UK Cosmo at Cambridge

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Book of Abstracts

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Scientific Talks / 1

Modelling of Astrophysical Systematics for Cosmology with LSST

Author: Nikolina Šarčević[1]

Co-authors: Danielle Leonard [2]; Markus Rau [3]

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LSST will provide an unprecedented wealth of astronomical data, with which we will be able to tightly constrain the values of the cosmological parameters, notably those which describe the poorly understood dark energy component. As weak lensing and galaxy clustering measurements provide a way to infer key cosmological quantities such as the dark matter distribution, the evolution of cosmic structure, and the expansion history of the Universe, detailed and rigorous analysis is necessary in order to glean as much information as possible from LSST measurements of these effects. This project developed a consistent and reliable framework (FISK) where three key systematic effects impacting weak lensing and galaxy clustering (intrinsic alignment of galaxies, galaxy bias and photometric redshift uncertainties) are modeled jointly. The results directly enable rigorous weak lensing and galaxy clustering constraints on cosmological parameters with LSST.

Scientific Talks / 2

Primordial black holes and stochastic inflation beyond slow roll

Author: Swagat Saurav Mishra[1]

[1] *University of Nottingham, UK*

Primordial Black Holes (PBHs) may form in the early universe, from the gravitational collapse of large density perturbations, generated by large quantum fluctuations during inflation. Since PBHs form from rare over-densities, their abundance is sensitive to the tail of the primordial probability distribution function (PDF) of the perturbations. It is therefore important to calculate the full PDF of the perturbations, which can be carried out non-perturbatively using the 'stochastic inflation' framework. In single field inflationary models, generating large enough perturbations to produce an interesting abundance of PBHs requires violation of slow roll. It is therefore necessary to extend the stochastic inflation formalism beyond slow roll, and consequently there has been a surge in the research interest in this direction in the recent years. A crucial ingredient for this is the stochastic noise matrix corresponding to the small wavelength fluctuations. In this talk, after providing a brief introduction to PBHs and ultra slow-roll inflation, the speaker will discuss analytical and numerical calculations of these matrix elements for an inflaton potential with a feature which violates slow roll and produces large, potentially PBH generating, perturbations. The talk will be based on the following work carried out at the Particle Cosmology Group, University of Nottingham, in collaboration with Prof. Edmund J. Copeland and Prof. Anne M. Green [arXiv: 2303.17375].

Scientific Talks / 3

Quantum field theory in curved spacetime and the CMB hemispherical power asymmetry

Authors: J Marto[1]; Sravan Kumar[None]

[1] *University of Beira Interior*

Before we ask what is the theory of quantum gravity, it is a legitimate quest to formulate a robust quantum field theory in curved spacetime (QFTCS). Several conceptual conundrums have been issues of concern over several decades because no S-matrix formulation is yet found in QFTCS. We argue that the institutional thinking of fixing the spacetime geometry, observers, and light cones and then quantizing the fields in that "intuitively"or "classically"fixed spacetime is the origin of the problem. In this talk, I shall present a new formalism of quantum field theory in curved spacetime based on the "quantum first"approach which leads us to a consistent S-matrix formulation. I will explicitly discuss the unitary QFT formulation de Sitter spacetime and then present how this formalism naturally explains one of the prominent CMB anomalies called the hemispherical power asymmetry (HPA). Furthermore, I shall present a new prediction for HPA in the context of primordial gravitational waves.

Scientific Talks / 4

Cosmology and strong gravity with a subdominant scalar field

Author: Georgios Antoniou[1]

[1] *University of Nottingham*

We discuss the cosmological evolution of a scalar field in theories motivated by beyond-GR compact object phenomenology, e.g. scalarization. Such theories predict strong-gravity deviations with respect to GR in the vicinity of very compact stars and black holes, but the asymptotic conditions are determined by cosmological arguments. We explore the stability of scalarization models on a cosmological background for a subdominant scalar field, we show the assumptions under which a late-time attractor is retrieved, and discuss their consistency with early time cosmology and inflation.

Scientific Talks / 5

The angular power spectrum of gravitational-wave transient sources as a probe of the large-scale structure

Authors: Arianna Renzini[1]; Jacob Golomb[1]; Marco Cavaglia[2]; Maria Sakellariadou[3]; Nikolaos Kouvatsos[4]; Yanyan Zheng[2]

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[2] *Missouri University of Science and Technology*

[3] *University of London (GB)*

[4] *King's College London*

We present a new, simulation-based inference method to compute the angular power spectrum of the distribution of foreground gravitational-wave transient events. As a first application of this method, we use the binary black hole mergers observed during the LIGO, Virgo, and KAGRA third observation run to test the spatial distribution of these sources. We find no evidence for anisotropy in their angular distribution. We discuss further applications of this method to investigate other gravitational-wave source populations and their correlations to the cosmological large-scale structure.

