Bridging high and low energies in search of quantum gravity - 2025 Cost Action CA23130 First Annual Conference

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LPNHE

Recueil des résumés

Contents

WG4 Low-energy high-precision experiment / 1

Testing Quantum Mechanics Underground: Collapse models and Pauli Exclusion Principle

Auteur: Catalina Curceanu[None]

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We are experimentally investigating possible departures from the standard quantum mechanics'predictions at the Gran Sasso underground laboratory in Italy.
In particular, with radiation detectors we are searching for signals predicted by the collapse models (spontaneous emission of radiation) which were proposed to solve the "measurement problem"in quantum physics and signals coming from a possible violation of the Pauli Exclusion Principle.
I shall present our recent results and future plans for gravity-related collapse studies and also more generic results on testing CSL (Continuous Spontaneous Localization) collapse models and discuss future perspectives.
I shall as well present the VIP experiment with which we look for possible violations of the Pauli Exclusion Principle by searching for "impossible"atomic transitions and the impact of this research in relation to Quantum Gravity models.

Working Group:

WG4 - Low-energy high-precision experiment

5

[Physics department seminar] Bridging high and low energies in search of quantum gravity

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The interplay between quantum mechanics and general relativity is one of the most profound open problems in fundamental physics. After decades of purely theoretical investigations, recent experimental advances turned the prospect of a phenomenological approach into a realistic possibility. On the one hand, searches for quantum gravity effects in astrophysical signals constitute nowadays an established field of fundamental research. On the other hand, table-top experiments with quantum systems are now advancing fast towards understanding the role of gravity in quantum systems and testing the possibility that gravity itself is quantized. Investigating the interface between high-energy quantum gravity and quantum aspects of gravity in the low-energy regime, using both theoretical and experimental tools, can provide complementary clues towards the construction of a phenomenologically viable theory of quantum gravity at all scales.

In this talk, I will give an overview of the state of the art and key open questions of this research programme and describe the related activities of the COST Action BridgeQG (Bridging high and low energies in search of quantum gravity).

Working Group:

6

[Outreach Event] La gravitation : de la relativité générale à la gravitation quantique

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La relativité générale et la mécanique quantique sont deux théories fondamentales de la physique : la relativité générale décrit la gravité et la structure à grande échelle de l'Univers, tandis que la mécanique quantique décrit le comportement de la matière et de l'énergie aux niveaux atomique et subatomique. Elles sont incompatibles lorsqu'elles sont appliquées à l'Univers primitif ou aux trous noirs, où la gravité et les effets quantiques sont tous deux importants.
La gravité quantique est une tentative d'unifier les deux théories, qui permettrait notamment de comprendre les phénomènes impliquant de grandes quantités de matière ou d'énergie sur de petites dimensions spatiales, tels que les trous noirs ou l'origine de l'Univers.
La mécanique quantique et la relativité générale sont très bien vérifiées et jusqu'à présent aucune expérience ne les contredit. Dans cette conférence on présentera les concepts de base des deux théories ainsi que de la gravité quantique. Des expériences possibles pour la detection de la gravité quantique seront aussi discutées.

Working Group:

WG3 Low-energy Gravitational Effects in Quantum Systems 1 / 7

Probing the Quantum Nature of Gravity through Diffusion

Auteurs: Andrea Vinante[1]; Angelo Bassi[2]; Giovanni Di Bartolomeo[2]; Jose Luis Gaona Reyes[2]; Oliviero Angeli[2]; Sandro Donadi[3]

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The quest to determine whether gravity is quantum has challenged physicists since the mid-20th century, due to the impracticability of accessing the Planck scale, where potential quantum gravity effects are expected to become relevant. While recent entanglement-based tests have provided a more promising theoretical path forward, the difficulty of preparing and controlling large mass quantum states has hindered practical progress. We present an alternative strategy that shifts the focus from complex quantum state manipulation to the simpler observation of a probe's motion. By proving that a classical and local gravitational field must inherently display randomness to interact consistently with quantum matter, we show that this randomness induces measurable diffusion in a probe's motion, even when the probe is in a classical state. This diffusion serves as a distinctive signature of classical gravity coupling to quantum matter. Our approach leverages existing experimental techniques, requiring only the accurate tracking of a probe's classical center-of-mass motion, and does not need any quantum state preparation, thereby positioning this method as a promising and practical avenue for advancing the investigation into the quantum nature of gravity.

Working Group:

WG3 - Low-energy gravitational effects in quantum systems

WG5 Connection between low-energy and high-energy quantum gravity 1 / 13

Quantum Coherence from Quantum Spacetime

Auteur: Iarley Lobo[1]

Co-auteurs: Gislaine Varão [1]; Giulia Gubitosi [2]; Moises Rojas [3]; Valdir Bezerra [1]

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We investigate the emergence of quantum coherence and quantum correlations in a two-particle system with deformed symmetries arising from the quantum nature of spacetime. We demonstrate that the deformation of energy-momentum composition induces a momentum-dependent interaction that counteracts the decoherence effects described by the Lindblad equation in quantum spacetime. This interplay leads to the formation of coherence, entanglement and other correlations, which we quantify using concurrence, the l_1-norm of coherence, quantum discord and Local Quantum Fisher Information. Our analysis reveals that while the openness of quantum spacetime ultimately degrades entanglement, it also facilitates the creation and preservation of both classical and quantum correlations. Finally, we examine the effects of temperature on this system.

