

New Horizons in Primordial Black Hole physics (NEHOP) – '24

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Book of Abstracts

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Session 9 / 3

Constraining primordial non-Gaussianities with primordial black hole induced gravitational waves**Author:** Theodoros Papanikolaou¹¹ *National Observatory of Athens***Corresponding Author:** papaniko@noa.gr

Ultra-light PBHs with masses $M < 5 \times 10^8 \text{g}$ can dominate transiently the energy budget of the Universe and reheat the Universe through their evaporation taking place before Big Bang Nucleosynthesis (BBN). Interestingly enough, the inhomogeneous distribution of a population of such light PBHs can induce the abundant production of GWs due to second-order gravitational effects. In this talk, we will discuss the effect of primordial non-Gaussianity on the clustering properties of PBHs as well as on the spectral shape of the aforementioned induced GW signal. In particular, focusing on local-type non-Gaussianity we find a distinctive double-peaked GW signal which, depending on the PBH mass M and the initial abundance of PBHs at formation time, i.e. $\Omega_{\text{PBH},f}$, can lie within the frequency bands of future GW detectors, namely that of LISA, ET, SKA and BBO, hence rendering this signal potentially detectable by GW experiments and promoting it as a novel portal probing primordial non-Gaussianities. Remarkably, by accounting on BBN bounds on the non-Gaussian GW amplitude we set model-independent constraints on the effective τ_{NL} on very small scales $k > 10^5 \text{Mpc}^{-1}$ otherwise inaccessible by CMB and LSS probes.

Session 11 / 4

 θ -vacua, asymmetric Hawking radiation and baryogenesis from primordial black holes**Author:** Archil Kobakhidze¹¹ *The University of Sydney***Corresponding Author:** archil.kobakhidze@sydney.edu.au

In empty Minkowski space, the CP-violating electroweak θ -term can be rotated away by the redefinition of quark and lepton states by anomalous B+L phase transformations. I will argue this is no longer true in black hole spacetime, where non-zero θ -term remains on the black hole horizon. This boundary term acts as a source of CP-asymmetric Hawking radiation. The phenomenon may be responsible for cosmological baryogenesis from primordial black holes.

Session 4 / 5

The Inflationary Butterfly Effect: non-perturbative dynamics from small-scale features**Author:** Angelo Caravano¹**Co-authors:** Keisuke Inomata ; Sebastien Renaux-Petel¹ *IAP Paris***Corresponding Author:** caravano@iap.fr

I will present the first non-perturbative study of a single-field model of inflation with a localized departure from slow-roll. Using lattice simulations, we find that small-scale oscillatory features in the potential can lead to drastic changes in the evolution of the inflationary Universe, with profound phenomenological implications. In certain cases, the entire Universe gets trapped in an eternal de Sitter state. In others, some regions get stuck in a false vacuum within the oscillatory feature, offering an alternative channel for primordial black hole (PBH) formation. Notably, these drastic non-perturbative effects occur when linear perturbation theory predicts $P_\zeta \simeq 10^{-2}$, demonstrating the importance of a fully nonlinear treatment in the regime relevant for PBH formation. Additionally, we compare our fully nonlinear lattice power spectra with perturbative 1-loop calculations.

Session 9 / 6

Dark Dresses around Primordial Black Holes: Phenomenological Implications

Author: Daniele Gaggero¹

¹ *Istituto Nazionale di Fisica Nucleare, Sezione di Pisa*

Corresponding Author: daniele.gaggero@pi.infn.it

I will discuss the interplay between the phenomenology of primordial black holes and the dark matter searches. I will focus on how a sub-dominant component of PBHs interacts with the bulk of the DM. In particular, I will describe how a DM “mini-halo” is expected to form around PBHs, with relevant phenomenological consequences. The focus will be on two relevant effects. (i) If the bulk of the DM is composed of WIMPs, the mini-halos would shine in gamma rays. Hence, a hypothetical future detection of a sub-dominant component of PBHs could allow to set very stringent constraints on the WIMP annihilation cross section. (ii) The dark mini-halo can significantly alter the accretion rate of baryonic matter. I will discuss this effect and its impact on the CMB bounds, stressing the importance of the accretion model. I will conclude by carefully reassessing the accretion bounds (both astronomical and cosmological) stressing the relevance of the astrophysical uncertainties.

Session 2 / 7

How does your black hole grow?

I will review some past work on slow roll inflation with a black hole, showing how the growth of the horizon can be computed. I will then discuss how the picture can change with ultra slow rolling scalars.

Session 7 / 9

Classical and stochastic δN formalisms

Authors: Alejandro Perez Rodriguez¹; Guillermo Ballesteros²; Julian Rey³; Mathias Pierre³; Thomas Konstandin³

¹ *IFT UAM-CSIC*

² *IFT-UAM/CSIC*

³ *DESY*

Corresponding Authors: alejandro.perezrodriguez@uam.es, thomas.konstandin@desy.de, mathias.pierre@desy.de, julian.rey@desy.de, guillermo.ballesteros@uam.es

The non-Gaussian tail of the PDF of primordial scalar perturbations is a key element to determine the abundance of primordial black holes. These primordial non-Gaussianities arise, at least partly, from the non-linear, super-horizon dynamics of inflationary perturbations. Such non-linear evolution is usually addressed through the stochastic δN formalism. This formalism is based on the deterministic δN formalism, which captures the non-linear relation between curvature and inflaton perturbations, and is then supplemented with the stochastic formalism of inflation, which accounts for the backreaction of quantum fluctuations into large-scale inflaton dynamics. In our work, we reconsider the underlying assumptions and implications of this calculation using both numerical and analytical methods, assessing the validity of several approximations commonly used in the literature.

Based on work in progress with Guillermo Ballesteros, Thomas Konstandin, Mathias Pierre and Julian Rey.

Session 5 / 10

The mass-distribution of LIGO's events as a probe for dark matter

Authors: Ilias Cholis¹; Mehdi El Bouhaddouti¹

¹ *Oakland University*

Corresponding Authors: melbouhaddouti@oakland.edu, cholis@oakland.edu

Primordial black holes (PBHs) may contribute to the observed abundance of dark matter. We use the black-hole mass distribution obtained from the detected binary black hole merger events by the LIGO/VIRGO gravitational-wave observatories, with a signal to noise ratio (SNR) > 8 . We search for and place limits on PBHs in the stellar-mass range. We also simulate binary black holes following models of formation of two separate populations of merging binaries: stellar-origin binary black holes and PBH binaries. For those we calculate the signal to noise ratio that would result on the LIGO detectors. Selecting only simulated merger events with a SNR > 8 , we fit the combination of these two components to the LIGO/VIRGO data. In our work, we rely on a wide range of black-hole mass distributions expected from models of formation of stellar-origin black holes and of PBHs.

Session 11 / 11

Gravothermalizing into cannibal stars and primordial black holes

Authors: Daniele Perri¹; Pranjal Ralegankar¹; Takeshi Kobayashi¹

¹ *SISSA*

Corresponding Authors: tkobayas@sissa.it, pralegan@sissa.it, dperri@sissa.it

Very little is known about the universe's history from after the end of inflation until the Big Bang nucleosynthesis (BBN), which spans more than 10^{39} orders of magnitude in time scales. In this work, we show that if there was a long period of matter domination (at least 10^8 scale factors) in this unknown period, and if the particle causing the matter domination has self-interactions, then the matter particles can undergo gravothermal collapse to form primordial black holes (PBHs). We show that $4 \rightarrow 2$ self-annihilations of the particles can form a 'cannibal star' and inhibit collapse to a black hole for some parameter space. For a range of black hole formation efficiency, we find that CMB and BBN constraints on PBHs can rule out significant regions of EMDE parameter space. Thus, we show how PBHs can offer a new window into a pre-BBN universe.

