Barcelona Black Holes (BBH) I: Primordial Black Holes

Monday, 27 May 2024 - Friday, 31 May 2024

UB Physics Faculty

Book of Abstracts

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Stochastic kicks in primordial black hole production

Authors: Eemeli Tomberg[1]; Sami Raatikainen[2]; Syksy Räsänen[None]

[1] *University of Lancaster*

[2] *University of Helsinki*

I discuss why stochastic effects are important in PBH formation and how they lead to spiky profiles for the curvature perturbation. When using the compaction function to set a collapse criterion, this can lead to a large enhancement of PBH abundance.

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Peak theory and non-Gaussianity

Author: Michiru Uwabo[1]

[1] *IBS-CTPU-CGA, Ochanomizu Univ.*

Spherical collapse is assumed in most of the works on PBH formation from the primordial curvature perturbation. According to the peak theory[1], sufficiently high peaks of a Gaussian random scalar field statistically have spherical symmetric shapes in the homogeneous and isotropic universe, which guarantees the above assumption. However, the PBH formation is related to highly non-linear regime of the perturbation and the non-Gaussianity may play an important role. In the talk, I will explicitly show how this argument can be modified if the curvature perturbation obeys non-Gaussianity.
[1] Bardeen et al. Astrophys.J. 304 (1986) 15-61

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Baryon asymmetry, gravitational waves and non-Gaussianities from primordial black hole formation

Author: Julian Rey[1]

[1] *DESY*

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We consider black hole formation due to the gravitational collapse produced by large density fluctuations generated during inflation. We show that non-Gaussian tails in the probability density function of curvature perturbations arise in these models from the delta N formalism, without resorting to stochastic inflation. Assuming the black holes form during an epoch of reheating with a stiff equation of state, we calculate the induced gravitational wave spectrum and constrain the parameter space by considering existing bounds on the total energy density of gravitational waves today. Finally, we calculate the lepton asymmetry generated by metric perturbations via the chiral gravitational anomaly and find that the large spectrum of scalar perturbations responsible for black hole formation induces a peak in the baryon asymmetry fluctuations on small scales.

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PBH formation during preheating

Author: Quim Iguaz Juan[1]

[1] *UMass Amherst*

Primordial Black Holes (PBHs) can form in the very early universe and can be associated with numerous cosmological and astrophysical signatures. We examined the production of large curvature perturbations that may lead to PBH formation in the early universe, in particular during the preheating phase that follows after inflation. At this stage, non-perturbative phenomena lead to the exponential amplification of field perturbations that can ultimately collapse into a black hole or form semi-stable configurations such as oscillons. The details of this phenomenon are directly linked to the features of the inflaton potential and type of inflation. We aim at easing the apparent confusion in the community regarding this issue and provide a consistent view of the conditions that actually lead to PBH formation.

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Yes

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Analytical model for black hole evaporation in cosmological space-time

Author: Semin Xavier[1]

Co-authors: Alan Sunny [2]; Shankaranarayanan Subramaniam [3]

[1] *Indian Institute of Technology Bombay, India*

[2] *INAF - Istituto di Astrofisica e Planetologia Spaziali, Via del Fosso del Cavaliere 100, and Department of Physics, University of Rome "Tor Vergata", Via Cracovia 90, Italy*

[3] *Indian Institute of Technology Bombay, India*

Current constraints suggest the primordial black holes(PBHs) in mass windows $10^{17} - 10^{23}$ gm are potential dark matter candidates. It has been argued that the PBHs less than 10^{15} gm would have evaporated by now. These analyses assume black holes are in an asymptotically flat space-time. However, realistic black holes are surrounded by local mass distributions and they are embedded in the expanding universe. In this talk, we focus on evaporating black holes in cosmological space-time. We analyze the evaporation process of an exact model for dynamical black hole space-time in general relativity. Our analysis shows that the decay rate of black holes in the cosmological background is different from the black holes in asymptotically flat space-time. We show that cosmological black hole decay is faster than the Schwarzschild black hole for larger masses. Our analysis has important

implications for the PBHs as a dark matter candidate. Our model suggests that the decay rate of the PBHs falls for lower masses, which is the opposite compared to the black holes in asymptotically flat space-time. In other words, it is not possible to completely rule out PBHs less than 10^{15} gm.

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Scalar perturbations from (thermal) stochastic sources

Authors: Alejandro Perez Rodriguez[1]; Guillermo Ballesteros[1]; Julian Rey[2]; Marcos Alejandro Garcia Garcia[3]; Mathias Pierre[2]

[1] *IFT UAM-CSIC*

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[3] *UNAM*

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We discuss the calculation of the power spectrum of scalar perturbations in the presence of stochastic source terms, providing insight on the expected outcome based on analytical approximations. We then focus on the case of warm inflation. In this scenario, the coupling of the inflaton to light fields during inflation leads to the former dissipating part of its energy into a thermal bath. The thermal fluctuations of this bath act as a stochastic source for inflaton perturbations, enhancing the inflationary scalar power spectrum and therefore increasing the predicted abundance of primordial black holes (and the corresponding scalar-induced gravitational waves), as well as modifying the CMB observables. We propose new numerical techniques based on the Fokker-Planck equation that improve both the precision and the computational efficiency of previous methods. Finally, we compare this setup with that of stochastic inflation, in which the backreaction of inflaton quantum fluctuations on the background is also modelled through stochastic terms.