Working Group:

WG5 - Connection between low-energy and high-energy quantum gravity

WG1 High Energy QG Theory 1 / 14

Bridging Energy Scales via Hamiltonian Renormalization

Auteur: Klaus Liegener[1]

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A renowned tool for relating theories at different scales is the famous Renormalization Group (RG). The RG flow enables the connection of theories at varying coarse-grained scales, ultimately aiming to bridge observations on cosmological scales with predictions from quantum theories of general relativity. In this talk, we adapt the RG framework to the Hamiltonian level, a key requirement for rigorous approaches such as loop quantum gravity. We will discuss specific conditions necessary for the continuum limit of operator algebras. Since studying the RG flow is generally complex—not only in quantum gravity—we propose methods to analyze the impact of different coarse-graining maps using emerging quantum computing technologies.

Working Group:

WG1 - High Energy QG Theory

WG5 Connection between low-energy and high-energy quantum gravity 2 / 15

Nonperturbative quantum black holes and their phenomenology

Auteurs: Aliasghar Parvizi[1]; Christian Pfeifer[2]; Klaus Liegener[None]; Saeed Rastgoo[3]

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I will discuss the theory behind some of the black holes in both loop quantum gravity and generalized uncertainty approaches, and present a number of phenomenological signatures they exhibit.

Working Group:

WG5 - Connection between low-energy and high-energy quantum gravity

WG1 High Energy QG Theory 2 / 16

Generalized Cotangent Geometry and Its Applications in Quantum Gravity

Auteur: Lucia Santamaria-Sanz[1]

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One of the main challenges in theoretical physics is the unification of general relativity and quantum field theory, leading to the development of a consistent theory of quantum gravity. In this talk, we explore how the deformation of special relativistic kinematics can provide a framework to describe residual effects of quantum gravity at low energies. We analyze how introducing a curved momentum space allows for the formulation of a deformed relativistic kinematics and how this geometric construction can be extended to curved spacetimes through the formalism of generalized Hamilton spaces. We discuss the constraints imposed by observer invariance on momentum conservation, the natural emergence of noncommutative spacetimes, and the privileged role of Snyder kinematics within this geometric framework. Finally, we present the implications for developing an effective theory of quantum gravity at low energies.

Working Group:

WG1 - High Energy QG Theory

WG5 Connection between low-energy and high-energy quantum gravity 2 / 18

Covariance in Spherically Symmetric Effective Models of Quantum Gravity and Quantum Black Holes

Auteur: Yongge Ma[1]

Co-auteurs: Cong Zhang [1]; Jinsong Yang [2]

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The effective models of quantum gravity are expected to make phenomenological predictions of the fundamental theories. The issue of general covariance in effective models of quantum gravity will be addressed in this talk, which arises when canonical quantum gravity leads to a semiclassical model described by an effective Hamiltonian constraint. In the context of spherically symmetric models,

general covariance is precisely formulated into a set of equations, leading to the necessary and sufficient conditions for ensuring covariance. Several candidates for effective Hamiltonian constraints, satisfying the covariance conditions and depending on a quantum parameter, are proposed. The resulting quantum modified black holes show the spacetime structures dramatically different from those of classical black holes.

Refs:
[1] Cong Zhang, Jerzy Lewandowski, Yongge Ma, Jinsong Yang, Black Holes and Covariance in Effective Quantum Gravity, arXiv:2407.10168, accepted by PRDLetters.
[2] Cong Zhang, Jerzy Lewandowski, Yongge Ma, Jinsong Yang, Black holes and covariance in effective quantum gravity: A solution without Cauchy horizons, arXiv:2412.02487.
[3] Jerzy Lewandowski, Yongge Ma, Jinsong Yang, Cong Zhang, Quantum Oppenheimer-Snyder and Swiss Cheese models, Phys. Rev. Lett. 130, 101501 (2023).
[4] Cong Zhang, Yongge Ma, Jinsong Yang, Black hole image encoding quantum gravity information, Phys. Rev. D 108, 104004 (2023).

Working Group:

WG5 - Connection between low-energy and high-energy quantum gravity

WG5 Connection between low-energy and high-energy quantum gravity 2 / 19

Testing modified dispersion relations with relativistic gas dynamics

Auteur: Manuel Hohmann[None]

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Far from the quantum regime, quantum gravity effects may be imminent in the form of modifications of the dynamics of classical systems. Such effects can be modeled by effective theories. One common approach of this type is to describe the influence of quantum gravity effects on the motion of massive or massless test particles by modified dispersion relations. Applying these relations to a distribution of test particles, one obtains the kinetic formulation of a relativistic gas. A modification of the dispersion relation thus becomes manifest as a modification of the gas dynamics. In my presentation I will show this for a simple example and explain how the modified gas dynamics can be used as an observational discriminator for effective quantum gravity models.

Working Group:

WG5 - Connection between low-energy and high-energy quantum gravity

WG3 Low-energy Gravitational Effects in Quantum Systems 1 / 20

Detecting post-Newtonian classical and quantum gravity via atom clock interferometry

Auteur: Eyuri Wakakuwa[1]

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Understanding physical phenomena at the intersection of quantum mechanics and general relativity remains one of the major challenges in modern physics. Among various approaches, experimental tests have been proposed to investigate the dynamics of quantum systems in curved spacetime and to examine the quantum nature of gravity in the low-energy regime. However, most previous studies have considered only Newtonian gravity, leaving the post-Newtonian regime largely unexplored. In this study, we propose an experimental test to investigate how post-Newtonian gravity affects quantum systems and to examine its quantum nature. Specifically, we design and analyze two types of experiments: one using a quantum clock interferometry setup to detect the gravitational field generated by a rotating mass, and another leveraging this effect to generate gravity-mediated entanglement. Although the proposed experiments are extremely challenging to implement, they are inherently suited for probing post-Newtonian gravity. Due to the symmetry of the configuration, the setup is insensitive to the Newtonian gravitational contribution while sensitive to the frame-dragging effect. Moreover, assuming the validity of quantum equivalence principle, our approach provides a potential means not only to test the quantum nature of gravity but also to explore the quantum nature of spacetime itself.