Session 1 / 12

Are supermassive black holes primordial?**Author:** Chris Byrnes¹¹ *University of Sussex***Corresponding Author:** ctb22@sussex.ac.uk

Black holes with masses between a million and a billion solar masses are seen in the centres of many galaxies, even at high redshift. Their origin remains unknown and hard to explain, raising the possibility that these black holes are primordial rather than astrophysical. I will discuss the motivation for this scenario and the difficulty in finding a working model, especially due to constraints from CMB spectral distortions which tightly constrain non-standard initial conditions on the relevant length scale for supermassive black holes.

Session 6 / 13

Light primordial black holes as a viable dark matter candidate**Author:** Valentin Thoss¹¹ *Ludwig-Maximilians-Universität München***Corresponding Author:** vthoss@usm.lmu.de

The energy injection through Hawking evaporation has been used to put strong constraints on primordial black holes as a dark matter candidate at masses below 10^{18} g. However, recent work has shown that Hawking's semiclassical approximation breaks down at latest after half-decay. Beyond this point, the evaporation could be significantly suppressed. In this work, we review existing cosmological and astrophysical bounds on primordial black holes. We show that the constraints disappear completely for a reasonable range of parameters, which opens a new window for light primordial black holes as a dark matter candidate.

Session 2 / 14

Primordial Black Holes Are True Vacuum Nurseries**Authors:** Andrew Cheek¹; Louis Hamaide^{None}; Lucien Heurtier²; Shiqian Hu²¹ *Astrocent, NCAC*² *King's College London***Corresponding Authors:** lucien.heurtier@kcl.ac.uk, shiqian.hu@kcl.ac.uk, louis.hamaide@kcl.ac.uk, acheek@camk.edu.pl

The Hawking evaporation of primordial black holes (PBH) reheats the Universe locally, forming hot spots that survive throughout their lifetime. We propose to use the temperature profile of such hot spots to calculate the decay rate of metastable vacua in cosmology, avoiding inconsistencies inherent to the Hartle-Hawking or Unruh vacuum. We apply our formalism to the case of the electroweak vacuum stability and find that a PBH energy fraction $\beta > 7 \times 10^{-80} (M/\text{g})^{3/2}$ is ruled out for black holes with masses $0.8 \text{ g} < M < 10^{15} \text{ g}$.

Session 2 / 15

Primordial Black Hole probes of Heavy Neutral Leptons**Authors:** Agnese Tolino¹; Valentina De Romeri^{None}; Yuber Perez^{None}¹ IFIC (CSIC-UV)**Corresponding Authors:** deromeri@ific.uv.es, yuber.f.perez-gonzalez@durham.ac.uk, atolino@ific.uv.es

In this talk, I will discuss possible probes of Heavy Neutral Leptons (HNLs) with Primordial Black Holes (PBHs).

If produced in the early Universe with an initial mass of $\sim 10^{15}$ g, PBHs are expected to evaporate at the present time producing sizable

fluxes of particles in their last instants. These “exploding” black holes will emit bursts of Standard Model particles as well as new degrees of freedom, if present.

We explore the possibility that HNLs mixing with the active neutrinos are emitted in the final evaporation stage of PBHs.

We evaluate the active neutrino fluence expected from such an explosion, to which the decays of the heavy sterile neutrinos contribute through a secondary emission.

We estimate the expected number of muon-neutrino events at IceCube and we infer sensitivities on the active-sterile neutrino mixing and the sterile neutrino mass.

Session 9 / 16

Signatures of domain wall networks: from gravitational waves to primordial black holes**Author:** Ricardo Z. Ferreira¹¹ U. Coimbra**Corresponding Author:** rzferreira@uc.pt

The Domain Wall (DW) problem is the fact that DW networks that result from the spontaneous breaking of discrete symmetries tend to dominate the universe's energy budget.

However, if the symmetry is not exact the network annihilates and the problem turns into a virtue, as the network tends to be an abundant component before its collapse, and is thus easier to probe.

In this talk, I will discuss recent progress in the study of the gravitational relics of DW networks - gravitational wave emission and primordial black holes formation - and the interesting possibility that such networks might be behind the recent GW signal observed at Pulsar Timing Arrays.

Session 11 / 17

Primordial Black Holes from Domain Wall Networks**Author:** Yann Gouttenoire^{None}**Corresponding Author:** yann.gouttenoire@gmail.com

Domain Wall Networks are defects of the quantum vacuum which can be generated after phase transition taking place in the early universe. Since we do not observe such objects today, if they form then they must annihilate early on. I will discuss recent advances in our understanding of how Primordial Black Holes can be produced during the annihilation stage. Wormholes to parallel universes can also be generated.

Session 10 / 18

Uphill inflation**Author:** Vadim Briaud¹¹ *LPENS***Corresponding Author:** vadim.briaud@phys.ens.fr

Primordial black holes (PBH) may form from large cosmological perturbations, produced during inflation when the inflaton's velocity is sufficiently slowed down. This usually requires very flat regions in the inflationary potential. In this talk, I will discuss another possibility, namely that the inflaton climbs up its potential. When it turns back, its velocity crosses zero, which triggers a short phase of "uphill inflation" during which cosmological perturbations grow at a very fast rate. This naturally occurs in double-well potentials if the width of the well is close to the Planck scale. I will discuss the effect of quantum diffusion in this scenario, which plays a crucial role, through the stochastic- δN formalism. Finally, I will discuss the amount of PBH that is expected to be produced in such a model.

Session 6 / 19

Close Encounters of the Primordial Kind**Authors:** Benjamin Lehmann¹; David Kaiser¹; Sarah Geller²; Tung Tran¹¹ *MIT*² *Massachusetts Institute of Technology***Corresponding Authors:** tungtran@mit.edu, bvl@mit.edu, sgeller@mit.edu, dikaiser@mit.edu

Primordial black holes (PBHs) remain a viable dark matter candidate in the asteroid-mass range. I will show that, if PBHs lie within this mass range and make up most or all of the dark matter, the PBH abundance would be large enough for at least one object to cross through the inner Solar System per decade. Since Solar System ephemerides are modeled and measured to extremely high precision, such close encounters could produce detectable perturbations to orbital trajectories with characteristic features. Using a suite of simple Solar System simulations, I will make the case that the abundance of asteroid-mass PBHs can be probed by existing and near-term data, potentially furnishing us with a new direct probe of PBH dark matter.

Session 4 / 20

Compaction function profiles from stochastic inflation**Author:** Eemeli Tomberg¹¹ *Lancaster University***Corresponding Author:** e.tomberg@lancaster.ac.uk

Primordial black holes can arise from quantum fluctuations produced during cosmic inflation. Stochastic inflation is a method to compute the fluctuation statistics non-perturbatively, including non-Gaussianities. I discuss recent progress in the numerical implementation of the method, allowing us to compute the radial dependence of the fluctuations' compaction function in random patches of space. These compaction function profiles are needed for accurate black hole predictions. Using example models of ultra-slow-roll inflation, I discuss the spiky, stochastic nature of the profiles, their

dependence on the curvature power spectrum, and the implications for the abundance and mass distribution of primordial black holes.

