaly freedom is imposed in order to obtain a modified Hamiltonian that forms a first-class algebra. In this way, we construct a family of deformations of spherical general relativity that respects the general covariance of the theory. The discussed procedure is implemented for vacuum and for two matter models: dust and scalar field. Although the specific details are yet to be worked out, the deformed Hamiltonians are expected to modify the dynamics predicted by general relativity, for instance, in astrophysical scenarios such as gravitational collapse.

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Probing of exotic quantum states in heavy ion collisions

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The spectroscopy of charmonium-like mesons with masses above the $2m_D$ open charm threshold has been full of surprises and remains poorly understood [1]. The currently most compelling theoretical descriptions of the mysterious *XYZ* mesons attribute them to hybrid structure with a tightly bound $c\bar{c}$ diquark [2] or $cq\bar{c}\bar{q}'$ tetraquark core [3 - 5] that strongly couples to S-wave $D^{(*)}\bar{D}^{(*)}$ molecular like structures. In this picture, the production of a *XYZ* states in high energy hadron collisions and its decays into light hadron plus charmonum final states proceed via the core component of the meson, while decays to pairs of open-charmed mesons proceed via the $D^{(*)}\bar{D}^{(*)}$ component. These ideas have been applied with some success to the *XYZ* states [2], where a detailed calculation finds a $c\bar{c}$ core component that is only above 5% of the time with the $D\bar{D}^{(*)}$ component (mostly $D^{(0)}\bar{D}^{(*0)}$) accounting for the rest. In this picture these states are compose of three rather disparate components: a small charmonium-like $c\bar{c}$ core with $r_{rms} < 1$ fm, a larger $D^{(+)}D^{(*-)}$ component with $r_{rms} = \hbar/(2\mu_+ B_+)^{1/2} \approx 1.5$ fm and a dominant component $D^{(0)}\bar{D}^{(*0)}$ with a huge, $r_{rms} = \hbar/(2\mu_0 B_0)^{1/2} > 9$ fm spatial extent. Here $\mu_+(\mu_0)$ and $B_+(B_0)$ denote the reduced mass for the $D^{(+)}D^{(*-)}$ ($D^{(0)}\bar{D}^{(*0)}$) system and the relevant binding energy $|m_D + m_{D^*} - M_{X(3872)}|$ ($B_+ = 8.2$ MeV, $B_0 < 0.3$ *MeV*). The different amplitudes and spatial distributions of the $D^{(+)}D^{(*-)}$ and $D^{(0)}\bar{D}^{(*0)}$ components ensure that the *X(3872)* is not an isospin eigenstate. Instead it is mostly $I = 0$, but has a significant (~ 25 %) $I = 1$ component. In the hybrid scheme, *XYZ* mesons are produced in high energy proton-nuclei collisions via its compact ($r_{rms} < 1$ fm) charmonium-like structure and this rapidity mixes in a time (t ~ $\hbar/\delta M$) into a huge and fragile, mostly $D^{(0)}\bar{D}^{(*0)}$, molecular-like structure. δM is the difference between the *XYZ* mass and that of the nearest $c\bar{c}$ mass pole core state, which we take to be that of the $\chi_{c1}(2P)$ pure charmonium state which is expected to lie about 20 ~ 30 MeV above $M_{X(3872)}$ [6]. In this case, the mixing time, $c\tau_{mix}$ 5 ~ 10 fm, is much shorter than the lifetime of *X(3872)* which is $c\tau_{X(3872)} > 150$ fm. The experiments with proton-proton and proton-nuclei collisions with $\sqrt{S_{pN}}$ up to 26 Gev and luminosity up to 10^{32} cm^{-2}s^{-1} planned at NICA may be well suited to test this picture for the *X(3872)* and, possibly, other *XYZ* mesons. In near threshold production experiments in the $\sqrt{S_{pN}} \approx 8$ GeV energy range, *XYZ* mesons can be produced with typical kinetic energies of a few hundred MeV (i.e. with $\gamma\beta \approx 0.3$). In the case of *X(3872)*, its decay length will be greater than 50 fm while the distance scale for the $c\bar{c} \to D^{(0)}\bar{D}^{(*0)}$ transition would be 2 ~ 3 fm. Since the survival probability of an r_{rms} ~ 9 fm "molecular" inside nuclear matter should be very small, *XYZ* meson production on a nuclear target with r_{rms} ~ 5 fm or more (A ~ 60 or larger) should be strongly quenched. Thus, if the hybrid picture is correct, the atomic number dependence of *XYZ* production at fixed $\sqrt{S_{pN}}$ should have a dramatically different behavior than that of the ψ', which is long lived compact charmonium state. The current experimental status of *XYZ* mesons together with hidden charm tetraquark candidates and present simulations what we might expect from *A*-dependence of *XYZ* mesons in proton-proton and proton-nuclei collisions are summarized.

