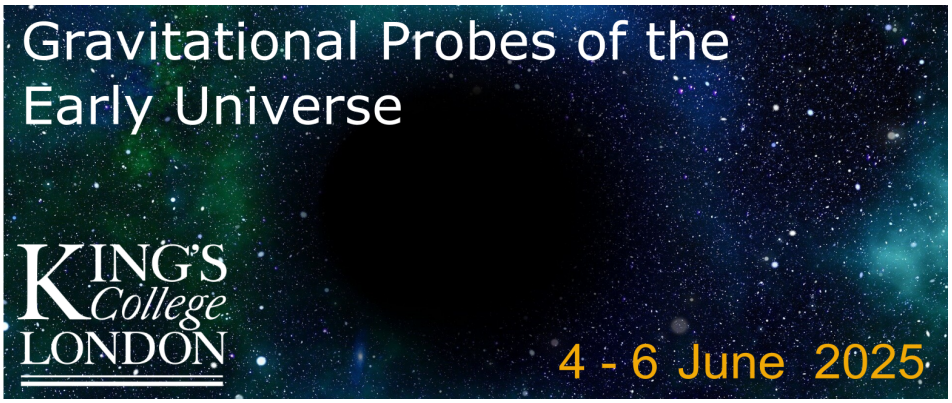
Gravitational Probes of the Early Universe

Wednesday 4 June 2025 - Friday 6 June 2025

Strand Campus King's College London



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Harvesting primordial black holes from stochastic trees

Author: Vincent VENNIN[1]

[1] *LPENS Paris*

Corresponding Author: vincent.vennin@ens.fr

When primordial inhomogeneities are produced with sufficiently large amplitude in the early universe, they may subsequently collapse into primordial black holes. I will explain why the effect of quantum diffusion during inflation needs to be taken into account in such a case, and how the statistics of cosmological fluctuations can be predicted within the formalism of stochastic inflation, and using stochastic trees. Quantum diffusion leads to a peculiar type of non-Gaussianity that cannot be captured by perturbative parameterizations. This leaves specific imprints on the statistics of collapsed structures that I will discuss. In particular, I will present recent results on the clustering of primordial black holes, which conditions the rate at which they merge and emit gravitational waves.

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WIMPs and New Physics Interpretations of the PTA Signal are Incompatible

Author: Yann Gouttenoire[1]

[1] *MITP*

Corresponding Author: ygoutten@uni-mainz.de

In order to explain the large amplitude of the nano-Hertz stochastic gravitational wave background observed in pulsar timing arrays (PTA), primordial sources must be particularly energetic. This is correlated to the generation of large density fluctuations, later collapsing into ultra-compact mini-halo (UCMHs). I will show that if dark matter is made of WIMPs, then photon and neutrino fluxes from UCMHs produced by curvature peaks, first-order phase transition and domain wall interpretations of the PTA signal, exceed current bounds.

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Open effective field theories for primordial gravitational waves

Author: Thomas Colas[1]

[1] *DAMTP - University of Cambridge*

Corresponding Author: tc683@cam.ac.uk

Friction and noise naturally emerge when gravitational waves propagate through unknown environments. In this talk, I will present a framework that extends effective field theories to systematically incorporate these effects. I will show how fundamental principles —such as symmetries, locality, and unitarity —place constraints on the form of dissipation and noise. Finally, I will discuss the phenomenological consequences for the tensor sector of the early universe, emphasizing potential observational signatures of these effects.

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Practical challenges in stochastic inflation

Author: Andrew Gow[1]

[1] *Institute of Cosmology and Gravitation, University of Portsmouth*

Corresponding Author: andrew.gow@port.ac.uk

The stochastic formalism of inflation allows the statistics of the curvature perturbation to be determined in a non-perturbative way, by reframing the quantum fluctuations during inflation as classical stochastic fluctuations. This is most important for the calculation of non-Gaussianity in the far tail of the perturbation probability distributions, where rare objects such as primordial black holes (PBHs) form. However, to determine the formation of PBHs of a certain size, it is necessary to find the PDF of the curvature perturbation coarse-grained on a particular scale. I will discuss the practical challenges involved with determining this PDF even for simple inflation models, utlising both analytical and numerical results.

