Searching for Quantum Gravity in the Sky

a Bad Honnef Physics School

Book of Abstracts

Quantum gravity phenomenology - The past, the now and the future

Christian Pfeifer (University of Bremen)

A fundamental theory of quantum gravity is still elusive, and the search for it is one of the most challenging and interesting endeavors in fundamental physics today. Moreover, on the theoretical side, the path from fundamental approaches to quantum gravity like the most famous Loop Quantum Gravity or String Theory, to quantitative observable predictions is a huge effort in progress, while on the experimental side a smoking gun observation for a quantum gravity effect is still missing. In order to bridge this gap between fundamental theories of quantum gravity and observations, a bottom-up approach emerged: quantum gravity phenomenology.

In this talk, I will provide an overview of phenomenological models of quantum gravity that describe the interaction between quantum gravity and particles and fields—in other words, the propagation of particles and fields on quantum spacetime. These models predict deviations from the usual behavior of particles and fields on classical curved spacetime as described by general relativity. In the future, we hope that such deviations will either be detected in observatories receiving cosmic messengers from the universe or in ultra-precise laboratory experiments, or, the absence of these effects will impose constraints on theories of quantum gravity, requiring them to avoid predicting the absent effects.

Theory and observables within deformed relativity

Giacomo Rosati (University of Wrocław)

I will review the basic ideas behind the deformation of relativistic symmetries (DSR approach), give some practical examples, and compare this approach with the one in which relativistic symmetries are broken at the Planck scale, i.e. the so-called Lorentz Invariance Violation (LIV) scenario.
I will then focus on how some particular observables, like time delays in the propagation of ultra-high energy astrophysical particles, are obtained in the DSR scenario

The search for time delays in GRB and AGN observations

Jelena Strišković (Josip Juraj Strossmayer University of Osijek)

Possible deviations from the Lorentz symmetry affect interaction and propagation of very-high-energy gamma rays (VHE, > 100 GeV) through space-time. Currently, there are two main lines of LIV studies with imaging atmospheric Cerenkov telescopes (IACTs). The Universe transparency method investigates how the change of the reaction energy threshold (due to LIV) changes the observed source's spectrum. On the other hand, the Time of flight method investigates the influence of LIV on the photon speed and consequently changes in the light curve. During this school we will focus on Time of flight method and search for time delays in GRB and AGN data obtained with IACTs„ on concrete real-life data.

Quantum gravity effects on astroparticle propagation: interaction threshold effects

Rafael Alves Batista (Sorbonne Université)

This lecture series explores the search for quantum gravity (QG) effects using astroparticle probes. The first lecture provides a comprehensive introduction, detailing how to model the transport of astroparticles in various astrophysical environments. It will cover fundamental concepts such as cross sections, mean free paths, and key interaction processes that influence gamma rays, cosmic rays, and neutrinos. The second lecture focuses on deviations from the standard picture presented in the first lecture, illustrating how QG effects alter the propagation of astroparticles. Special emphasis will be placed on how interaction thresholds are modified due to QG effects. The final lecture deals with advanced modelling techniques that can be employed for this type of study, specifically transport equations and Monte Carlo methods, and presents several astrophysical scenarios as case studies for detecting potential QG signals.

- Lecture 1: Introduction and the Basics
    - Overview of the lecture series and objectives
    - Importance of studying quantum gravity effects on astroparticle propagation
    - Modelling the propagation of astroparticles
        - relevant ingredients for model-building
    - Review of particle interactions
        - cross sections
    - mean free paths
    - Interaction processes relevant for astroparticle propagation
        - threshold computations
        - examples of threshold calculations
        - examples of interactions (pair production, Compton scattering, photopion production, etc)
    - Importance of these interactions in the context of astroparticle propagation
- Lecture 2: Particle interactions and QG phenomenology
    - Departing from the standard picture: QG effects
        - Lorentz invariance violation (LIV)
        - deformed special relativity (DSR)
    - (Re-)computing interaction thresholds
    - Revisiting relevant interactions
    - Expected observational signatures:
        - high-energy gamma rays
        - ultra-high-energy cosmic rays
        - high-energy neutrinos
- Lecture 3: Modelling astroparticle propagation with QG effects
    - Numerical methods
        - transport equations
        - Monte Carlo methods
    - Case studies
        - gamma-gamma pair production
        - photodisintegration of cosmic rays
    - Confronting models and observations
        - expected signals