Session 14 / 21

Relic neutrino decay solution to the excess radio background mystery

Author: Pasquale Di Bari¹

¹ *University of Southampton*

Corresponding Author: p.di-bari@soton.ac.uk

I will first discuss why the excess radio background measured by the balloon borne experiments ARCADE 2 is a mystery and might be an indication of new physics. After having reviewed a few solutions that have been proposed and that are now ruled out I will focus on the possibility that the excess is explained by radiative decays of relic neutrinos, showing how they produce a very nice fit to the data. I will then talk about possible models of neutrino decays able to produced such a solution. I will finally comment on possible links of such a solution with other cosmological anomalies and tensions.

Session 9 / 22

Timekeepers of the Universe: The recent gravitational wave observation by PTA and PBH.

Author: Antonio Junior Iovino¹

Co-authors: ANTONIO RIOTTO ²; Alexandros Kehagias ³; Andrea Iannicari ⁴; Davide Perrone ⁴; Gabriele Franciolini ⁵; Hardi Veermae ⁶; Ville Vaskonen ⁶

¹ *Università degli studi di Roma "La Sapienza"*

² *UNIVERSITY OF GENEVA*

³ *Natl. Tech. U., Athens*

⁴ *University of Geneva*

⁵ *University of Rome, La sapienza*

⁶ *KBFI*

Corresponding Authors: davide.perrone@unige.ch, gabriele.franciolini@uniroma1.it, antonio.riotto@unige.ch, antoniojunior.iovino@uniroma1.it

The recent data releases by multiple pulsar timing array (PTA) experiments show evidence for Hellings-Downs angular correlations indicating that the observed stochastic common spectrum can be interpreted as a stochastic gravitational wave background. We study whether the signal may originate from gravitational waves induced by high-amplitude primordial curvature perturbations. Such large perturbations may be accompanied by the generation of a sizeable primordial black hole (PBH) abundance. We discuss in which scenarios the inclusion of non-Gaussianities in the computation of the abundance can lead to a signal compatible with the PTA experiments without overproducing PBHs. The talk si based on these papers:
<https://inspirehep.net/literature/2759520>
<https://inspirehep.net/literature/2672979>

Session 7 / 23

Clustering of primordial black holes from quantum diffusion during inflation

Authors: Chiara Animali¹; Vincent Vennin²

¹ *LPENS, CNRS UMR8023 Paris*

² *LPENS, Paris*

Corresponding Author: animalichiara@gmail.com

When investigating primordial black hole (PBH) formation scenarios, a central question is to characterise their initial clustering, which then determines their subsequent clustering evolution throughout cosmic history. In this talk I will present how to compute PBH clustering in the presence of non-perturbative non-Gaussianities, making use of the stochastic- δN formalism. To this end, I will show how to derive the two-point statistics of the curvature perturbation in stochastic inflation, consistently including volume-weighting effects. Due to the presence of exponential tails, the joint distribution of large fluctuations is of the form $P(\zeta_{R_1}, \zeta_{R_2}) = F(R_1, R_2, r)P(\zeta_{R_1})P(\zeta_{R_2})$, where ζ_{R_1} and ζ_{R_2} denote the curvature perturbation coarse-grained at radii R_1 and R_2 , around two spatial points distant by r . This implies that, on the tail, the reduced correlation function, defined as $P(\zeta_{R_1} > \zeta_c, \zeta_{R_2} > \zeta_c) / [P(\zeta_{R_1} > \zeta_c)P(\zeta_{R_2} > \zeta_c)] - 1$, is independent of the threshold value ζ_c . This contrasts with Gaussian statistics where the same quantity strongly decays with ζ_c , and shows the existence of a universal clustering profile for all structures forming in the exponential tails. Structures forming in the intermediate (i.e. not yet exponential) tails may feature different, model-dependent behaviours.

Session 6 / 24

Cosmological particle production and PBHs

Authors: Enrico Bertuzzo^{None}; Gabriel Massoni Salla¹; Renata Zukanovich Funchal^{None}; Yuber Perez^{None}

¹ *Physics Institute of the University of Sao Paulo*

Corresponding Authors: yuber.f.perez-gonzalez@durham.ac.uk, gabriel.massoni.salla@usp.br

Among many mechanisms that produce particles via gravitational interactions, the production of particles from the expansion of the universe represents a simple and irreducible source of particles from the early universe, that can account for the present abundance of dark matter. Another feasible and interesting mechanism is to have a population of primordial black holes that, through evaporation, produce the correct amount of dark matter. Since these black holes can alter the cosmological history, inject entropy and emit particles on their own, they can non-trivially impact the gravitational production of particles from the expansion and change the predicted fraction of dark matter. In this talk, I will discuss the interplay between these two mechanisms, while highlighting how the final abundance of dark matter changes in the presence of the primordial black holes. We also investigate the possibility of the dark matter produced from the expansion to generate primordial black holes by gravitational collapse, thus providing a novel production mechanism for the latter.

Session 2 / 25

Gravitational Microlensing of Asteroid Mass PBHs

Author: Renee Key¹

¹ *Swinburne University of Technology*

Corresponding Author: rkey@swin.edu.au

Gravitational microlensing is known as a productive method for exoplanet discovery and characterisation, and crucially, it also provides an experimental avenue to constrain the galactic PBH abundance in the mass regime from $\sim 10\text{--}12 M_\odot$ (i.e. asteroid-mass scale) to $\sim 1000 M_\odot$. The key to probing the very lowest masses is fast cadence observations on the order of hours to minutes. We previously conducted a 5-night DECam survey of the Large Magellanic Cloud (LMC), monitoring 2 million LMC stars in a single very broad optical filter to a limit of $r \approx 23$ at ≈ 40 second cadence, with the primary motivation being to place constraints on the PBH abundance in the Galactic halo in the asteroid- to Jupiter-mass regime ($-12 \leq \log M/M_\odot \leq -4$). A galactic halo population of PBHs are a simple solution to the dark matter (DM) problem. Being dark, massive and non-baryonic, the PBH fits the phenomenological traits defining Cold DM. This talk will present the most stringent results on asteroid-mass PBHs in the Milky Way halo by incorporating considerations of second-order realistic corrections to the microlensing signal, such as finite source effects and wave optics. The main discussion of this talk will be the detection pipeline, a discussion on the pipeline efficiency and 95% C.L on the fraction of PBHs that exist as halo DM within the standard halo model.

Session 12 / 26

Scalar-Induced Gravitational Waves and its impact in understanding cosmology

Author: Anjali Abirami Kugarajh¹

¹ *Gran Sasso Science Institute*

Corresponding Author: anjali.kugarajh@gssi.it

Observations of gravitational waves (GW) from mergers of binary black holes has opened up a new door into cosmology. Due to their weak interaction with matter, we hope to observe Primordial GWs among the various signals that are expected from current and future-generation detectors. This offers a new and exciting opportunity to explore the physics of the early Universe. Quantum vacuum fluctuations are the standard generation mechanism and due to its quantum nature, Primordial GWs come in the form of a stochastic background (SGWB). One contribution to the latter arises from “scalar-induced” GWs (SIGWs), that are produced by second-order effects and coupling of scalar perturbations. Furthermore, the primordial fluctuations which produce SIGWs can additionally collapse to form primordial black holes (PBHs), providing a new channel to study their formations scenario and abundance.

In this talk I will briefly present the motivation to study SIGW. To understand the signature of SIGW that we can observe, I present our computations of the source term, first in a generic gauge and later by imposing the Newtonian gauge. In addition, we discuss how SIGW can be used to understand and probe both standard cosmology and beyond General Relativity, specifically considering modified gravity models. In particular we look at the effect of the modifications in the source term, considering the first-order corrections.