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Relativistic Effects on Continuous Variable Quantum Key Distribution

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The laws of Quantum Mechanics not only have far-reaching scientific and philosophical implications on our conceptual understanding of nature, but are also the foundation of many different everyday and cutting-edge technologies, such as the unconditional secure exchange of information between two parties usually termed Quantum Key Distribution (QKD). The huge recent progress in the experimental realization of QKD [1,2,3] enforces the discussion of the future vision of a globally operating network of satellites and ground stations exchanging information unconditionally secure over hundreds and thousands of kilometers. In these scenarios not only the influence of the atmosphere distorts the distribution of information, but also general and special relativistic effect become relevant. In this contribution the focus lies on Continuous Variable Quantum Key Distribution (CVQKD), where the quantum information is encoded in continuous degrees of freedom of the employed quantum resources. This is because CVQKD might be beneficial compared to its discrete variable counterpart (DVQKD) regarding the secret key rates over long distances [4]. The contribution shows how the gravitational red shift and the special relativistic Doppler-Effect affect the secret key rates between satellites and ground stations and shows the limitation of the secret key rates due to these relativistic effects under the usage of current state of the art technology.

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Viability of teleparallel theories of gravity

Daniel Blixt

Abstract

Conventionally general relativity is described in terms of curvature which depends on the Levi-Civita connection. Modified theories of gravity such as $f(R)$ have been proposed to challenge general relativity. These modified theories of gravity can be motivated by explaining observations, such as describing inflation where $f(R)$ for instance have been very successful. Even though general relativity normally is described by the Levi-Civita connection there are alternative but equivalent formulations where a flat (zero curvature) connection is used. If curvature is assumed to be zero but torsion is non-vanishing one may formulate a theory named "teleparallel equivalent to general relativity". With this formulation of general relativity as a starting point one may end up with modified theories of gravity very different from curvature-based theories such as $f(R)$. Gravity theories based on a flat connection are called teleparallel theories of gravity. The 2 most simple and popular teleparallel gravity theories are called "new general relativity" and $f(T)$. In this poster I will present the status of the viability of these theories based on results from their Hamiltonian analysis and from perturbation theory.

Challenging general relativity using the temperature of galactic dark matter halos

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The proportions of observed light elements from the Big Bang nucleosynthesis (BBN) place a tight constraint on the expansion profile of the universe. If dark matter (DM) is proved to be light, a GR-based cosmology, due to its dependence on the radiation content of the universe, cannot explain the BBN observations.
We place an upper bound on the mass of DM by arguing that its temperature cannot be negative. To find the upper bound, we analyze the observations of more than hundreds of late-type galaxies.
We assume that (1) the corresponding halos are stable and Virialized, and (2) DM in them obeys either the Fermi-Dirac or the Maxwell-Boltzmann distributions. We show that the mass to the temperature of DM in the outer regions of these halos is galaxy-independent. The universality of this temperature suggests that it is set at the freeze-out in the early universe. Using the latter, we show that the mass of DM is in the range of $10\ \text{eV} < m < 100\ \text{eV}$.

Position in models of quantum mechanics with a minimal length

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Quantum mechanical models with a minimal length are often described by modifying the commutation relation between position and momentum. One first consequence is that position eigenstates are not included in such models due to the presence of a minimal uncertainty in position. Furthermore, depending on the particular modification of the position-momentum commutator, when such models are considered from momentum space, the position operator is changed and a measure factor appears to let the position operator be self-adjoint. Although such modifications in momentum space represent small complication, at least formally, the (quasi-)position representation acquires numerous issues, source of misunderstandings. In fact, such representation is formally similar to that in which states are described in terms of Gaussian states in standard quantum mechanics. Consequently, the position operator is no longer a multiplicative operator and the momentum of a free particle does not correspond directly to its wave-number, with a consequent modification of the de Broglie relation.
Here, I review such issues, clarifying some of the aspects of minimal length models, with particular reference to the representation of the position operator. Furthermore, I show how such a (quasi-)position description of quantum mechanical models with a minimal length affects results concerning simple systems, resulting in new effects and noteworthy.

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BMS algebras in 4 and 3 dimensions, their quantum deformations and duals

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BMS symmetry is a symmetry of asymptotically flat spacetimes in vicinity of the null boundary of spacetime and it is expected to play a fundamental role in physics. It is interesting therefore to investigate the structures and properties of quantum deformations of these symmetries, which are expected to shed some light on symmetries of quantum spacetime. This poster presents the structure of the algebra of extended BMS symmetries in 3 and 4 spacetime dimensions, focussing on the recently uncovered fact [1,2] that these algebras contain an infinite number of distinct Poincaré subalgebras. Then we use these subalgebras to construct an infinite number of different Hopf algebras which are quantum deformations of the BMS algebras. We also discuss different types of twist-deformations and the dual Hopf algebras, which could be interpreted as noncommutative, extended quantum spacetimes.