Working Group:

WG3 - Low-energy gravitational effects in quantum systems

WG3 Low-energy Gravitational Effects in Quantum Systems 2 / 21

Foundations of Relational Quantum Field Theory

Auteur: Samuel Fedida[1]

Co-auteur: Jan Glowacki [2]

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Starting from operationally motivated principles, we derive a relational theory of observables in Minkowski spacetime from which the notion of scalar quantum fields naturally emerges. We expand on quantum reference frames in spacetime and demonstrate that most properties of quantum fields arise as direct consequences of constraints on quantum reference frames – that is, quantum fields should be understood as what observers "see" using an imperfect measurement setup. We show that such quantum fields satisfy the usual axioms of constructive quantum field theory, including notions of covariance and causality conditions, provided natural assumptions at the level of the quantum reference frames. We indeed highlight that analogous objects to the textbook Wightman quantum fields show up in certain classes of quantum reference frames in spacetime.

Working Group:

WG3 - Low-energy gravitational effects in quantum systems

WG1 High Energy QG Theory 2 / 23

What quantum foundations teach us about black holes

Auteurs: Ladina Hausmann[1]; Renato Renner[1]

[1] *ETH Zürich*

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Black holes provide a setting to test assumptions about the interplay of quantum theory and gravity. These tests have led to several puzzles, such as the xeroxing or firewall paradox. A common feature of these puzzles is that they combine the perspectives of an infalling observer and an exterior observer, who, for fundamental reasons, have access to different systems. In quantum foundations, so-called Wigner's friend experiments study observers with different perspectives, without involving gravity. Recent versions have shown that even mild assumptions about the combination of different observers'perspectives are inconsistent with quantum theory. A careful analysis of the firewall paradox reveals that it, too, relies on this assumption. Therefore, the firewall paradox may not stem from inconsistent assumptions about quantum gravity, but from quantum theory's limitations in consistently combining multiple observers'viewpoints.

Working Group:

WG1 - High Energy QG Theory

WG1 High Energy QG Theory 2 / 24

Bound on Gravitational Wave Luminosity from Non-Perturbative Quantum Effects of Gravity

Auteur: Wolfgang Wieland[1]

[1] *University of Erlangen Nuremberg*

Auteur correspondant wolfgang.wieland@fau.de

This talk presents recent developments on a non-perturbative quantisation of gravitational subsystems on a light cone. Starting from the covariant phase space for the γ-Palatini–Holst action, we identify an auxiliary conformal field theory (CFT), which carries a representation of the constraint algebra of general relativity on a null surface. In the model, the radiative data, which is encoded into the shear of each null generator, is mapped into an auxiliary $SU(1,1)$ current algebra on each light ray. We study the resulting quantum theory for both bosonic and fermionic representations. In the fermionic representation, the central charge on each null ray is positive, for bosons it is negative. To avoid non-unitary representations, the central charge must be positive. I explain how this requirement alters the spectrum of the radiated power. In this way, we obtain a bound on the radiated power (Bondi flux) of gravitational waves in asymptotically flat spacetimes. The talk is based in part on arXiv:2402.12578, arXiv:2401.17491, arXiv:2104.05803, arXiv:2504.10802.

Working Group:

WG1 - High Energy QG Theory

WG1 High Energy QG Theory 2 / 28

Understanding gravitationally induced decoherence parameters in neutrino oscillations using a microscopic quantum mechanical model

Auteurs: Alba Domi[1]; Kristina Giesel[1]; Lukas Hennig[1]; Max Joseph Fahn[2]; Michael Kobler[1]; Roman Kemper[1]; Thomas Eberl[1]; Ulrich Katz[1]

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[2] *Università di Bologna*

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In this talk, the role of gravitationally induced decoherence in open quantum systems is explored in the context of neutrinos. A microscopic quantum mechanical model introduced by Blencowe and Xu is applied to neutrino oscillations, motivated by the coupling between neutrinos and the gravitational wave environment suggested by linearised gravity. The analysis demonstrates that, for neutrino oscillations in vacuum, gravitationally induced decoherence matches phenomenological models, with decoherence parameters exhibiting an inverse quadratic energy dependence. When matter effects are included, the decoherence parameters depend on the varying matter density across the earth's layers. Moreover, the form of the decoherence parameters is explicitly derived from the microscopic model, providing a physical interpretation. This talk is based on the work in "Understanding gravitationally induced decoherence parameters in neutrino oscillations using a microscopic quantum mechanical model", published in JCAP, 2024, 11, 006.

Working Group:

WG1 - High Energy QG Theory

WG2 High Energy QG Experiments / 30

Superluminal neutrino cascades and ultra-high-energy neutrino events

Auteurs: Jose Luis Cortes[1]; José Manuel Carmona[1]; Maykoll Reyes[1]

[1] *University of Zaragoza / CAPA*

Auteurs correspondants: cortes@unizar.es, jcarmona@unizar.es, mkreyes@unizar.es

The recent detection of a neutrino event with an energy of approximately 100 PeV by KM3NeT has opened the window of ultra-high-energy (UHE) neutrino astronomy. This newly accessible regime offers an unprecedented opportunity to explore new physics. In particular, a population of UHE neutrinos has implications for scenarios of Lorentz Invariance Violation (LIV), where neutrinos with a modified dispersion relation may decay during propagation, altering the expected flux of cosmic neutrinos. In this talk, we will address some limitations of previous studies of LIV constraints on superluminal neutrinos based on the KM3-230213A event, and present a unified framework that could be applied to constrain LIV models predicting superluminality in the detection of future UHE neutrino events.