Session 7 / 27

Dark matter spikes around stellar-mass black holes: Evidence of a primordial origin?

Author: Aurora Ireland¹

¹ *University of Chicago*

Corresponding Author: anireland@uchicago.edu

Recent observations of black holes in two nearby low-mass x-ray binary systems have suggested possible evidence of dark matter density spikes. It has long been established that cold dark matter should form dense spikes around intermediate-mass and supermassive black holes due to the adiabatic compression of the dark matter profiles and accretion. Lighter black holes of a stellar origin, however, are not expected to develop spikes, and so it is unclear how these observed stellar-mass black holes could have acquired such features. Primordial black holes, on the other hand, likely come equipped with dark matter mini-spikes. In this talk, we explore the possibility that these stellar-mass black holes may actually be primordial in origin, confronting the data with predictions of the mini-spike radial profile for a range of dark matter models.

Session 12 / 28

Memory burden effect in solitons: consequences for primordial black holes

Author: Michael Zantedeschi¹

¹ *Tsung-Dao Lee Institute, Shanghai, China*

Corresponding Author: michael.zantedeschi1@gmail.com

The essence of the memory burden effect is that a load of information carried by a system stabilizes it. This universal effect is especially prominent in systems with a high capacity of information storage, such as black holes and other objects with maximal microstate degeneracy, the entities universally referred to as saturons. The phenomenon has several implications. The memory burden effect suppresses a further decay of a black hole, the latest, after it has emitted about half of its initial mass. As a consequence, the light primordial black holes (PBHs), that previously were assumed to be fully evaporated, are expected to be present as viable dark matter candidates. In this talk I will review the memory burden effect and establish a precise correspondence in solitons and in black holes.

Finally, I will identify cer

Session 3 / 29

Gravitational Leptogenesis and Primordial Gravitational Waves during PBH-induced Reheating

Authors: Basabendu Barman¹; Suruj Jyoti Das²; Md Riajul Haque³; Yann Mambrini⁴

¹ *Department of Physics, School of Engineering and Sciences, SRM University AP*

² *Institute for Basic Science, CTPU*

³ *Centre for Strings, Gravitation, and Cosmology, Department of Physics, Indian Institute of Technology Madras*

⁴ *Université Paris-Saclay, CNRS/IN2P3, IJCLab*

Corresponding Authors: basabendu88barman@gmail.com, yann.mambrini@ijclab.in2p3.fr, riaj.0009@gmail.com, surujjd@gmail.com

We explore the possibility of dynamically producing the observed matter-antimatter asymmetry of the Universe entirely from the evaporation of primordial black holes (PBH), that are formed in an inflaton-dominated

background. Considering the inflaton (ϕ) to oscillate in a monomial

potential $V(\phi) \propto \phi^n$, we show that it is possible to obtain

the desired baryon asymmetry via vanilla leptogenesis from evaporating

PBHs of initial mass

$\lesssim 10$ g. The feasible parameter space is

heavily dependent on the shape of the inflaton potential during reheating

(determined by n), the energy density of PBHs (determined by β), and the nature of the coupling between the inflaton and the Standard Model (SM). We further include in our analysis the minimal gravitational leptogenesis set-up through inflaton scattering via a graviton, that opens up an even larger window for PBH mass, depending on the background equation of state. We finally show that such gravitational leptogenesis scenarios can be tested with upcoming gravitational wave (GW) detectors, courtesy of the blue-tilted primordial GW with inflationary origin, thus paving a way to probe a PBH-induced reheating and leptogenesis era.

Session 4 / 30

Inflation and primordial black hole production in Starobinsky-like supergravity

Author: Ryotaro Ishikawa¹

Co-author: Sergei Ketov¹

¹ *Tokyo Metropolitan University*

Corresponding Authors: ketov@tmu.ac.jp, ishikawa-ryotaro@ed.tmu.ac.jp

A viable model of large-field (chaotic) inflation with efficient production of primordial black holes is proposed in Starobinsky-like (modified) supergravity leading to the "no-scale-type" Kähler potential and the Wess-Zumino-type ("renormalizable") superpotential. The cosmological tilts are in good (within 1σ) agreement with Planck measurements of the cosmic microwave background radiation. In addition, the power spectrum of scalar perturbations has a large peak at smaller scales, which leads to a production of primordial black holes from gravitational collapse of large perturbations with the masses about 10^{17} g. The masses are beyond the Hawking (black hole) evaporation limit of 10^{15} g, so that those primordial black holes may be viewed as viable candidates for a significant part or the whole of the current dark matter. The parameters of the superpotential were fine-tuned for those purposes, while the cubic term in the superpotential is essential whereas the quadratic term should vanish. The vacuum after inflation (relevant to reheating) is Minkowskian. The energy density fraction of the gravitational waves induced by the production of primordial black holes and their frequency were also calculated in the second order with respect to perturbations.

Session 3 / 31

How Primordial Black Holes constrain leptogenesis

Author: Jacob Gunn¹

¹ *University of Naples Federico II*

Corresponding Author: jacobwilliam.gunn@unina.it

The parameter spaces of leptogenesis and ultralight ($M_{\text{PBH}} \leq 10^9$ g) Primordial Black Holes (PBHs) are notoriously difficult to constrain, but while experiments struggle to probe sterile neutrino masses heavier than a few GeV, the new window into the early universe opened by Gravitational Wave (GW) astronomy offers realistic hopes of detecting GW signals associated with PBHs. Since ultralight PBHs would be born, live and die in or around the era of leptogenesis, even tiny populations can have profound effects on a wide range of leptogenesis models. In particular, for $M_{\text{PBH}} \geq 10^6$ g, the entropy injection from PBHs has been shown to be highly incompatible with thermal leptogenesis, leading us to draw stringent mutual exclusion limits between the two scenarios. In this talk I discuss how GW observations of PBHs can rule out models of leptogenesis far beyond the reach of direct detection experiments, and how searches for light sterile neutrinos are impacted. I elucidate the fascinating interplay between leptogenesis and PBHs in the early universe, and show how we can

glean information about leptogenesis and PBHs from future experimental results. I will also cover some recent and highly interesting developments concerning particle processes in hot-spots.

Session 8 / 32

Quantum tunneling in the early universe: Stable magnetic monopoles from metastable cosmic strings

Author: Rinku Maji¹

¹ *Institute for Basic Science, Center for Theoretical Physics of the Universe*

Corresponding Author: rinkumaji9792@gmail.com

We discuss a novel mechanism for producing topologically stable monopoles (TSMs) from the quantum mechanical decay of metastable cosmic strings in the early universe. For a dimensionless string tension parameter $G\mu \approx 10^{-9} - 10^{-5}$, the monopoles are superheavy with masses of order $10^{15} - 10^{17}$ GeV. The stochastic gravitational wave emission arises from metastable strings with $G\mu \sim 10^{-9} - 10^{-5}$ and should be accessible at HLVK and future detectors, including the Einstein Telescope and Cosmic Explorer. Monopoles with masses of order $10^8 - 10^{14}$ GeV arise from metastable strings for $G\mu$ values from $\sim 10^{-22}$ to 10^{-10} . We discuss the parameter space for producing these monopoles at an observable level with detectors such as IceCube, KM3NeT, Pierre Auger, and ANITA. This mechanism yields TSMs that carry two units ($4\pi/e$) of Dirac magnetic charge and some screened color magnetic charge in an $SO(10)$ model.