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Experimental gravity with electromagnetic and gravitational waves

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Observations of black holes through the electromagnetic and gravitational spectrum have been used to understand their nature and the fundamental properties of the material in their vicinity. Our ability to learn about the underlying physics, however, depends heavily on our understanding of the gravity theory that describes the geometry around these compact objects, and for the electromagnetic observations, also on the complex astrophysics that produces the observed radiation. In this work, we study our current ability to constrain and detect deviations from general relativity using (i) the electromagnetic radiation emitted by an accretion disk around a black hole, and (ii) the gravitational waves produced when comparable-mass black holes collide, and when a small compact object falls into a supermassive one in an extreme mass-ratio inspiral. Our analysis combines relativistic ray-tracing and Markov-Chain Monte-Carlo sampling techniques, as well as analytical and numerical calculations of the geodesic motion of test particles. On the electromagnetic side, we found that even when a simple astrophysical model for the accretion disk is assumed a priori, the uncertainties, and covariances between the parameters of the model and the parameters that control the deformation from general relativity, make any test of general relativity very challenging with current accretion disk spectrum observations. On the gravitational wave side, we quantified the importance of geodesic chaos in the generation of gravitational waves, and place constraints on deformations of classical solutions. Moreover, we also compared the constraining capabilities of these two types of observations and find that current gravitational wave observations have already placed constraints on possible modifications to general relativity than are more stringent than what can be achieved with current and future electromagnetic observations.

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Multiverse in the asymptotically safe inflation

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The inflationary paradigm explains why the universe is homogeneous, flat, and isotropic. Furthermore, inflaton fluctuations in the early universe are a seed of the large structure formation. In his recent work [1], Tom Rudelius showed that quantum fluctuations of the scalar field may drive the inflation eternally. Eternal inflation produces scattered pockets of causally disconnected universes, known as the multiverse, that we are unable to directly detect. It is reasonable to impose the "no eternal inflation principle", which restricts values of the free parameters and initial conditions of the inflationary model.
The CMB data and the eternal inflation considerations suggest that the initial value of the inflaton is above one Planck Mass. At superplanckian scales, some form of UV-completion is necessary to investigate the quantum gravitational behavior of the system. Asymptotic Safety of quantum gravity based on the Functional Renormalization Group Equations and non-Gaussian fixed points provides a UV-complete theory. In our recent work [2] have found, that flatness of effective inflationary potentials stemming from various AS models induces eternal inflation. For a single vacuum potentials, direct numerical simulations agree with the analytical conditions for eternal inflation obtained in [1].
Furthermore, a new eternal inflation mechanism, based on quantum tunneling through the potential barrier was found. Models with multiple vacua such as [3] allow tunneling from a region that leads to the end of inflation, to the region dominated by classical eternal inflation. This phenomenon cannot be detected by the local, analytical framework developed in [1]. The numerical investigation, however, provides a probability distribution for eternal inflation around the maximum of the potential.

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Pattern for a star filled with imperfect fluid

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A static, spherically symmetric spacetime with negative pressures is conjectured inside a star. The gravitational field is repulsive and so a central singularity is avoided. The positive energy density and the pressures of the imperfect fluid are finite everywhere. The Tolman-Komar energy of the space is negative, as for a de Sitter geometry. From the Darmois-Israel junction conditions on the star surface one finds the constant length \$b\$ from the metric and the expression of the surface tension \$\sigma\$ of the thin shell separating the interior from the Schwarzschild exterior. Some properties of the timelike and null geodesics in the Painleve-Gullstrand coordinates are investigated.

Modified gravity theories as effective descriptions of quantum gravity: lessons and cautionary tales

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Modified gravity theories are often advocated as effective descriptions of quantum gravity. It is therefore important to identify common dynamical features in such theories, as well as possible shortcomings of specific models (e.g., with regard to singularity resolution).

First, I will focus on theories where the initial cosmological singularity is resolved and replaced by a non-singular bounce, and study the propagation of (shear) anisotropies through the bounce in Bianchi I. We showed in [1] that there is a large class of modified gravity theories where the evolution of anisotropies admits a simple and universal description, which can be formulated as algebraic transition rules between Kasner exponents in the pre- and post-bounce phases. This result generalizes previous findings in loop quantum cosmology and in mimetic gravity and shows the much broader extent of their applicability.

Next, I will focus on a version of mimetic gravity originally proposed by Mukhanov and Chamseddine; this resolves the initial singularity in FLRW models, and was also argued to resolve the singularity in the Schwarzschild black-hole interior (modelled as a Kantowski-Sachs spacetime). However, using dynamical system techniques to analyze the dynamics of Kantowski-Sachs model in this theory, we showed in [2] that there is no singularity resolution in this case. Furthermore, solutions cannot be matched to a null black-hole event horizon and, therefore, do not correspond to the interior of a static and spherically symmetric black hole. This is a cautionary example about the risks of extrapolating the black-hole interior/Kantowski-Sachs isometry beyond general relativity.

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The Cosmological Model Based on the Uncertainty-Mediated Dark Energy

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Existence of the effective Lambda-term is a commonly-accepted paradigm of the modern cosmology, but the physical essence of this quantity remains absolutely unknown by now, and its numerical values are drastically different in the early and modern Universe. In fact, the Lambda-term is usually introduced in the literature either by postulating the arbitrary additional terms in the Lagrangians or by employing the empirical equations of state.