Working Group:

WG2 - High Energy QG Experiment

WG1 High Energy QG Theory 2 / 31

Disentangling Lorentz symmetry breaking and deformation in photon absorption

Auteur: Maykoll A. Reyes[1]

Co-auteurs: Filip Resic [2]; Jose Luis Cortes [3]; José Manuel Carmona Martínez [3]; Tomislav Terzić [4]

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[3] *University of Zaragoza / CAPA*

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The transparency of the universe to high-energy gamma rays is governed by interactions with low-energy photons from the Cosmic Microwave Background (CMB) and Extragalactic Background Light (EBL) via Breit-Wheeler pair production. New physics models that suppress this process predict increased transparency, offering a testable scenario. This talk explores how such suppression arises within Lorentz invariance violation (LIV) and doubly special relativity (DSR) frameworks. We will compare the computation of the optical depth and the resulting survival probability in both escenarios, showing how potential anomalous transparency measurements could effectively discriminate between these two models beyond Lorentz invariance.

Working Group:

WG1 - High Energy QG Theory

WG3 Low-energy Gravitational Effects in Quantum Systems 1 / 33

Progress on satellite-to-ground single-photon interference experiment: toward a quantum test in curved spacetime

Auteurs: Yu-Huai Li[1]; Hui-Nan Wu[1]

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The emergence of quantum mechanics and general relativity has transformed our understanding of the natural world significantly. However, integrating these two theories presents immense challenges, and their interplay remains untested. Recent theoretical studies suggest that single-photon interference over large spatial separations offers a promising approach to probing the interface between quantum mechanics and general relativity. To explore this possibility, we have recently conducted a series of ground-based verification experiments using unbalanced interferometers to simulate long-baseline single-photon interference under realistic atmospheric conditions. These efforts have demonstrated the feasibility of high-precision phase measurements over multi-kilometer free-space channels and validated key technologies such as high-brightness single-photon sources and ultra-stable interferometric control. Nowadays, we are developing a satellite payload specifically designed to perform satellite-based single-photon interference experiments, with the goal of ultimately testing gravitationally induced phase shifts in curved spacetime. Together, these developments mark a significant step toward experimental tests of quantum physics in the presence of gravity.

Working Group:

WG3 - Low-energy gravitational effects in quantum systems

WG5 Connection between low-energy and high-energy quantum gravity 2 / 38

Emergent Scalar Field Dynamics on Curved Spacetime in Group Field Theory

Auteurs: Daniele Oriti[None]; Stefano Liberati[None]

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Working within the relational framework of group field theories and specifically its application to cosmology, we derive the explicit solution to the GFT condensate effective dynamics including the treatment of scalar perturbations. This first step allowed us to investigate further the matter content and formulate its dynamics in the form of QFT on a curved background. This, in turn, produced additional emergent properties that the field theory possesses in comparison with the classical one, which was further mirrored at the level of the perturbation. In the latter case, we attained a modified dispersion relation for the perturbed field.

Working Group:

WG5 - Connection between low-energy and high-energy quantum gravity

WG1 High Energy QG Theory 3 / 39

Operator dressing & proto-gauge theory from quantum mereology

Auteur: Oliver Friedrich[1]

Co-auteur: Varun Kushwaha [2]

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Instead of quantizing a classical phase space, the program of quantum mereology takes abstract Hamiltonian operators defined in some Hilbert space as its starting point, and investigates under which conditions such a setting induces semi-classical dynamics. We advance this program by studying the emergence of entire sets of degrees-of-freedom from random Hamiltonians. We show that these emergent degrees-of-freedom can be interpreted as the modes of a proto-gauge theory. And we demonstrate that these modes are overlapping, i.e. they obey non-trivial commutation relations and are reminiscent of (e.g. gravitationally) dressed operators and of the framework of holographic QFT that we recently proposed in https://arxiv.org/abs/2402.11016 .

Working Group:

WG1 - High Energy QG Theory

WG1 High Energy QG Theory 3 / 43

Simulations and the Resulting Spectra for Reactions in Astrophysical Electromagnetic Cascades with Lorentz Invariance Violation

Auteurs: Andrey Saveliev[1]; Rafael Alves Batista[None]

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Lorentz Invariance Violation (LIV) is a feature of several quantum gravity models in which Lorentz symmetry is broken at high energies, leading to potential changes in particle behavior and interactions. In this study, we present simulations (and the corresponding methods) of the propagation of astrophysical electromagnetic cascades with LIV, which in particular results in new types of reactions such as the Vacuum Cherenkov effect or Photon Decay, which are forbidden when Lorentz Symmetry is conserved. In particular, we derive, for the first time, spectra for the vacuum Cherenkov reaction, and confirm our results numerically. These results can be used to derive limits on LIV.

Working Group:

WG1 - High Energy QG Theory

WG1 High Energy QG Theory 3 / 44

Beyond Standard Cosmology: New Statistical Approaches to Lorentz Invariance Violation

Auteur: Denitsa Staicova[1]

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The Hubble tension poses serious questions not only to cosmology, but also to fundamental physics. In this talk, we will summarize our results so far as to how combining Lorentz Invariance Violation (LIV) time-delay measurements from gamma-ray bursts (GRBs) with standard cosmological datasets (BAO, SN) reveal interdependence between quantum gravity phenomena and cosmological models, how the choice of a model for the intrinsic time delay affects the LIV results and how we could use statistical tools to gain new information about the constraining power of our datasets. Our findings emphasize the importance of going beyond standard cosmological approaches when exploring potential evidences of quantum gravity across different energy scales.