Session 10 / 33

Can primordial black holes form without fine-tuning?

Author: Andrew Gow¹

¹ *Institute of Cosmology & Gravitation, University of Portsmouth*

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

Primordial black holes (PBHs) may form in the early universe, and could have relevance to cosmic evolution, particularly as a dark matter candidate. Forming PBHs requires increased power on small scales, corresponding to some kind of feature in the inflaton potential. I will present a study of the fine-tuning of PBH formation for four representative inflation models, discussing the different sources of tuning and potential mitigation methods

Session 8 / 35

Evaporating Kerr black holes as probes of new physics

Authors: João Rosa¹; Marco Calza¹

¹ *University of Coimbra*

Corresponding Authors: marco.calza89@gmail.com, jgroso@uc.pt

In the string axiverse scenario, primordial black holes (PBHs) can sustain non-negligible spin parameters as they evaporate. We show that tracking both the mass and spin evolution of a PBH in its

final hour can yield a purely gravitational probe of new physics beyond the TeV scale, allowing one to determine the number of new scalars, fermions, vector bosons, and spin-3/2 particles. Furthermore, we propose a multi-messenger approach to accurately measure the mass and spin of a PBH from its Hawking photon and neutrino primary emission spectra, which is independent of putative interactions between the new degrees of freedom and the Standard Model particles, as well as from the Earth-PBH distance.

Session 8 / 36

Realistic and conservative bounds on primordial black holes from the CMB

Authors: Daniele Gaggero¹; Dominic Agius²; Francesca Scarcella³; Gregory Suczewski⁴; Mauro Valli⁵; Rouven Essig⁴

¹ *Istituto Nazionale di Fisica Nucleare, Sezione di Pisa*

² *IFIC (University of Valencia)*

³ *Laboratoire Universe et Particules de Montpellier (LUPM), Université de Montpellier & CNRS*

⁴ *C.N. Yang Institute for Theoretical Physics, Stony Brook University*

⁵ *INFN Sezione di Roma*

Corresponding Authors: dominic.agius@ific.uv.es, danielle.gaggero@pi.infn.it

This talk examines the cosmic microwave background (CMB) bounds on solar mass and heavier primordial black holes (PBHs). While the CMB bound is often regarded as the most stringent in this mass regime, its computation relies on several astrophysical assumptions, including accretion geometry, dark matter halo formation, and the treatment of energy injection and deposition. By applying realistic accretion models incorporating ionization fronts and halo effects, we aim to refine these constraints and identify the most conservative bound from current cosmological observations.

Session 2 / 37

Constraints on Primordial Black Holes From Stars in Ultra-Faint Dwarf Galaxies

Authors: Nicolas Esser¹; Petr Tinyakov²; Sven De Rijcke³

¹ *Université Libre de Bruxelles (ULB), Theoretical Physics Group (PhysTH)*

² *Universite Libre de Bruxelles (ULB)*

³ *Ugent*

Corresponding Authors: sven.derijcke@ugent.be, nicolas.esser@ulb.be, petr.tiniakov@ulb.be

If primordial black holes (PBHs) constitute the dark matter (DM), stars forming in dark-matter dominated environments with low velocity dispersions, such as ultra-faint dwarf galaxies, may capture a black hole at birth. The capture probability is non-negligible for PBHs of masses around 10^{20} g, and increases with stellar mass. Moreover, infected stars are turned into virtually invisible black holes on cosmologically short time-scales. Hence, the number of observed massive main-sequence stars in ultra-faint dwarfs should be suppressed if the DM was made of asteroid-mass PBHs. This would impact the measured mass distribution of stars, making it top-light (i.e. depleted in the high-mass range). Using simulated data that mimic the present-day observational power of telescopes, we show that already existing measurements of the mass function of stars in local ultra-faint dwarfs could be used to constrain the fraction of DM composed of PBHs in the - currently unconstrained - mass range of 10^{19} - 10^{21} g.

Session 10 / 38

Primordial Black Holes and Induced Gravitational Waves from a Smooth Crossover beyond Standard Model

Author: Albert Escrivà¹

¹ *Nagoya University*

Corresponding Author: escriva.manas.albert.y0@a.mail.nagoya-u.ac.jp

GWs induced by primordial fluctuations can be affected by the modification of the sound speed c_s^2 and the equation of state parameter w once the curvature fluctuations reenter the cosmological horizon. That softening can also significantly boost the production of PBHs at the mass scale where the softening arises. In this work, we consider a hypothetical softening of w and c_s^2 caused by a smooth crossover beyond Standard Model theories, for what we numerically compute the secondary induced GWs considering the case of a flat scale-invariant power spectrum. We find that if the amplitude of the power spectrum is sufficiently large, the characteristic feature of the GW signal caused by the smooth crossover can be detected by future space-based gravitational wave interferometers and differentiated from the pure radiation case. At the same time, depending on the mass scale where the crossover occurs, such a scenario can have compatibility with PBHs being all the dark matter when $\mathcal{A} \sim \mathcal{O}(10^{-3})$, with a mass function very sharply peaked around the horizon mass scale of the minimum of the sound speed. Our results show that the GW signal can be used to resolve the existing degeneracy of sharply peaked mass function caused by peaked power spectrums and broad ones in the presence of softenings of w and c_s^2 .

Session 6 / 39

Numerical First Order QED calculations of Hawking Radiation from Asteroid Mass PBHs

Author: Emily Koivu¹

Co-authors: John Kushan¹; Gabriel Vasquez¹; Makana Silva²; Christopher Hirata¹

¹ *The Ohio State University*

² *Los Alamos National Lab*

Corresponding Authors: koivu.1@osu.edu, kushan.2@buckeyemail.osu.edu, hirata.10@osu.edu, vasquez.119@osu.edu, makanas@lanl.gov

Asteroid mass primordial black holes (mass $10^{16} - 10^{21}$ grams) are viable candidates to describe the total dark matter content of the universe. One of the interesting features of these primordial black holes (PBHs) being a source of dark matter is their Hawking temperature is greater than 100 keV, meaning that charged particle pairs can easily be created for nontrivial hawking radiation signatures. Because of this generation of particles on Quantum Electrodynamics (QED) energy scales, it is necessary to rigorously investigate the Hawking radiation spectra not just at zeroth order, but also at first order in the coupling constant where electrons and positrons could also interact with emitted photons. Previously, our group has created an analytic expression for the first order Hawking radiation spectra from dissipative effects for a Schwarzschild PBH. This talk will demonstrate the numerical implementation of that result for a range of black hole masses, as well as demonstrate which processes are most impactful at different energy scales. This work is critical in understanding upcoming keV -MeV surveys that will be able to directly search for asteroid mass PBHs, and is part of the first steps towards a complete treatment of QED interactions on black hole spacetimes.

Session 11 / 40

Primordial black hole formation from a nonspherical density profile with a misaligned deformation tensor

Author: Chulmoon Yoo¹

¹ Nagoya Univ.