        - uncertainties
    - Summary and conclusions

Data analysis for anomalous threshold reactions

Caterina Trimarelli (University of Geneva)

The analysis of data related to anomalous threshold reactions is a crucial tool for investigating potential signals of new physics in the context of quantum gravity phenomenology. These reactions, which manifest as deviations from expected behavior in the energy threshold for certain particle interactions, can provide key insights into modifications of dispersion relations for various cosmic messengers, including photons, neutrinos, gravitational waves, and cosmic rays. This lecture will focus on models based on modified dispersion relations and how these models are compared with observational data to test their consistency and constrain possible new physics. The methodologies for identifying and quantifying deviations from standard predictions will be discussed, with an emphasis on how data analysis can refine or challenge these theoretical models.

Lecture 1
How to deal with data analysis in LIV scenario?
All the tools we need

1) Data set then different experiments for different messengers
2) Statistical tools
3) physical interactions in the standard case

Lecture 2

if LIV?

1) How the interactions change?
2) Build the model and expectations
3) Simulation tools (CORSIKA, conex etc)
4) Constrain the models

Lecture 3

Examples for the 4 different messengers.

Reaching the boundaries of general relativity - Tensions in Cosmology

Jackson Levi Said (University of Malta)

Our understanding of the Universe is at a turning point, and the confrontation of the latest observations from different leading research groups is starting to show a meaningful tension in our standard explanation of the evolution of the Universe. Since the late 1990s, it has been well-established that the Universe is currently undergoing a period of accelerated expansion which is caused by dark energy. This is a poorly understood form of energy but has had robust agreement with real-world measurements. The so-called standard model of cosmology is made up of a currently accelerating Universe driven by dark energy together with dark matter that boosts the level of growth of galaxies in the early Universe, and an underlying gravitational field that is described by Einstein's theory of general relativity. In this scenario, gravity can be visualized as a mechanism that affects the geometry around objects and across the cosmos.

The increasing strain in our standard cosmological model appears in various expressions of cosmic evolution ranging from the current expansion velocity of the Universe to the growth of the largest scale structures in the cosmos. This question of cosmic tensions may be addressed in several ways. Firstly, by further analyzing the latest cosmological surveys there may be important experimental features that could potentially influence these results. Secondly, it may be that the rapid advances in data analysis, including those related to machine learning, may need to be connected with the most widely used tools in the community. Finally, as the wealth of observational data continues to increase and the techniques of analyzing these measurements become more robust, it may be that we are experiencing a paradigm shift in our understanding of the Universe. This would call for a new explanation of how the Universe is evolving which meets more naturally the challenge of cosmic tensions. The opportunity provided by this development may also provide answers to long-standing fundamental questions including the nature of dark energy, the role of dark matter, and the fundamental nature of gravity.

Searching for quantum gravity in the lab, instead of the sky

Flaminia Giacomini (ETH Zürich)

This lecture offers a complementary perspective on where we may observe quantum effects in gravity. In particular, we will focus on the study of gravitating quantum systems, for instance a massive quantum system prepared in a quantum superposition of positions and sourcing a gravitational field.
This scenario has recently attracted a lot of attention: experiments are working towards realising macroscopic quantum superpositions of gravitational sources in the laboratory, and it is expected that measuring the gravitational field associated to a quantum source will give information about some quantum aspects of gravity. However, there are still open questions concerning the precise conclusions that these experiments could draw on the nature of gravity, such as whether experiments in this regime will be able to test more than the Newtonian part of the gravitational field.
In my lecture, I will first give a broad introduction to the field and present the most discussed physical situations. Then, I will argue that quantum information tools, such as theorems and communication protocols, can play an important role in identifying these effects and clarifying in which sense they are quantum. Finally, I will provide a personal perspective on why a theoretical study is needed to plan a new generation of experiments testing quantum aspects of gravity in a broader sense than what proposed so far.