Working Group:

WG1 - High Energy QG Theory

Working Group Introductions 1 / 45

WG2: What you always wanted to know but were afraid to ask about high-energy quantum gravity experiments

Auteurs: Alba Domi[1]; Tomislav Terzić[2]

[1] *ECAP-FAU*

[2] *University of Rijeka, Faculty of Physics*

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In this talk, we will review key experiments testing quantum gravity–related effects, outline current experimental results, and explore future prospects in the field. Most notably, we will highlight key peculiarities in our observations and analyses that influence results and may not be immediately apparent to those outside the field.
Our goal is to offer deeper insight into this area of research, opening it up to a broader community

and to share everything you have always wanted to know about experimental high-energy searches for quantum gravity, but were afraid to ask.

Working Group:

WG2 - High Energy QG Experiment

WG1 High Energy QG Theory 3 / 47

Time Dilation in Planck-scale-deformed Special Relativity

Auteur: Pietro Pellecchia[None]

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I will show how to derive finite boost transformations within the theory of Deformed Special Relativity based on the bicrossproduct-basis κ-Poincarè Hopf algebra.
This enables to establish key properties of the theory, such as worldline covariance and the spacetime metric.
These results allow the derivation of a Planck-scale-modified time dilation factor, which may be relevant for quantum gravity phenomenology, particularly in the context of lifetime observations.

Working Group:

WG1 - High Energy QG Theory

WG1 High Energy QG Theory 3 / 49

The regularization of spacetime singularities

Auteur: Vania Vellucci[1]

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Spacetime singularities are often regarded as evidence of the fundamental incompleteness of General Relativity (GR). It is generally expected that a quantum theory of gravity will prevent their formation. In this talk, I will explore various proposed 'regular' geometrical structures that could effectively replace classical singularities as the end states of gravitational collapse. I will discuss their physical viability, (in)stability, and the possibility for distinguishing from singular GR black holes through gravitational wave observations

Working Group:

WG1 - High Energy QG Theory

WG5 Connection between low-energy and high-energy quantum gravity 2 / 50

Correspondence between Modified Gravity and Generalized Uncertainty Principle

Auteur: Aneta Wojnar[1]

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I will briefly examine the connection between modified theories of gravity and models based on the Generalized Uncertainty Principle (GUP). This relationship provides a framework for testing gravity proposals using tabletop experiments. Using the Landau model of liquid helium as a representative example, we will analyze the underlying details. Similarly, GUP models can be reformulated in terms of modifications to the Poisson equation, allowing their analysis through planetary seismic data.

Working Group:

WG5 - Connection between low-energy and high-energy quantum gravity

WG4 Low-energy high-precision experiment / 51

Superconducting electro-mechanics to explore the effects of general relativity in massive superpositions

Auteur: Gary Steele[1]

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The combination of time dilation in general relativity with the possibility in quantum mechanics for masses to exist in a quantum superposition of being in two places at the same time leads to a prediction of quantum uncertainty in the definition of local time, something incompatible with our understanding of quantum mechanics. With no theoretical solution to the fundamental conflict, experimental observations will play a crucial role in constraining possible theoretical attempts to bridge the gap between the two theories. Here, I will give an overview of our approach to experimentally testing the combination of quantum mechanics and general relativity. Key to this is the determination of the requirements on physical parameters to perform experiments where both theories potentially interplay. We use these requirements to compare different systems, focusing on mechanical oscillators which can be coupled to superconducting circuits. And finally, we discuss the opportunities and challenges in achieving this regime using superconducting qubits coupled to massive mechanical resonators.

Working Group:

WG4 - Low-energy high-precision experiment

WG1 High Energy QG Theory 3 / 52

Revisiting noncommutative spacetimes from the relative locality principle

Auteur: José Javier Relancio Martínez[1]

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Relativistic deformed kinematics leads to a loss of the absolute locality of interactions. In previous studies, some models of noncommutative spacetimes in a two-particle system that implements locality were considered. In this talk, we present a characterization of the Poisson-Lie algebras formed by the noncommutative space-time coordinates of a multi-particle system and Lorentz generators as a possible restriction on these models. The relativistic deformed kinematics derived from these algebras are also discussed. Finally, we show its connection with cotangent bundle geometries.

Working Group:

WG1 - High Energy QG Theory

WG3 Low-energy Gravitational Effects in Quantum Systems 2 / 54

Low-Energy Test of Quantum Gravity via Angular Momentum Entanglement

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Currently envisaged tests for probing the quantum nature of the gravitational interaction in the low-energy regime typically focus either on the quantized center-of-mass degrees of freedom of two spherically-symmetric test masses or on the rotational degrees of freedom of non-symmetric masses under a gravitational interaction in the Newtonian limit. In this talk, I am going to present a novel proposal based on the interaction between the angular momenta of spherically-symmetric test masses considering the general relativistic correction related to frame-dragging that leads to an effective dipolar interaction between the angular momenta. In this approach, the mass of the probes is not directly relevant; instead, their angular momentum plays the central role. It is possible to demonstrate that, while the optimal entangling rate is achieved with a maximally delocalized initial state, significant quantum correlations can still arise between two rotating systems even when each is initialized in an eigenstate of rotation. Additionally, the robustness of the generated entanglement against typical sources of noise is explored while emphasizing that the combination of angular momentum and spherically-symmetric test-masses mitigates the impact of many common noise sources.

Working Group:

WG3 - Low-energy gravitational effects in quantum systems

WG5 Connection between low-energy and high-energy quantum gravity 2 / 56

The quantum group structure of quantum reference frame transformations

Auteurs: Diego Fernández-Silvestre[1]; Flaminia Giacomini[2]; Giulia Gubitosi[3]; Ángel Ballesteros[1]

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Quantum gravity and quantum information both call for a generalization of reference frame transformations. In quantum gravity, quantum groups naturally implement such generalization in some noncommutative spacetimes. In quantum mechanics, the concept of quantum reference frame emerged when linking reference frames to quantum systems. The connection between quantum groups and quantum reference frame transformations could then provide a deeper understanding of the relation between the quantization of observers and the quantization of spacetime.