In the series of recent papers [1–3], we tried to provide a more rigorous physical basis for the effective Lambda-term, starting from the time–energy uncertainty relation in the Mandelstam–Tamm form, which is appropriate for the long-term evolution of quantum systems. This results in the time-dependent Lambda-term, decaying as $1/t$. The corresponding uncertainty-mediated cosmological model possesses a number of specific features, some of which look rather appealing:

1. While the standard cosmology involves a few very different stages (governed by the Lambda-term, radiation, dust-like matter, and again Lambda-term), our model provides a universal description of the entire evolution of the Universe by the same “quasi-exponential” function.
2. As follows from the analysis of causal structure, the present-day cosmological horizon comprises a single domain developing from the Bing Bang. Therefore, the problems of homogeneity and isotropy of the matter, the absence of topological defects, *etc*. should be naturally resolved.
3. Besides, this model naturally explains the observed approximately flat 3D space, *i.e.*, solution with zero curvature is formed “dynamically”, starting from the arbitrary initial conditions.
4. The age of the Universe turns out to be much greater than in the standard cosmology; but this should not be a crucial drawback of the model, because the most of well-known problems in cosmology are associated with insufficient rather than excessive age of the Universe.

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Quantum approach to a Bianchi II singularity

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A quantum state in a Bianchi II model is studied in its approach to a cosmological singularity, by means of the evolution of its moments. Classically this system presents a transition between two Bianchi I models, with a specific and well-known transition law, which is derived based on the conservation of certain physical quantities. However, in the quantum theory fluctuations and quantum moments of higher order of the different variables arise, modifying these quantities and consequently the transition rule. We focus on the so-called locally rotationally symmetric (LRS) and vacuum cases, as a first step towards a more complete study. Indeed, the main goal is to generalize this analysis to the Bianchi IX spacetime, which can be seen as a succession of Bianchi II models. Ultimately, these results may lead to a better understanding of the role played by quantum effects in the BKL conjecture.

Big Bang Nucleosynthesis and running coupling constants

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Big Bang Nucleosynthesis is one of the main and few observational resources we have from the universe previous to the CMB epoch. We have obtained numerical results showing that the cosmological Lithium problem could be explained by letting the constants involved in the theory, mainly Newton's constant, have a value different from the one which is observed nowadays. We will discuss the possibility of explaining this behavior in the framework of running coupling constants in Quantum Field Theories/modified theories of Quantum Gravity.

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Quasi-Normal Modes(QNM) are a well-studied phenomenon in metric theories of gravity, where they can serve as "fingerprints" for a given space-time. They are therefore useful in searching for deviations from General Relativity(GR), particularly in cases where simpler techniques may fail to identify existing deviations. The current work begins by briefly describing what QNM are and how they are produced. This is followed by an explanation of their role in the search for evidence of modified gravity in the context of gravitational wave observations. The challenges associated with translating theoretical expectations into practical results are also described, as are possible resolutions to said challenges. Finally, we discuss the current relevance of QNM—with regard to testing for deviations from GR—in light of Advanced LIGO's detection of gravitational waves.

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The Scale Invariant Vacuum Theory as viable Cosmology Model

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Recent studies in applying the Weyl's original gauge symmetry idea within the framework of the Weyl's Integrable Geometry to modern observational data in cosmology has resulted in the Scale Invariant Vacuum (SIV) paradigm. A sequence of papers by Prof. André Maeder has shown that SIV is a viable contender to standard LamdaCDM model see [1] for recent review. It has been also shown that the growth of the density perturbations of the early universe can be modeled within SIV without the need of dark matter [2]. Furthermore, SIV has been able to explain the asymptotic limit of the Radial Acceleration Relation (RAR) in Dwarf Spheroidals better than MOND and Dark Matter models [3]. An overview of the SIV results will be summarized and discussed subject to the time constraints of the workshop.

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Relativistic effective action of dynamical gravitomagnetic tides for slowly rotating neutron stars

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Gravitomagnetic quasi-normal modes of neutron stars are resonantly excited by tidal effects during a binary inspiral, leading to a potentially measurable effect in the gravitational-wave signal. We take an important step towards incorporating these effects in waveform models by developing a relativistic effective action for the gravitomagnetic dynamics that clarifies a number of subtleties. Working in the slow-rotation limit, we first consider the post-Newtonian approximation and explicitly derive the effective action from the equations of motion. We demonstrate that this formulation opens a novel way to compute mode frequencies, yields insights into the relevant matter variables, and elucidates the role of a shift symmetry of the fluid properties under a displacement of the gravitomagnetic mode amplitudes. We then construct a fully relativistic action based on the symmetries and a power counting scheme. This action involves four coupling coefficients that depend on the internal structure of the neutron star and characterize the key matter parameters imprinted in the gravitational waves. We show that, after fixing one of the coefficients by normalization, the other three directly involve the two kinds of gravitomagnetic Love numbers (static and irrotational), and the mode frequencies. We discuss several interesting features and dynamical consequences of this action, and analyze the frequency-domain response function (the frequency-dependent ratio between the induced flux quadrupole and the external gravitomagnetic field), and a corresponding Love operator representing the time-domain response. Our results provide the foundation for deriving precision predictions of gravitomagnetic effects, and the nuclear physics they encode, for gravitational-wave astronomy.