Based on 2208.14978 and 2304.05978 with G. Ballesteros, M.A.G. García, M. Pierre, J. Rey.

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High frequency gravitational wave to test light primordial black holes

Author: Kazunori Kohri[1]

[1] *NAOJ*

To prove that primordial black holes are dark matter, various frequencies of gravitational waves will need to be observed in the future. I will explain some aspects of the theory and new methods for observing high frequency gravitational waves.

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Loop corrections in models of inflation with PBHs formation

Author: Hassan Firouzjahi[1]

[1] *IPM*

We study loop corrections in models of single field inflation which undergo an intermediate phase of USR inflation to generate PBHs. We calculate the loop corrections in power spectrum and bispectrum of CMB scale modes induced from small scale modes which become superhorizon during the USR phase. We consider the effects of both cubic and quartic interactions and investigate the effects of the sharpness of the transition from the USR phase to the final attractor phase.

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Primordial black holes: how to produce and probe them

Author: Philippa Cole[1]

[1] *University of Milan-Bicocca*

Observational constraints have closed off all but one mass-window for primordial black holes making up all of the dark matter, and there are some specific conditions required for their production in the first place. However, they remain a tantalising dark matter candidate because they require no new beyond the standard model particles and they would additionally provide a lot of information about the very early universe, particularly about inflation, if found. I will review the most plausible mechanisms for producing primordial black holes as well as highlight the difficulty of not over-producing them. I will also emphasise why it's worth checking every last window for signatures of their existence, and how, with a focus on future gravitational wave experiments, we can probe the remaining viable space in a consistent way.

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Formation of primordial black holes: introduction, spins and type II

Author: Tomohiro Harada[1]

[1] *Rikkyo University*

Tomohiro Harada

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Yes

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Simulations of Primordial Black Hole formation

Author: Albert Escriva[1]

[1] *Nagoya University*

Primordial Black Holes is currently considered a candidate for the dark matter. Still, to give realistic and reliable predictions about their production and abundance, we need to accurately infer the initial conditions that can lead those black holes to be procured. In that sense, numerical simulations of PBH formation are generally essential. In this talk, I will describe how to accurately infer these conditions in different scenarios, starting from the standard case of PBH formation from a radiation fluid to move later to PBH production from vacuum bubbles generated during inflation. I will also describe scenarios where a time-dependent equation of state can play a crucial role, like the QCD crossover or from physics beyond the Standard Model, and its connection with scalar induced gravitational waves. Finally, I will discuss some ongoing research regarding non-standard configurations of the gravitational collapse.

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Primordial Black Holes and Gravitational Waves from Domain Walls

Author: Alessio Notari[None]

Unstable domain wall (DW) networks in the early universe can emit a large amount of gravitational waves (GW) before annihilating.
In the context of the recent GW signal reported by Pulsar Timing Arrays (PTA) collaborations, I will explore them as a possible interpretation.
Next, I will address a crucial question: do unstable Domain Wall networks also lead to significant production of Primordial Black Holes (PBH)? I will then present two main consequences. Firstly, I will assess the compatibility of the DW interpretation of the PTA signal with observational constraints on PBHs. Secondly, I will consider the possibility that Dark Matter can be entirely in the form of asteroid-mass PBHs, resulting from the DW collapse. In this case, I will demonstrate that observable GW signals should be detectable at interferometers (such as LIGO-Virgo-KAGRA and future instruments like LISA and Einstein Telescope).

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Can short scales influence large scales during inflation?

Author: Jacopo Fumagalli[1]

[1] *ICCUB - Universitat de Barcelona*

How small-scale enhanced scalar fluctuations influence large scales, for instance, the one probed by the CMB, has recently been the object of an intense debate. In this context, I will discuss how one-loop diagrams from small-scale modes may -only apparently- lead to scale invariant corrections at large scales.
I will then discuss ways to have resonant IR cascades, namely cases where loop corrections can be significant in the -near- infrared.

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Stochastic Inflation in General Relativity

Author: Gerasimos Rigopoulos[None]

I provide a formulation of Stochastic Inflation in full general relativity that goes beyond the slow-roll and separate universe approximations. All degrees of freedom are included in the dynamics and all gradient terms are kept. The stochastic source terms are gauge invariant and defined in terms of the only dynamical scalar degree of freedom in single-field inflation, the Mukhanov-Sasaki variable, and the linearized tensors. The equations can therefore be formulated in any gauge. We validate the efficacy of these Langevin dynamics directly using an example in uniform field gauge, obtaining the stochastic e-fold number in the long wavelength limit without the need for a first-passage-time analysis. These equations enable a well-posed implementation for 3+1 numerical relativity simulations with stochastic noise and can potentially illuminate the problem of PBH production via full 3D numerical simulations.

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Opening / 17

Cristiano Germani

Opening / 18

Germani (opening)

ICCUB / 19

Xavier Luri (ICCUB, presentation)

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The statistics of Primordial Black Holes

Author: Cristiano Germani[None]

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Non-Gaussianities in the PBH Formation and Induced GWs

Author: Shi Pi[None]

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Limits on PBH as Dark Matter Constituents from Supermagnied Stars in Lensing Galaxy Clusters

Author: Jordi Miralda[1]

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Closing remarks

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