In this talk, I will present the correspondence between quantum reference frame transformations and transformations generated by a quantum deformation of the Galilei Lie group with commutative time, at first order in the quantum deformation parameter. This correspondence is made explicit once the quantum group noncommutative transformation parameters are represented on the phase space of a quantum particle, provided that the quantum deformation parameter is inversely proportional to the mass of the particle serving as the quantum reference frame.

Working Group:

WG5 - Connection between low-energy and high-energy quantum gravity

WG2 High Energy QG Experiments / **57**

Neutrino oscillations and decoherence: insights from microscopic models

Auteurs: Alba Domi[1]; Joao Coelho[2]; Kristina Giesel[3]; Max Joseph Fahn[4]; Renata Ferrero[5]; roman kemper[3]

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Decoherence plays a key role in neutrino oscillations by describing how environmental interactions —such as with matter or gravity—can alter flavor oscillation patterns and reveal aspects of neutrino quantum behavior. Typically, studies of neutrino oscillations encode decoherence by making a phenomenological ansatz for the dissipator. Such decoherence effects can also be systematically derived from first principles using microscopic interaction models. In this talk, I will show how some assumptions in the microscopic models and the phenomenological models can be related.

Working Group:

WG2 - High Energy QG Experiment

WG2 High Energy QG Experiments / **60**

Testing in-vacuo dispersion with GRB neutrinos

Auteur: Domenico Frattulillo[1]

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Some previous studies based on IceCube neutrinos had found intriguing preliminary evidence that some of them might be GRB neutrinos with travel times affected by quantum properties of spacetime delaying them proportionally to their energy, an effect often labeled as “quantum-spacetime-induced in-vacuo dispersion”.
We introduce a novel approach to the search of quantum-spacetime-affected GRB neutrinos which restricts the analysis to GRBs of sharply known redshift. Our estimate of the magnitude of the in-vacuo-dispersion effects is fully consistent with what had been found using previous approaches and even if our findings are still inconclusive, since their significance is quantified by a p-value of little less than 0.01, they provide motivation for monitoring the accrual of neutrino observations by IceCube and KM3NeT. Finally, assuming in-vacuo dispersion, we contemplate the possibility that the recently announced ultra-high-energy neutrino KM3-230213A, with energy of ~220 PeV, might be a GRB neutrino.

Working Group:

WG2 - High Energy QG Experiment

WG2 High Energy QG Experiments / 62

New constraints on Lorentz invariance violations from H.E.S.S. observations of the blazar PKS 2155-304 flaring period of July 2006

Auteur: Ugo Pensec[None]

Co-auteur: Julien Bolmont [1]

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Lorentz invariance is a cornerstone of modern physics. However, certain quantum gravity models suggest potential violations of Lorentz symmetry (LIV) at high energy scales. Blazars, such as PKS 2155-304, are powerful, variable sources of very high-energy gamma rays and provide an ideal setting for testing such phenomena. We analyze the temporal and spectral properties of the July 29, 2006 PKS 2155-304 flare recorded by the H.E.S.S. experiment. A likelihood technique is used to measure energy-dependent time delays in the arrival times of gamma-ray photons that could indicate LIV effects. No significant LIV effect is observed and a stringent constraint on the energy scale of the tested model E_{QG} is set.

Working Group:

WG2 - High Energy QG Experiment

WG2 High Energy QG Experiments / 65

Assessing SWGO Sensitivity to Lorentz Invariance Violation through Transparency Studies

Auteurs: Filip Reščić[1]; Luis Recabarren Vergara[2]

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This work presents a sensitivity study exploring the capability of the planned Southern Wide-Field Gamma-Ray Observatory (SWGO)—a future water Cherenkov detector array to be built in Chile and designed to probe gamma rays up to the PeV scale—enabling studies such as the search for potential signatures of Lorentz Invariance Violation (LIV). Focusing on transparency studies, we simulate the gamma-ray flux from selected astrophysical sources and model their spectra under both standard special relativity and a quadratic subluminal LIV scenario. The analysis is based on a specific SWGO array configuration and incorporates the corresponding instrument response functions. By comparing the simulated fluxes to the projected detector sensitivity, we assess the potential of SWGO to constrain LIV-induced spectral anomalies.

Working Group:

WG2 - High Energy QG Experiment

WG3 Low-energy Gravitational Effects in Quantum Systems 2 / 66

Towards generalized group structures for changes of quantum reference frames: the twisted Poincaré case

Auteur: Gaetano Fiore[1]

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An ordinary change between two classical reference frames (RF) A, B can be seen as a point g in a Lie group manifold G; g sharply specifies the orientation and motion (of the origin) of B relative to A, while the group product encodes the composition of two changes into a third one. So far, physical theories are characterized by their covariance under a suitable G. If A, B are classical RFs but the state of B relative to A is mixed (i.e., a classical statistical distribution), or more generally if A and/or B are quantum RFs (i.e., use "clocks"and "rulers"that are themselves quantum systems), then in general one cannot describe the associated "unsharp"changes of RF without some generalized group (GG) structure.
In the talk I will discuss some general requirements for GGs and how Hopf algebras (or "quantum groups ") H may fulfill the latter. Remarkably, covariance under H allows for noncommutative (NC) spacetime coordinates. As a non-trivial example of H I will consider the "quantum Poincaré group" H of covariance of the NC Minkowski spaces with coordinates fulfilling commutation relations of the type $[x^\mu, x^\nu] \equiv i\theta^{\mu\nu}$ =const.
Work in collaboration with F. Lizzi.