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Inflationary Gravitational Waves as a Probe of the Unknown Expansion History of the early Universe

Author: Swagat Saurav Mishra[1]

[1] *University of Nottingham, UK*

Corresponding Author: swagatam18@gmail.com

One of the key predictions of the standard inflationary paradigm is the quantum mechanical generation of tensor fluctuations due to the rapid accelerated expansion of space, which later constitute a stochastic background of primordial Gravitational Waves (GWs). The amplitude of the (nearly) scale-invariant inflationary tensor power spectrum at large cosmological scales provides us with crucial information about the energy scale of inflation. Furthermore, the spectral energy density of the GWs at sufficiently small scales (or, large frequencies) serves as an important observational probe of the post-inflationary primordial dynamics. In fact, the small-scale spectral tilt of the GWs is sensitive to the (unknown) post-inflationary equation of state (EoS) of the universe: with a softer (than radiation) EoS resulting in red-tilted GWs, while a stiffer EoS resulting in blue-tilted GWs. The post-inflationary dynamics of the Universe, however, is generically expected to be quite complex, potentially involving a number of distinct cosmic epochs. In this talk, the speaker will discuss the possibility of multiple sharp transitions in the EoS of the post-inflationary universe and illustrate the corresponding spectral energy density of the inflationary GWs. The region of the parameter space which leads to a potentially detectable signal in the upcoming GW detectors, without violating the current constraints, will be explicitly presented.

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Induced gravitational wave probes of the primordial black hole reheating scenario

Author: Yann MAMBRINI[None]

Corresponding Author: yann.mambrini@th.u-psud.fr

In this talk, we will analysis the gravitational wave spectrum generated in the Universe filled by an inflaton field and a population of primordial black holes.

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Cosmological trackers from perturbations

Author: Martin Mosny[1]

[1] *University of Oxford*

Corresponding Author: martin.mosny709@gmail.com

Compared to standard cosmology, string cosmologies motivate an extended period of kination after inflation that can be followed by a cosmological tracker and then an epoch of moduli domination. Conventionally, such trackers occur when there is a scalar field with an exponential potential and an additional fluid whose energy density balances the kinetic and potential energy density of the scalar field. In this talk we show that a tracker can also be reached even when the universe only contains a scalar field, with no additional fluid. In this case perturbations in the scalar field can effectively behave like a radiation fluid, leading to a radiation tracker at late times.

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Superstring Phases in the Early Universe

Author: Joseph Conlon[1]

[1] *Oxford University*

Corresponding Author: joseph.conlon@physics.ox.ac.uk

I describe how evolving moduli and kination epochs in the early universe can lead to a novel post-inflationary string tracker solution, in which 75% of the energy density of the universe is in the form of a gas of fundamental string loops.

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Mapping inflationary loop corrections to boundary terms

Author: Laura Iacconi[1]

[1] *Queen Mary University of London*

Corresponding Author: l.iacconi@qmul.ac.uk

Both single- and multi-field models of inflation might lead to enhanced scalar fluctuations on scales much smaller than those seeding the large-scale structure formation. In these scenarios, it is possible that the spike of power at high wavenumber might induce large corrections to the scalar power spectrum, e.g. in the form of loop corrections, potentially endangering the perturbativity of the underlying models. In this talk we discuss recent developments in the calculation of the 1-loop correction to a large-scale adiabatic mode. We demonstrate that non-volume-suppressed corrections only contribute at the boundaries of the momentum integral. To achieve this we employ expansion methods, such as the δN formalism, as well as more general expansions that do not rely on assumption of validity of the separate universe picture.