TAL TECH

The role of non-Gaussianity in early universe phenomenology

Summary

The advent of GW astronomy opened an unprecedented window to probe the early universe. Primordial density fluctuations can be responsible for both the production of gravitational waves and primordial black holes, which are a candidate for dark matter. Both production mechanisms rely on whether the primordial curvature fluctuations follow Gaussian statistics. This project explores the phenomenological implications of strongly non-Gaussian curvature perturbations for gravitational wave and PBH phenomenology. This includes developing theoretical tools for the study of such scenarios, model building and the analysis of experimental signatures observable by the LIGO-Virgo-Kagra gravitational wave interferometers and PTA experiments, as well as future gravitational wave detectors such as LISA and ET.

Research field:	Applied physics and mathematics
Supervisor:	Hardi Veermäe
Availability:	This position is available.
Offered by:	School of Science National Institute Of Chemical Physics And Biophysics
Application deadline:	Applications are accepted between June 01, 2025 00:00 and June 30, 2025 23:59 (Europe/Zurich)

Description

In the broadest sense, the research entails the general study of early universe models producing non-trivial curvature power spectra and the resulting phenomenology. The main focus is on scenarios with strongly non-Gaussian features and their implications for cosmological gravitational wave (GW) backgrounds as well as the accompanying primordial black hole phenomenology. The PhD project is very topical and lies at the front line of gravitational wave phenomenology. In particular, the proposed theoretical research complements the rapid technological development of GW observatories by developing more accurate computational tools. These are needed to probe a wider array of early universe phenomena. The project will be divided into the following subtopics:

1. Modelling of early universe scenarios that can lead to detectable GW signatures, including models of cosmic inflation and spectator fields. Particular emphasis will be put on the modelling sources for strong non-Gaussianity.
2. Developing and applying abstract mathematical tools and computational methods for scalar-induced GWs in the strongly non-Gaussian regime, for which it is necessary to go beyond the perturbative approach.
3. Exploring the phenomenological consequences of strong non-Gaussianity primordial curvature perturbations for late time observables, including GWs but not limited to them. Developing methods to detect imprints of non-Gaussianity in cosmological GW backgrounds.
4. Contributing to the theory of PBH formation from strongly non-Gaussian perturbations. So far, all approaches for estimating the PBH abundance rely on simplifying assumptions. To employ the full discovery potential of future GW experiments, such as LISA for probing dark matter in the form of PBHs, it is crucial to test their validity or develop methods in which such assumptions can be relaxed.
5. Analysing the prospects for detecting anisotropies in the stochastic GW background arising from various cosmological sources—such as inflation, PBH, and strong non-Gaussianity—and forecasting their detectability with next-generation GW detectors.
6. The theoretical results will be applied to study available GW data as well as to explore the prospects of detecting potential GW signatures from the early universe with planned GW detectors.

Responsibilities and (foreseen) tasks

- Modelling building of early universe scenarios that can produce strong non-Gaussian curvature perturbations
- Development of abstract mathematical methods and efficient numerical tools for working with strong non-Gaussian fields
- Development of computational methods for PBH formation in strongly non-Gaussian fluctuations
- Development of methods for detecting imprints of non-Gaussianity in cosmological GW backgrounds.
- Analysis of available GW data and of prospects of future GW detectors.

- Active participation in scientific seminars and discussions in the research institute.
- Participation in topical conferences and workshops where the project's findings are presented.

Applicants should fulfil the following requirements:

- A master's degree in physics
- A clear interest in the topic of the position
- Excellent command of English
- Strong and demonstrable writing and analytical skills
- Capacity to work both as an independent researcher and as part of an international team

<u>The candidate should submit a research plan for the topic. The candidate can expand on the listed research questions and tasks.</u>

We offer:

- 4-year PhD position
- The chance to do high-level research.
- Opportunities for conference visits, research stays and networking with leading universities and research centers

About the department

The Laboratory of High Energy and Computational Physics (HEPC) of the National Institute of Chemical Physics and Biophysics (NICPB) provides an active international atmosphere with over 20 researchers from different countries. It is a member of the CERN CMS experiment and the ESA LISA consortium and has ongoing collaborations with researchers from several other European universities. HEPC has competence in theoretical and experimental particle physics, cosmology, gravitational wave phenomenology and high-performance computing and aims to carry out systematic interdisciplinary research on dark matter, dark energy, cosmic inflation, gravity and the interplay of those physical phenomena.

(Additional information)

For further information, please contact Hardi Veermäe hardi.veermae@cern.ch

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