Randers pp-waves

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In this work we study Randers spacetimes of Berwald type and analyze Pfeifer and Wohlfarth's vacuum field equation of Finsler gravity for this class. We show that in this case the field equation is equivalent to the vanishing of the Finsler Ricci tensor, analogously to Einstein gravity. This implies that the considered vacuum field equation and Rutz's equation coincide in this scenario. We also construct all exact solutions of Berwald-Randers type to vacuum Finsler gravity, which turn out to be composed of a CCNV (covariantly constant null vector) Lorentzian spacetime, commonly known as pp-wave, and a 1-form given by the pp-wave distinguished null vector. We therefore refer to the found solutions as Randers pp-waves.

Can the viability of f(R) theory of gravity can explain the nature of dark energy?

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From 1990 onwards, the breakthrough discovery of mysterious dark energy got cosmology into a completely new era. As per physicists, this so called hypothetical form of energy has negative pressure and is responsible for the accelerated expansion of the universe. To explain the nature of this hypothetical form of energy, various kinds of multiple theories are being proposed, from modified theories of gravity to scalar field theories to dynamical cosmological constant theory and many more, to explain the mysterious nature of dark energy. From the past two decades, infinite number of theories have been proposed by the community of physicists. To limit these infinitely many theories and to consider a viable candidate among these theories, physicists proposed a fundamental requirement known as ‘precision test’ according to which a theory will be considered viable if the predictions made by the theory is tested by comparison of prediction with experimental data and the theory should be consistent on all scales.

Considering this, I will discuss one such theory known as f(R) theory of modified gravity. I will begin with precision tests, in general, then, I will discuss about the viability of f(R) theory of gravity related to the precision tests, accompanied by its status so far. Then, I will try to answer how f(R) theory of modified gravity can be used to explain the nature of dark energy. Finally, I will conclude with the future perspective of f(R) theory of modified gravity from the lens of dark energy, accompanied by a possibility, to go beyond this approach.

Cosmological Features of the Extended Quasi-Dilaton Massive Gravity Theory

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Firstly, we introduce the quasi-dilaton massive gravity theory which is extended by new terms and we indicate our motivations for this research. Moreover, we obtain the point like Lagrangian and it should be mentioned that according to our cosmological application purpose we adopt the FLRW universe. In the following stage, we calculate the Friedman and constraint equations for this theory. Also, we analysis self-accelerating background solutions with use of Stueckelberg constraint. Finally, in this presentation, we illustrate the cosmological features of the theory elaborately.

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Dark energy after GW170817 revisited: Gravitational wave propagation through inhomogeneities

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We constructed a new class of quintic Horndeski theories with the property that on flat FRW backgrounds gravitational waves propagate exactly with the speed of light, c^2_gw = 1. Such theories became increasingly interesting after the LIGO/Virgo discovery of GW170817 that implied that any deviation between these propagation speeds |c^2_gw - 1| has to be smaller than 10^-15.
Quintic Horndeski theories with the property c^2_gw = 1 were previously claimed not exist. We discovered a loophole in these previous arguments giving rise to a new class of potentially viable theories.
However, considering the impact of scalar inhomogeneities on GW propagation using higher order perturbation theory, we discovered that these models are nevertheless excluded: already a Newtonian potential with amplitude 10^-5 will lead on average to |c^2_gw - 1| > 10^-7 for gravitational waves with frequencies relevant for LIGO/Virgo.

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Reaching Planck scale sensitivity with muon lifetimes from Finsler measures

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Planck scale modified dispersion relations are one way how to capture the influence of quantum gravity on the propagation of fundamental point particles effectively. We derive the time dilation between an observer's or particle's proper time, given by a Finslerian length measure induced from a modified dispersion relation, and a reference laboratory time. To do so, the Finsler length measure for general first order perturbations of the general relativistic dispersion relation is constructed explicitly. From this we then derive the time dilation formula for the κ-Poincaré dispersion relation in several momentum space bases, as well as for modified dispersion relations considered in the context of string theory, loop quantum gravity and Hořava-Lifshitz gravity. Most interestingly we find that the momentum Lorentz factor in the present and future colliders can, in principle, become large enough to constrain the κ-Poincaré dispersion relation in the bicrossproduct basis as well as a string theory induced modified dispersion relation, at Planck scale sensitivity with help of the muon's lifetime.