Corresponding Author: yoo.chulmoon.k6@f.mail.nagoya-u.ac.jp

We perform the numerical simulation of primordial black hole formation from a nonspherical profile of the initial curvature perturbation ζ . We consider the background expanding universe filled with the perfect fluid with the linear equation of state $p = w\rho$ ($w = 1/3$ or $1/5$), where p and ρ are the pressure and the energy density, respectively. The initial condition is set in a way such that the principal directions of the second derivatives of ζ and $\Delta\zeta$ at the central peak are misaligned, where Δ is the Laplacian. In this setting, since the linearized density is proportional to $\Delta\zeta$, the inertia tensor and deformation tensor $\partial_i\partial_j\zeta$ are misaligned. Thus tidal torque may act and the spin of a resultant primordial black hole would be non-zero in general, although it is estimated to be very small from previous perturbative analyses. As a result, we do not find a finite value of the spin within our numerical precision, giving support for the negligibly small value of the black hole spin for $1/5$

lesssim

lesssim $1/3$. More specifically, our results suggest that the dimensionless PBH spin s is typically so small that $s \ll 0.1$ for w

gtrsim 0.2 .

Session 4 / 43

Primordial black hole formation: Type II B

Author: Tomohiro Harada¹

¹ Rikkyo University

Corresponding Author: harada@rikkyo.ac.jp

Primordial black holes (PBHs) may have formed from a sufficiently large amplitude of perturbation in the early Universe. The central aim of the formation studies is to predict the abundance and other properties of PBHs for a given cosmological scenario. After briefly introducing the standard setup and revisiting the compaction function, we here present our recent work on the numerical simulation of the time evolution of type II perturbations in the radiation-dominated universe. One of the striking features is that such a perturbation may result in a spacetime with bifurcating trapping horizons, which we would call a type II B PBH.

Session 5 / 44

Observational constraints on the abundance of Primordial Black Holes

Author: Anne Green¹

¹ University of Nottingham

Corresponding Author: anne.green@nottingham.ac.uk

I will overview the current status of observational constraints on the abundance of Primordial Black Holes (PBHs) of all masses, including astrophysical uncertainties on stellar microlensing constraints,

constraints on (more realistic) extended mass functions, and prospects for probing asteroid mass PBHs.

Session 8 / 45

Determining mass and spin of light PBHs

Authors: Marco Calza¹; João Rosa¹

¹ *University of Coimbra*

Corresponding Authors: marco.calza89@gmail.com, jgrosa@uc.pt

We propose methods to determine the mass and spin of PBHs based on measuring specific features of the primary emitted Hawking spectra. In the previous edition of this conference, we focused on masses between 5×10^7 and 10^{12} kg and adimensional spin parameter $a = 0.1$ – 0.5 . Now we extend those ranges in distant independent ways.

We investigate values of $a \lesssim 0.6$, measuring the energy and emission rate at the dipolar and quadrupolar peaks in the primary photon spectrum. This method is valid for any mass of the PBH.

We propose a multi-messenger approach to accurately measure the mass and spin of a PBH from its Hawking photon and neutrino primary emission spectra. This is of particular interest for temperature beyond the TeV scale since it is independent of putative interactions between new possible degrees of freedom and the Standard Model particles.

Session 1 / 46

Early structure and binary formation with primordial black holes

Author: Samuel Young¹

Co-author: Fabian Schmidt²

¹ *University of Sussex*

² *Max Planck Institute for Astrophysics*

Corresponding Author: sam.young@sussex.ac.uk

Partially due to the detection of gravitational waves LIGO, Virgo and KAGRA (LVK), there has been renewed interest in the possibility that primordial black holes (PBHs) make up all, or a fraction of, dark matter. However, the origin of the LVK black holes is still not well understood. To explore the possibility that (at least some) of the LVK black holes are primordial in nature requires an understanding of the environments in which binary PBHs might form and evolve, and how PBHs can affect structure formation. In this talk, I will present the first results from a new suite of fully collisional cosmological simulations with PBH dark matter, looking at how early structure formation is affected, and how this affects the formation and evolution of binary PBHs.

Session 7 / 47

Primordial black hole formation during preheating?

Author: Pasquale Dario Serpico¹

¹ *LAPTh, CNRS*

Corresponding Author: serpico@lapth.cnrs.fr

One of the main difficulties in scenarios involving primordial black holes (PBHs) are the rather special conditions required to produce them, typically demanding major tunings in the inflationary potential or very specific conditions following phase transitions. Some authors have found a promising alternative in the preheating epoch, just after inflation, when metric feedback would resonantly boost the growth of perturbations to the point of generically creating PBHs. This phenomenon could be followed by simply studying a quadratic approximation for the (post-accelerated expansion) inflaton potential. We revisit this issue, discussing the extent to which: i) This framework effectively eases the formation of PBHs. ii) The quadratic approximation for the inflaton potential generically captures the quantitative dynamics. iii) The inflaton self-potential beyond the quadratic approximation can be used to boost PBH formation.

Session 10 / 48

Primordial Black Holes: formation and cosmological impact in the current Universe

Author: Ilia Musco¹

¹ *INFN, Sapienza University of Rome*

Corresponding Author: ilia.musco@roma1.infn.it

Primordial black holes (PBHs) could have been formed in the very early Universe from large amplitude perturbations of the metric. Their formation is naturally enhanced during phase-transitions, because of the softening of the equation of state, from the electron weak transition, corresponding to PBHs as CDM candidate, till the Nucleosynthesis, when the PBHs formed could be the seeds of SMBHs. The quark-hadron phase in particular has received lots of attention recently, with a characteristic scale between 1 and 3 solar masses and the abundance of PBHs significantly increased. Performing detailed numerical simulations we have computed the modified mass function for such black holes, showing that the minimum of the QCD transition works as an attractor solution. Making then a confrontation with the LVK phenomenological models describing the GWTC-3 catalog, we have found that a sub-population of such PBHs formed in the solar mass range is compatible with the current observational constraints and could explain some of the interesting sources emitting gravitational waves detected by LIGO/VIRGO in the black hole mass gap, such as GW190814, and other light events.

Session 7 / 49

Curvature Perturbations Protected Against One Loop

Author: Keisuke Inomata¹

¹ *Johns Hopkins University*

Corresponding Author: keisukeinomata0123@gmail.com

I examine one-loop corrections from small-scale curvature perturbations to the superhorizon-limit ones in single-field inflation models, which have recently caused controversy. I consider the case where the Universe experiences transitions of slow-roll (SR) \rightarrow intermediate period \rightarrow SR. The intermediate period can be an ultra-slow-roll period or a resonant amplification period, either of which enhances small-scale curvature perturbations. I assume that the superhorizon curvature perturbations are conserved at least during each of the SR periods. Within this framework, I show that the superhorizon curvature perturbations during the first and the second SR periods coincide at one-loop level in the slow-roll limit.

Session 3 / 50**Black Holes as New Dark Matter Factories****Author:** Volodymyr Takhistov¹¹ *QUP, KEK***Corresponding Author:** vtakhist@post.kek.jp

We present a new general paradigm for the production of dark matter (DM) relic abundance, regurgitated DM, based on the evaporation of early Universe primordial black holes (PBHs) themselves formed from DM particles. We discuss a minimal realization of the model with dark sector in which a first-order phase transition results in the formation of Fermiball remnants that collapse to PBHs, which then emit DM particles. We show that the regurgitated DM scenario allows for DM over many decades in mass, including parameter space considered excluded. Further, we highlight how evaporating PBHs can serve as unique factories of sterile neutrinos in PBH sterile neutrino genesis, which minimally couple only to active neutrinos. Contrary to the conventionally studied sterile neutrino production mechanisms, this novel mechanism does not depend on the active-sterile mixing. A unique signal is coincidence of induced gravitational waves associated with PBH evaporation and X-rays from sterile decays.