Working Group:

WG3 - Low-energy gravitational effects in quantum systems

WG1 High Energy QG Theory 4 / 71

Free fields and discrete symmetries in κ-Minkowski

Auteur: Tadeusz Adach[1]

[1] *University of Wrocław*

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I will present recent advances in the theory of free scalar and fermionic fields defined on κ-Minkowski noncommutative spacetime, emphasizing how the choice of Lagrangian (which becomes trivial in the commutative limit) affects the canonical conserved charges associated with κ-Poincaré symmetries and their algebra. These results will be analyzed through the lens of discrete symmetries –C, P, T and their combinations. I will introduce a novel approach in which discrete symmetries can be deformed at the Planck scale, providing new insights into the implications of κ-Poincaré for quantum gravity phenomenology.

Working Group:

WG1 - High Energy QG Theory

WG1 High Energy QG Theory 4 / 74

Perturbative signatures of a superimposed quantum universe

Auteur: Lisa Mickel[1]

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In the quest of finding a quantum description of the early universe, we consider a quantised flat FLRW background together with quantum perturbations. We compute quantum trajectories for a universe that can be in a superposition of semiclassical background (and perturbation) states and investigate how the evolution of cosmological perturbations is influenced by the quantum nature of the background. It is of particular interest whether and how such quantum effects can translate into imprints on observable quantities. In addition to probing the quantum nature of our universe, our results thereby pave the way to obtain insights into the physical consequences of ambiguities in the quantum theory.

Working Group:

WG1 - High Energy QG Theory

WG3 Low-energy Gravitational Effects in Quantum Systems 1 / 75

Testing Quantum Mechanics and the Nature of Gravity through Diffusion

Auteur: Sandro Donadi[1]

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Is gravity fundamentally quantum, like the other three fundamental interactions, or is it classical? Could gravity play a fundamental role in wave function collapse, as suggested by models such as the Diósi–Penrose (DP) model? These questions remain open.

Many proposed experiments aimed at addressing these questions rely on creating spatial superpositions of large masses. For instance, tests of gravity's quantumness—such as the Bose–Marletto–Vedral (BMV) protocol—seek to detect entanglement between two masses in spatial superposition. Similarly, interferometric experiments with large-mass superpositions have been suggested for testing the DP model, which predicts position-dependent collapse. However, creating and maintaining such large-mass superpositions remains extremely challenging.

In this talk, I propose an alternative strategy. Both classical gravity and the DP model predict a minimum, unavoidable amount of diffusion. This opens the possibility of testing these proposals without needing large-mass superpositions, by instead looking for their characteristic diffusive effects. This approach has already proven successful in the context of the DP model, allowing the parameter-free version of the model to be ruled out. I will present this result in detail and discuss how similar experimental strategies can be extended to test the quantum vs classical nature of gravity.

Working Group:

WG3 - Low-energy gravitational effects in quantum systems

80

Welcome address

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Working Group Introductions 1 / 82

WG1: Quantum gravity and its phenomenology - theoretical perspectives from high energy

Auteurs: Alessia Platania[None]; Christian Pfeifer[1]

[1] *ZARM, University of Bremen*

Auteur correspondant christian.pfeifer@zarm.uni-bremen.de

We will give a brief overview of current approaches to quantum gravity and its phenomenology, with an emphasis on some of the core topics of the working group WG1 "High Energy Quantum Gravity".

Working Group:

WG1 - High Energy QG Theory

Working Group Introductions 2 / 83

WG6: Dissemination and Diversity - Status report and future plans

Auteurs: Denitsa Staicova[1]; Jelena Striskovic[2]

[1] *INRNE, Bulgarian Academy of Sciences*

[2] *Josip Juraj Strossmayer University of Osijek, Department of Physics*

Status report of WG6 "Dissemination and Diversity" activities and future prospects.

Working Group:

WG6 - Dissemination and Diversity

Working Group Introductions 2 / 84

WG3: Low-energy gravitational effects in quantum systems

Auteur: Lin-Qing Chen[None]

This talk introduces the research foundations of WG3, which focuses on the theoretical development of gravitational interactions in quantum systems within the low-energy regime. We explore foundational questions about the nature of gravity and the role of observers, with an emphasis on identifying experimentally testable phenomena. Topics include quantum clocks, quantum reference frames, gravitationally induced decoherence models, theoretical frameworks and new protocols for tabletop experiments probing quantum aspects of gravity. These investigations are closely connected with the experimental developments in WG4, and the concepts and theoretical frameworks explored in WG1 and WG5, with many further synergies yet to be uncovered.

Working Group:

WG3 - Low-energy gravitational effects in quantum systems

WG3 Low-energy Gravitational Effects in Quantum Systems 1 / 85

Reassessing Quantum Einstein Equivalence Principle

Auteur: Caslav Brukner[None]

Auteur correspondant caslav.brukner@univie.ac.at

The Einstein Equivalence Principle (EEP) underlies general relativity, asserting, from operational viewpoint, that a freely falling laboratory can locally eliminate gravitational effects. But does EEP still hold when the lab is a quantum system—delocalized, entangled, or in a nonclassical spacetime? In such cases, no single classical coordinate choice may exist to render spacetime Minkowskian. This talk explores how to generalize EEP to the specific quantum regime by introducing local quantum coordinates through suitable quantum-controlled diffeomorphisms. I will show that this framework allows one to transform to the lab's quantum frame and locally cancel gravitational effects, preserving the spirit of EEP in quantum settings. Implications for quantum gravity and foundational questions will also be discussed.

Working Group:

WG3 - Low-energy gravitational effects in quantum systems

WG1 High Energy QG Theory 4 / 86

QED in Ashtekar-Barbero variables and its implications

Auteur: Federica Fragomeno[1]

[1] *University of Alberta*

Auteur correspondant ffragome@ualberta.ca

We explore the modifications to fundamental geometric variables of Loop Gravity induced by the presence of fermions, and examine the resulting gravitational dynamics. This analysis is then extended to incorporate Quantum Electrodynamics (QED). Finally, we discuss potential approaches for quantizing the system, outlining possible directions for future research.