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Testing the sensitivity and limitations of a massive spin-2 boson model using the Contur approach

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The Standard Model (SM) of particle physics gathers and classifies all the essential building blocks of nature, along with the sub-atomic forces that bind them together. This theoretical framework has been verified at the Large Hadron Collider at CERN and other collider experiments like Fermilab and the Stanford Linear Accelerator Centre. Yet, the SM has unresolved issues, such as the hierarchy problem. This issue could be solved by "Beyond the Standard Model" theories with additional spatial dimensions. Some of these theories predict the existence of a spin-2 boson. This project utilizes a theoretical model of the graviton to set limits and constrain the window of detection of the latter at the LHC. This analysis uses Herwig, Rivet, and Contour software packages to set constraints on the parameter space of a spin-2 boson model by comparing theoretical predictions to the data gathered by the ATLAS and CMS detectors at CERN. The two dominant production mechanisms of the spin-2 boson explored here are the Drell-Yan and the Vector Boson Fusion (VBF) processes. This project found the window where the spin-2 boson could possibly be detected. We conclude that the Drell-Yan process sets tighter constraints on the parameter space of the model than the VBF mechanism. Furthermore, we find that, for values of the relevant couplings equal to 1, only spin-2 boson masses above 6 TeV and 900 GeV are allowed for the Drell-Yan and VBF processes respectively.

Superfluid dark matter: Beyond the modified gravity and dark matter dichotomy

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The putative effects of dark matter are most easily explained by a collisionless fluid on cosmological scales and by Modified Newtonian Dynamics (MOND) on galactic scales. Superfluid dark matter (SFDM) provides a simple explanation for why this behavior differs with scale: It is caused by a single underlying substance with two phases. I will highlight successful experimental tests and predictions of SFDM regarding strong lensing and the Milky Way rotation curve. I will also discuss three problems due to the double role of the aforementioned single underlying substance and introduce an improved model which avoids these problems.

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Freely falling bodies in standing wave space-time

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The phenomena of standing waves are mostly studied in the context of mechanical or electromagnetic waves. In the context of General Relativity, the issue of how to define standing gravitational waves was addressed by Bondi and later by Stefani. We study the motion of free masses subject to the influence of standing gravitational waves in the polarized Gowdy cosmology with a three-torus topology. We study how freely falling particles in this spacetime behave, we investigate the geodesic equation and the geodesic deviation equation. We show that antinodes attract freely falling particles and trace the velocity memory effect.

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A study of Traversable Wormholes in Modified Gravity and Non-linear Equation of State

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(Dated:)

We present traversable wormholes (TW) in the Einstein's general theory of relativity which are obtained considering density profile in the framework of modified Newtonian dynamics (MOND). Scalar field in addition to MOND are obtained to study the TW for comparison. The shape functions for wormholes which corresponds a constant redshift function are determined to investigate the null energy conditions. It is noted that TW exists with MOND density profile in the presence of exotic matter. The presence of massless scalar field with MOND density profile allows TW when NEC is also obeyed at the throat depending on the initial value of the scalar fields. In the case of a modified matter sector, we consider a non-linear equation of state $p = A\rho - B\sqrt{\rho_o \rho}$ where $A,\ B$and ρ_o is a dimensional constant) in Einstein gravity to obtain TW. A new class of TW solutions are obtained depending on the parameters values. In this case it is found that the TW exists with normal matter when the density at the throat satisfies a lower bound, $\rho(r_0) \geq \rho_{cr}$ and with exotic matter when $\rho(r_0) < \rho_{cr}$ where $\rho_{cr} = \left(\frac{B}{A+1}\right)^2 \rho_o$

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Testing Relativistic Gravity:
Geodesy, the Redshift, and Clock Effects

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A common methodology to test GR and other theories of gravity is the formulation of observable effects in a parametrized post-Newtonian (ppN) framework. In this contribution, the focus is on relativistic geodesy and related concepts such as the mutual redshift of observers on (or close to) the Earth's surface, the observers' acceleration, and clock effects in the comparison of orbiting and ground-based clocks.

We deliberately base our analysis and definition of observables on the use of clocks and their comparison since clocks provide the most precise measurement instruments available in modern experiments.

Within a ppN framework, fundamental notions and observables in the field of geodesy are described to explore the possibilities for tests of gravitational theories. Central notions such as the redshift, the relativistic geoid, the gravitational potential, and the concept of height are addressed. It is shown that all the relativistic notions reduce to their well-known Newtonian form in the weak-field limit.

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Propagation of quantum gravity-modified gravitational waves on a classical FLRW spacetime

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The linearized Einstein field equations provide a low energy wave equation for propagation of gravitational fields which may be originated from a high energy source. Motivated by loop quantum gravity (LQG), we propose the polymer quantization scheme to derive the effective propagation of such waves on a classical FLRW spacetime. To overcome the challenge of polymer quantizing a time-dependent Hamiltonian, we rewrite such a Hamiltonian in a time-independent manner in the extended phase space, polymerize it, and then transform it back to the usual phase space. This way we obtain a time-dependent polymer Hamiltonian for the gravitational waves. We then derive the effective equations of motion and show that i) the form of the waves are modified ii) the speed of the waves depend on their frequencies iii) the quantum effects are amplified by the distance/time the waves travel.