Session 12 / 51**Characterising spacetime during cosmological collapse****Author:** Robyn Munoz¹¹ *University of Sussex***Corresponding Author:** rlm36@sussex.ac.uk

We look into whether the spherical collapse model is a good approximation in a numerical relativity cosmological simulation and describe the spacetime's evolution during nonlinear collapse. In the simulation, we evolve a quasi-spherical structure, where fully nonlinear initial conditions are provided by perturbing the Λ CDM model with the comoving curvature perturbation, defined as a 3D sinusoidal. Then it is fully evolved with the Einstein Toolkit code. This is compared to the spherical collapse model, and the spacetime's evolution is described with both gravito-electromagnetism and the Petrov classification.

Session 4 / 52**The inflation trilogy and primordial black hole dark matter****Authors:** Paulo Ferraz¹; João Rosa¹¹ *University of Coimbra***Corresponding Authors:** jgrosa@uc.pt, paulobernardo1995@gmail.com

We propose an inflation scenario with three independent stages of cold, warm and thermal inflation, respectively, driven by different scalar fields, motivated by the large number of such fields predicted by most extensions of the Standard Model. We show, in particular, that the intermediate period of warm inflation naturally leads to large density fluctuations on small scales, which can lead to primordial black hole formation in the mass window where they may account for all dark matter. This type of scenario yields a distinctive primordial black hole mass function due to the final period of thermal inflation, which dilutes the abundance of very light black holes.

Session 8 / 53

Limits on the Burst Rate of Exploding Black Holes**Author:** Joaquim Iguaz Juan¹¹ *UMass Amherst***Corresponding Author:** jiguazjuan@umass.edu

Primordial Black Holes (PBHs) could play a relevant role in several physical phenomena. They are particularly attractive as a candidate for dark matter, seeds of supermassive black holes, sources of gravitational waves, etc. In addition, the observation of an evaporating black hole would provide definitive information on the elementary particles present in nature, including new degrees of freedom beyond the Standard Model. VHE gamma-ray observatories such as HAWC and LHAASO, among others, provide the technology to potentially detect such an extraordinary and unprecedented event. Although the PBH abundance is tightly constrained in the mass range of interest, we critically revisit the assumptions underlying the bounds and study how they are modified in alternative scenarios where a large number of degrees of freedom are introduced. We also provide a realistic assessment of the capacity of current and future VHE gamma-ray telescopes to detect an exploding PBH in the coming years.

Session 6 / 54

Constraining Primordial Black Holes through Big Bang Nucleosynthesis**Authors:** Andrea Boccia¹; Fabio Iocco²; Luca Visinelli³¹ *Scuola Superiore Meridionale*² *Università di Napoli "Federico II"*³ *Shanghai Jiao Tong University***Corresponding Authors:** luca.visinelli@sjtu.edu.cn, andrea.boccia-ssm@unina.it, fabio.iocco.unina@gmail.com

In this analysis, we investigate the scenario wherein Primordial Black Holes (PBHs) with very low masses ($M_{\text{PBH}} \lesssim 10^9 \text{ g}$) undergo evaporation during the Big Bang Nucleosynthesis (BBN) epoch. This evaporation process leads to a non-standard behavior in the expansion rate of the Universe, which plays a crucial role in determining the freeze-out of nuclear reactions. This non-standard expansion rate may have implications for the asymptotic primordial abundance of light nuclei. We present numerical solutions for the background metric, considering different values of PBH mass and abundance at their formation. Subsequently, we share results for the abundances of light nuclei, obtained by incorporating the non-standard Hubble rate into the BBN code Parthenope3.0, such results are then used to obtain upper bounds at 95% confidence level for the PBHs relative abundance at formation in the range $4 \times 10^8 \text{ g} \lesssim M_{\text{PBH}} \lesssim 10^9 \text{ g}$.

Session 14 / 55

Primordial Black Holes with a Spectator Field**Author:** Ioanna Stamou¹¹ *Université libre de Bruxelles (ULB)*

Corresponding Author: ioanna.stamou@ulb.be

This presentation introduces a cosmological mechanism featuring a spectator field and investigates its connection to the formation of primordial black holes (PBHs) and dark matter. By considering fluctuations during inflation, we study a natural PBH formation process that doesn't rely on exotic physics in the potential and the fine-tuning issue can be avoided. Observational constraints demonstrate the mechanism's ability to reproduce PBH abundance and mass distribution. This mechanism can be applied in a variety of theoretical framework and it can give us remarkable results.

Session 1 / 56

Primordial Black Holes - Positivist Perspective and Quantum Quid-

Author: Florian Kühnel¹

¹ *MPP & LMU Munich*

Corresponding Author: mail@floriankuehnel.net

I review the observational evidence for primordial black holes from a variety of lensing, dynamical, accretion and gravitational-wave effects. As I will show, all of these (over 20) may be explained by a single and simple unified model, naturally shaped by the thermal history of the Universe. In the second part of my talk, I will comment on the novel feature of vorticity in black holes, which may yield the very first astrophysical observable for quantum effects in these compact bodies.

Session 5 / 57

Can primordial black holes explain LIGO/Virgo observations?

Author: Sébastien Clesse¹

¹ *University of Brussels (ULB)*

Corresponding Author: sebastien.clesse@ulb.be

The current merger rate prescriptions for primordial black holes (PBHs) only apply to peaked mass distributions. For an extended mass distribution that includes features from the QCD epoch, additional effects must be taken into account that can importantly change these rates. Based on new estimations of the merger rates of early and late PBH binaries, I will present an update of the status of PBHs to explain the LIGO/Virgo observations of compact binary coalescences, and of the allowed dark matter fraction made of stellar-mass PBHs based on gravitational-wave observations.

Session 3 / 58

Black Holes in the Early Universe

Author: Dan Hooper¹

¹ *Fermilab/University of Chicago*

Corresponding Author: danhooper99@gmail.com

Cosmology textbooks typically assume that the early universe was dominated by relativistic particles. But if even a relatively small number of black holes were created after inflation, they would have constituted an increasingly large fraction of the total energy density as the universe expanded. I'll argue that it is well-motivated to scenarios in which the early universe included an era in which low-mass ($< 10^9$ grams) primordial black holes dominated the total energy density. Within this context, I'll discuss Hawking radiation as a mechanism to produce both dark radiation and dark matter. I'll also talk about the possibility that these black holes may have undergone mergers before evaporating, leading to potentially detectable gravitational waves signals, and to the production of a "hot graviton background". Such black holes could have also played an important role in the process of baryogenesis.

Session 9 / 60

Primordial monopoles, black holes and gravitational waves

Author: Qaisar Shafi¹

¹ *Delaware U., Bartol Inst.*

TBC

Session 13 / 61

Primordial black hole formation from a massless scalar field

Author: Gabriele Palloni¹

Co-authors: Ilia Musco²; Paolo Pani²

¹ *Universitat de València*

² *INFN, Sapienza University of Rome*

Corresponding Authors: gabriele.palloni@uv.es, paolo.pani@uniroma1.it, ilia.musco@roma1.infn.it

We consider primordial black holes formation from adiabatic cosmological perturbation of the Early Universe dominated by a massless scalar field. These are sourced by a time independent curvature profile imposed on super horizon scale, corresponding to pure growing modes of the scalar field. Assuming spherical symmetry we study the collapse of these cosmological perturbations using the comoving and the constant mean curvature gauge, showing that the behaviour of a massless scalar field is equivalent to a perfect fluid where the pressure is equal to the total energy density (i.e. equation of state $p = \rho$). Using a numerical code based on the BSSN conformal decomposition, developed specifically for this problem, we computed the threshold δ_c , defined as the peak of the compaction function $\mathcal{C}(r)$ measured on super horizon scales. This is equivalent to the relative mass excess measured at the cosmological horizon crossing.