Working Group:

WG1 - High Energy QG Theory

Working Group Introductions 2 / 87

WG5: Bridges challenges opportunities

Auteur: Giovanni Amelino-Camelia[None]

Auteur correspondant gac0000@gmail.com

I offer a perspective on some research directions relevant for the COST Action, including IR/UV mixing, quantum-gravity-induced decoherence, spacetime fuzziness, quantum reference frames and the laws of particle propagation in a quantum spacetime. I also highlight two opportunities for phenomenology: the mystery concerning the origin of the KM3-230213A neutrino and the Caesium-Rubidium discrepancy for measurements of the fine structure constant.

Working Group:

WG5 - Connection between low-energy and high-energy quantum gravity

WG2 High Energy QG Experiments / 88

When astroparticles arrive at Earth - new ways for investigating LIV

Auteur: Denise Boncioli[None]

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Lorentz invariance can be tested by making use of ultra-high energy cosmic rays (UHECRs), namely the highest energy particles in the Universe. Their interactions in the extragalactic space can be altered if some level of Lorentz invariance violation (LIV) is present, which may lead to detectable fingerprints in the expected fluxes.
The scenario is actually more complicated than expected, due to the fact that the best astrophysical description of the UHECR energy spectrum and mass composition is found corresponding to values of maximum energy of UHECRs at the sources smaller than or comparable to the typical threshold energy for photo-meson or photo-disintegration reactions. For this reason, the sensitivity to deviations from Lorentz invariance (LI) in the UHECR propagation is milder than expected, and alternative approaches need to be investigated.
We therefore explore new ways to investigating LIV with astroparticles, by studying the development of the cascade of particles in the atmosphere, and the expected modifications in terms of muonic

and electromagnetic components in showers initiated by hadronic particles. Showers initiated by photons, and the LIV modifications in the Earth atmosphere and Earth crust, will be also scrutinised, to the aim of opening new ways to better constrain this fundamental symmetry.

Working Group:

WG2 - High Energy QG Experiment

WG1 High Energy QG Theory 1 / 89

Probing quantum gravity at all scales

Auteur: Astrid Eichhorn[1]

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To develop observational tests of quantum gravity, we require lever arms that translate Planck-scale predictions into predictions at observationally accessible scales. In my talk, I will use asymptotically safe quantum gravity as a case study. I will show, how the interplay of quantum gravity with matter (both visible and "dark") shapes the properties of matter fields in and beyond the Standard Model at the Planck scale. I will then show how to translate these Planck-scale predictions into predictions of Standard-Model properties as well as predictions about the properties of the dark matter and the dark energy using the Renormalization Group flow as a lever arm.

Working Group:

WG1 - High Energy QG Theory

WG3 Low-energy Gravitational Effects in Quantum Systems 2 / 90

The general structure of quantum-classical theories: for gravity and more

Auteur: Antoine Tilloy[None]

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It is possible to couple quantum and classical variables consistently (i.e. without paradoxes like faster than light signalling) provided one accepts a certain amount of stochasticity. This is useful, for example, if one wants to entertain the possibility that spacetime is fundamentally classical. These hybrid dynamics are not trivial (like meanfield) but they are nothing fancy either, and one way to construct them is via "measurement and feedback". I will explain how this is concretely done, and how the construction gives some intuition about the type of physics one can expect. I'll also try to mention some of the challenges in applying this formalism to gravity.

Working Group:

WG3 - Low-energy gravitational effects in quantum systems

WG5 Connection between low-energy and high-energy quantum gravity 1 / 91

Asymptotic symmetries and observables in 4d gravity

Auteur: Ana-Maria Raclariu[None]

Auteur correspondant ana-maria.raclariu@kcl.ac.uk

In this talk I will review recent progress in our understanding of large-distance features of gravity in (3+1)-dimensional asymptotically flat spacetimes. I will explain how one can extract from the asymptotic expansions of Einstein's equations a tower of charges whose conservation governs the low-energy (or soft) expansion of a graviton to all orders. The first in this tower are supertranslation charges well-known to generate 4d BMS transformations, while the leading soft graviton mode is directly related to the gravitational memory effect. I will conclude by discussing the potential relevance of these ideas for experiments aiming to probe vacuum spacetime fluctuations in quantum gravity.

Working Group:

WG5 - Connection between low-energy and high-energy quantum gravity

WG4 Low-energy high-precision experiment / 93

Exploring gravity with micro-mechanical oscillators

Auteur: Francesco Marin[None]

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The status of three optomechanical experiments is presented. The first one sets upper bounds on possible deformations of the standard commutator between position and momentum. The second one aims to detect the gravitational force between two silicon micro-oscillators in a high-purity state. The third one explores the motion of levitated nanospheres in the quantum regime.

Working Group:

WG4 - Low-energy high-precision experiment

Working Group Introductions 3 / 99

WG4: Low-energy high-precision experiments bridging quantum and gravity

Auteur: Catalina Curceanu[None]

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Working Group 4 (WG4) of the BridgeQG COST Action is dedicated to exploring how low-energy, high-precision experiments can offer unique insights into the relation between quantum physics and gravity. While high-energy approaches seek to probe gravity at the Planck scale, WG4 focuses on tabletop experiments to test predictions from quantum mechanics and General Relativity, including theories and models of Quantum Gravity. By bringing together expertise from theory experimental physics, WG4 aims to identify promising experimental platforms, develop new synergies, and

connect measurable effects to quantum gravity models. This talk presents WG4's objectives, current landscape, and opportunities for cross-disciplinary collaboration within the broader BridgeQG community.

Working Group:

WG4 - Low-energy high-precision experiment