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Ultrahigh Energy Cosmic Rays from Supermassive Black Holes candidates

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Origin of ultrahigh-energy cosmic rays (UHECRs) with energy exceeding GZK-cutoff limit remains unclear. Recent detections of extragalactic high-energy neutrino may indicate the source of primary UHECRs being an extragalactic supermassive black hole (SMBH). It appears that extraction of energy from rotating electromagnetized black hole by the novel, ultra-efficient regime of the magnetic Penrose process could indeed foot the bill. Ionization of particles, such as neutron beta-decay, skirting close to the SMBH candidates located in the centres of some of the nearby galaxies can energize protons up to the ZeV energies. Applied to a supermassive black hole at the centre of the Milky Way, we get proton energy of the order coinciding with the knee of the cosmic ray spectrum, supporting thus the presence of a PeVatron at the Galactic centre. It is remarkable that the process requires neither extended acceleration zone, nor fine-tuning of accreting matter parameters and relies purely on the properties of the black hole magnetosphere. Further, this leads to certain verifiable constraints on the black hole mass, magnetic field strength and the distance to potential UHECR source. The presentation is mainly based on papers [1,2].

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Impact of Earth's Gravity on the Frequency Stabilization of Optical Cavities

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Nowadays, science can rely on high-precision measuring devices, as atomic clocks and gravitational wave detectors. These instruments help to answer open questions of physics, like the time-variation of fundamental constants, the structure of the early universe, and the nature of dark matter. The accuracy of atomic clocks and gravitational wave detectors only became possible due to modern methods of laser frequency stabilization. In stare-of-the-art experiments, this is done by optical reference cavities, which are capable to stabilize the frequency of laser light to relative 10^{-17} and beyond. As known from Einstein's theory of general relativity, the propagation of light in the presence of massive objects is affected by gravity. That, consequently, also holds for laser light in the Earth's gravitational field. For an optical cavity, in which a laser beam goes around a billion times between two highly reflective mirrors, this gravitational influence affects the output intensity [1] and can set a limit on the stabilization of the cavity output frequency [2]. In this contribution, we in particular investigate how this gravitational limit on frequency stabilization depends on the properties of the laser beam and the cavity setup and discuss the implications of our findings for future Earth-based cavity experiments.

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Probing gravitational waves from pulsars in Jordan-Brans-Dicke theory

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I shall talk about gravitational waves in the Jordan-Brans-Dicke (JBD) theory. The general theory of relativity (GR) has only two tensor polarization states (due to quadrupole emission) but a generic metric theory of gravity can also possess vector as well as scalar polarizations. The JBD theory is one of the attempts to modify GR by varying gravitational constant G and it has three polarization states. The first two states are the same as in GR and the third one is the scalar polarization which is dominated by the dipole emission. In our work, we have extracted these three polarizations for a particular case of a rotating neutron star with a mountain on its equator. Later on, we examined the response of a detector for these three polarizations and derived the F-statistic (due to quadrupole emission) and D-statistic (due to dipole emission) to estimate the signal parameters. Finally, we have performed the Monte Carlo simulations to demonstrate the accuracy of our analysis.

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The Geometry of Finsler spacetimes

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Abstract: We briefly review the main features of Finsler spacetime geometry, with a focus on Finsler spacetimes possessing cosmological symmetry.

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Metric Reconstruction with Gravitational Waves and Shadows

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In this poster I present two recent works that either use black hole quasi-normal modes [1] or the black hole shadow-size [2] to constrain the underlying metric of the space-time. Both types of observations are accessible by current and future activities of the LIGO/Virgo/KAGRA gravitational wave detectors or the Event Horizon Telescope. By combining Bayesian analysis with parametrized black hole metrics it is possible to approximate the underlying black hole space-time and solve the inverse problem, under some simplifying assumptions that will be outlined. I discuss opportunities, limitations and moreover, how both types of observations are complementary to each other.

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Asymptotic Extended Uncertainty Principle

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In the last 30 years the interest in (Quantum) Gravity corrections to Heisenberg's uncertainty relation has experienced a steady increase. On the one hand, the Generalized Uncertainty Principle (GUP) is often invoked to phenomenologically account for a quantum gravitationally induced minimal length. On the other hand, there are indications that the curvature of space-time alters the uncertainty relation too as summarized under the term Extended Uncertainty Principle (EUP). I present a formalism which allows for the perturbative derivation of the EUP for arbitrary spatial curvature models. The leading curvature induced correction is proportional to the Ricci scalar evaluated at the expectation value of the position operator. By Born reciprocity this method can be equivalently applied in curved momentum space allowing for a GUP or curved momentum space quantum mechanics.