Session 5 / 62

Primordial Black Hole Relics as Dark Matter Candidates

Author: AMIRAH ALJAZAERI¹

¹ *University of Sussex*

Corresponding Author: aa2409@sussex.ac.uk

During the talk, I will delve into the unique candidate of Planck mass Primordial Black Hole (PBH) relics as dark matter. These relics, arising from the evaporation of light PBHs with initial masses ranging from $1g$ to approximately 10^6g , possess the potential to account for the entirety of dark matter in our universe. My presentation will encompass a thorough review of existing constraints on PBH abundance, incorporating the consideration of Planck mass relics. Additionally, I will provide visual representations, such as plots, illustrating the new perspective on dark matter as PBH relics.

Session 13 / 64

PBH from Numerical Relativity

Author: Eugene Lim¹

¹ *King's College London*

Corresponding Author: eugene.lim@kcl.ac.uk

We simulated the formation of spinning and non-spinning PBH from the collapse of superhorizon density fluctuations using full numerical relativity in the case of the approximately matter dominated case. We showed that there are two formation mechanism (1) direct collapse where the perturbation itself forms a BH and (2) accretion collapse where the perturbation generate a potential well which causes subsequent BH formation due to accretion. We argue that the dynamics of formation matters in the final properties of the PBH, which is not captured by the usual “kinematics” threshold arguments

Session 14 / 65

Supermassive primordial black holes for nano-Hertz gravitational waves

Authors: Hai-Long Huang¹; Yun-Song Piao²

¹ *School of Physical Sciences, University of Chinese Academy of Sciences*

² *University of Chinese Academy of Sciences*

Corresponding Authors: huanghailong18@mails.ucas.ac.cn, yspiao@ucas.ac.cn

We investigate the formation of primordial black holes (PBHs) during the inflation by nucleation of supercritical bubbles in a multiverse scenario. We find that when the inflaton slowly passes by a neighboring vacuum, the nucleating rate of supercritical bubbles would inevitably attain a peak, so the mass distribution of multiverse PBHs, and the mass of peak can be up to $10^{18}M_{\odot}$. We also present a mechanism for the origin of initial clustering of such supermassive PBHs (SMPBHs), which can significantly magnify the merger rate of SMPBH binaries, and show the possibility that the merging of such SMPBH binaries explains recent NANOGrav signal.

Session 13 / 66

Dark Matter, Black Holes and Phase Transitions

Author: Michael Baker¹

¹ *UMass Amherst***Corresponding Author:** michael.james.baker@cern.ch

Phase transitions can have a dramatic impact on physics in the early universe. We illustrate this by discussing a novel mechanism of dark matter production and a related novel mechanism of primordial black hole production, both of which hinge on cosmological phase transitions.

Session 6 / 67

The detection of a population of stellar mass primordial black holes

Author: Michael Hawkins¹¹ *University of Edinburgh***Corresponding Author:** mrsh@roe.ac.uk

After many years where the belief that dark matter is in the form of elementary particles has been the dominant paradigm, there is now growing support for the idea that at least in part dark matter is made up of primordial black holes. Although there have been a number of observational and theoretical pointers in this direction, there are two areas where a strong case has been made that primordial black holes have actually been detected. Recently, the detection of gravitational waves from black hole mergers has opened up the possibility that the merging objects are primordial black holes and not stellar remnants. The other area where claims for the detection of primordial black holes have been made is from the microlensing of compact bodies such as stars and quasars. This is the subject of my talk, where I shall present evidence that the population of compact bodies responsible for the observed microlensing is made up of stellar mass primordial black holes, and that these bodies must make up at least a substantial fraction of the dark matter.

Session 14 / 68

One-loop power spectrum in ultra slow-roll inflation and implications for primordial black hole dark matter

Author: Jesus Gambín Egea¹¹ *Instituto de Física Teórica***Corresponding Author:** j.gambin@csic.es

A possible way to generate primordial black holes as candidates for the entirety of dark matter is a large power spectrum of inflationary curvature fluctuations. Recently, questions have been raised regarding the validity of perturbation theory in this context. We compute the one-loop power spectrum in ultra-slow roll inflation, including all relevant interactions for such analysis, along with counterterms that absorb the ultraviolet divergences. We compare the one-loop and tree-level contributions to the power spectrum, finding that perturbation theory remains valid in realistic ultra-slow roll models.

Session 11 / 69

Searching for primordial black hole populations with resonant cavities

Corresponding Author: luca.visinelli@sjtu.edu.cn

The FINUDA magnet for Light Axion Search (FLASH) is a large resonant cavity haloscope planned to probe new physics as part of the INFN Frascati National Laboratories near Rome (Italy). The frequency range accessible overlaps with the Very High Frequency (VHF) range of the radio wave spectrum and allows for a search in high frequency gravitational waves (HFGW) in the frequency range (100–300) MHz, allowing to scan for the existence of light primordial black holes in the asteroid mass window. I present the setup of the experiment and the sensitivity forecasts for the detection of HFGWs. The considerations for the astrophysical framework that can be probed are drawn. Based on 2309.00351 and ongoing work.

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Arrival / Registration

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Welcome

Session 13 / 72

Scalar field fragmentation after inflation, oscillon formation and decay

Author: Swagat Saurav Mishra¹

Co-authors: Edmund J Copeland²; Rafid Mahbub³

¹ *University of Nottingham, UK*

² *University of Nottingham*

³ *Gustavus Adolphus College, Minnesota*

Corresponding Authors: swagat.mishra@nottingham.ac.uk, mahbub@gustavus.edu, ed.copeland@nottingham.ac.uk

The transition epoch between the end of inflation and the beginning of thermal radiation domination, known as ‘reheating’, remains as one of the fundamental open problems in Cosmology. During the earliest stages of reheating, the oscillating inflaton condensate is supposed to decay non-perturbatively (via parametric resonance) into other lighter bosonic degrees of freedom that are coupled to the inflaton. This period is termed as ‘preheating’. However, if the external couplings of the inflaton are weak enough, then the homogeneous inflaton condensate might get fragmented by strong attractive self-interactions to form quasi-stable solitonic objects, known as ‘oscillons’. We discuss the possibility of oscillon formation during the preheating phase of asymptotically flat inflationary potentials that are favoured by CMB observations. A detailed numerical analysis was performed to study the post-inflationary dynamics of asymptotically flat potentials using the publicly available lattice simulation code ‘CosmoLattice’ for the relevant parameter range. Oscillons were found to be present for the entirety of the runtime of our simulations, comprising more than 40% of the total energy density. We also provide a thorough discussion on the formation and decay of oscillons in presence of an external coupling. Under certain circumstances, the oscillons can collapse to form copious amount of Primordial Black Holes.

Session 10 / 74**Constraining peaked power spectrum**

Author: Xavier Pritchard¹

¹ *University of Sussex*

Corresponding Author: xp40@sussex.ac.uk

It has been understood for a long time that the reduction in the equation of state during a phase transition in the Early Universe leads to an exponential enhancement in the formation rate of PBHs. However, this exponential sensitivity to the EoS (via the collapse threshold) is the same sensitivity that PBH formation shows to the amplitude of the primordial power spectrum. In this talk I will focus on peaked power spectrum and show the challenges associated with motivating populations of primordial black holes with the standard model.

Session 1 / 77**Welcome****Session 12 / 79****Dinner Details**

Corresponding Author: jessica.turner@durham.ac.uk