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Phase shifts of arbitrary matter wave interferometers in post-Newtonian spacetimes

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We present a systematic approach to calculate all relativistic phase-shift effects in matter wave interferometer (MWI) experiments up to (and including) order c^{-2}, corresponding to a weak gravitational field. The whole analysis is derived from first principles and even admits test of General Relativity (GR) apart from the usual Einstein Equivalence Principle (EEP) tests, consisting of universality of free fall (UFF) and local position in- variance (LPI) deviations, by using the more general 'parametrized post-Newtonian' (PPN) formalism. We collect general phase-shift formulas for a variety of well-known MWI schemes and calculate how modern experimental setups could measure PPN induced deviations from GR without the use of macroscopic test masses. This procedure should be seen as a way to easily calculate certain phase contributions, without having to redo all relativistic calculations in new MWI setups.

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Low-mass stars and tests of gravitational theories

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I will briefly present how modified gravity affects early evolution of low-mass stellar objects. Some of these effects can be used to constrain particular theories of gravity.

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Gravitational lensing by a black hole in non-Riemannian spacetimes

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One of the consequences of Einstein's general theory of relativity is bending of light as it passes through a gravitational field. Examining the path of light in a very strong gravitational field of a black hole can provide a huge amount of information about the geometry and characteristics of the surrounding space.
On the other hand, the path of light rays, extent, and shape of gravitational lensing, are directly related to the type of background geometry in which light is emitted. Since the theory of general relativity in very high energies and very strong gravitational fields is expected to be corrected, researchers have been looking at the phenomenon of gravitational lensing in the context of alternative theories for general relativity to find out the needed corrections for the results of general relativity and these corrections are likely to be more significant in a very strong gravitational field of a black hole.
Among the various theories that have been proposed for correcting the gravity in high energies, gauge theories of gravity have great importance. One of the important results of these theories is changing the geometry for the background in general relativity, Riemannian space-time, to a non-Riemannian geometry in which, in addition to curvature, there is also torsion. In these theories, the presence of torsion coupled to spin of a matter can affect the path of light rays and correct the results of gravitational lensing.
In this work, we want to study the effects of non-Riemannian geometry on the gravitational lensing of a black hole, and in particular the effects of torsion and spin in this context.

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Forth-order gravity in five-dimensional teleparallelism

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Special relativity (SR) unites space and time as a pseudo-Euclidean space-time but does not explain the existence of any field or particle. General relativity (GR) rejects SR, and explains gravity as a curvature of a pseudo-Riemannian manifold; the other fields/particles combine the energy-momentum tensor (EMT) and remain unexplained. Einstein was not content with GR; the sides of GR-equation he compared with a marble palace (LHS, tensor $G_{\mu\nu} = R_{\mu\nu} - g_{\mu\nu} R/2\,, G_{\mu\nu;\nu} \equiv 0$) and an old shed (RHS with the EMT). Later Einstein explored frame field $h^a{}_\mu(x^\nu)$ and second order equations which symmetry group combines symmetries of both SR (Latin indexes) and GR (Greek indexes) – a third or united relativity, although Einstein call it "teleparallelism".

There exist (among the list of compatible equations found by Einstein and Mayer) an exceptional, non-Lagrangian frame-field equation which solutions do not admit co-singularities (the principal terms do not remain regular for one-degenerate co-frame matrices), and, for *D*=5, contra-singularities (degeneration of contra-frame density of some weight; the weight defines the choice *D*=5, *D*=4 is just forbidden) as well [1].

The theory has many interesting features: a set of 15 polarizations of different functionality, including three linearly unstable ones; topological charges and quasi-charges [2], with QM emerging through averaging along the huge extra dimension, a scale *L*. It leads to a simple cosmological model with a single O_4-symmetrical expanding (relativistic) wave (longitudinal polarization). The proper EMT (where only three stable polarizations play the role) appears in a prolonged, forth-order symmetrical equation $G_{\mu\nu;\lambda;\lambda} + G_{\varepsilon\tau}\left(2R_{\varepsilon\mu\tau\nu} - \frac{1}{2} g_{\mu\nu} R_{\varepsilon\tau}\right) = -T_{\mu\nu}(\Lambda'^2, \ldots)$, where $\Lambda^a{}_{\mu\nu} = h^a{}_{\mu,\nu} - h^a{}_{\nu,\mu} = 2h^a{}_{[\mu;\nu]}$; this equation follows also from a "Lagrangian" quadratic in the field equation.

So, one can consider static 4d-equation $\triangle^2\, \varphi(x^\alpha) = -\rho(x^\alpha)$ and suggest that masses are greatly extended along the extra dimension, the scale *L*. A point "mass" $aR^{-3}\delta(R)$ gives the next solution (every large mass/over-density is accompanied by an under-density, so the logarithmic growth should stop somewhere) $\varphi(R) = \frac{a}{8} \ln R^2 - bR^{-2}$.

For extended masses, at scales $r \ll L$ one obtains the Newton's force $\varphi' \sim r^{-2}$, while for large scales $r \gg L$ the law is different: $\varphi' \sim r^{-1}$. The second-order equation also should be accounted for and this restricts the number of solutions; at some constraint on the set a, b the first correcting term (the Rindler term) $\delta\varphi \sim r/L^2$ can vanish [1].

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