Scientific Talks / 6

How to find the Feynman Rules from any scalar-tensor theory and not collapse in the process

Author: Sergio Sevillano[None]

Co-authors: Ed Copeland [1]; Michael Spannowsky [2]; Peter Millington [3]

[1] *Nottingham University*

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[3] *University of Manchester*

The ability to represent perturbative expansions of interacting quantum field theories in terms of simple diagrammatic rules has revolutionized calculations in particle physics. However, in the case of extended theories of gravity, deriving this set of rules requires linearization of gravity, perturbation of the scalar fields, and multiple field redefinitions, making this process very time-consuming and model dependent. In this talk, I will motivate and present FeynMG, a Mathematica extension of FeynRules that automatizes this calculation, allowing for the application of quantum field theory techniques to scalar-tensor theories.

Scientific Talks / 7

Dictionary Learning: A Novel Approach to Detecting Binary Black Holes in the Presence of Galactic Noise with LISA

Authors: Charles Badger[1]; Katarina Martinovic[1]

Co-authors: Alejandro Torres-Forné [2]; José Font [2]; Mairi Sakellariadou [1]

[1] *King's College London*

[2] *Universitat de València*

The noise produced by the inspiral of millions of white dwarf binaries in the Milky Way may pose a threat to one of the main goals of the space-based LISA mission: the detection of massive black hole binary mergers. We present a novel study for reconstruction of merger waveforms in the presence of Galactic confusion noise using dictionary learning. We discuss the limitations of untangling signals from binaries with total mass from $10^2 M$ to $10^4 M$. Our method proves extremely successful for binaries with total mass greater than ~$3\times10^3 M$ up to redshift 3 in conservative scenarios, and up to redshift 7.5 in optimistic scenarios. In addition, consistently good waveform reconstruction of merger events is found if the signal-to-noise ratio is approximately 5 or greater.

Scientific Talks / 8

Dark Energy (and modified gravity) in two body problem: theoretical implications and observational constraints

Author: David Benisty[None]

General Theory of Relativity needs at least one modification - the Cosmological Constant. Yet there are possibilities for other modified theories of gravity to explain the accelerated expansion. In this talk I'm going to discuss the impact of Modified Gravity on the two-body problem. In particular, with the latest observational constraints from the galactic center and the S-stars, binary pulsars and the Milky and Andromeda dynamics.

Scientific Talks / 9

The observed number counts in luminosity distance space

Authors: Chris Clarkson[1]; José Fonseca[2]; Stefano Zazzera[3]; Tessa Baker[None]

[1] *University of Cape Town*

[2] *Instituto de Astrofísica e Ciências do Espaço, Universidade do Porto*

[3] *Queen Mary University of London*

Next generation surveys will provide us with an unprecedented number of detections of supernovae Type Ia and gravitational wave merger events. Cross-correlations of such objects offer novel and powerful insights into the large-scale distribution of matter in the universe. Both of these sources carry information on their luminosity distance, but remain uninformative about their redshifts; hence their clustering analyses and cross-correlations need to be carried out in luminosity distance space, as opposed to redshift space. In this paper, we calculate the full expression for the number count fluctuation in terms of a perturbation to the observed luminosity distance. We find the expression to differ significantly from the one commonly used in redshift space. Furthermore, we present a comparison of the number count angular power spectra between luminosity distance and redshift spaces. We see a wide divergence between the two at large scales, and we note that lensing is the main contribution to such differences. On such scales and at higher redshifts the difference between the angular power spectra in luminosity distance and redshift spaces can be roughly 50%. We also investigate cross-correlating different redshift bins using different tracers, i.e. one in luminosity distance space and one in redshift, simulating the cross-correlation angular power spectrum between background gravitational waves/supernovae and foreground galaxies. Finally, we show that in a cosmic variance limited survey, the relativistic corrections to the density-only term ought to be included.

Scientific Talks / 10

Spinning primordial black holes in a matter dominated universe

Author: Eloy de Jong[1]

Co-authors: Eugene Lim [1]; Josu Aurrekoetxea [2]

[1] *King's College London*

[2] *University of Oxford*

Interest in primordial black holes (PBHs) has spiked since the first detection of gravitational waves, and a few mass windows remain in which PBHs may still make up an appreciable part of dark matter. In a matter dominated universe, e.g. in the case of a first-order QCD phase transition, PBH production is enhanced and PBHs may have large dimensionless spins. We investigate the re-entry and collapse of superhorizon perturbations with initial dimensionless spins of $\chi_0^\xi \sim 0.1$ in this setting using full 3+1D numerical relativity simulations. We find that PBHs are formed with dimensionless spins $\chi_{\rm PBH}$ smaller than but the same order of magnitude as χ_0^ξ and argue this suggests no PBHs with $\chi_{\rm PBH} > 0.5$ are produced. Furthermore, we find that the addition of angular momentum only has a minor effect on the PBH mass and accretion rate. Additionally, we discuss apparent black hole horizons and cosmological horizons in the context of numerical relativity simulations of expanding spacetimes.

Scientific Talks / 11

Multi-field inflation with large scalar fluctuations: non-Gaussianity and perturbativity

Author: Laura Iacconi[1]

Co-author: David Mulryne [1]

[1] *Queen Mary University of London*

Recently multi-field inflation models that can produce large scalar fluctuations on small scales have drawn a lot of attention, primarily because they could lead to primordial black hole production and generation of large second-order gravitational waves. In this talk, we focus on models where the scalar fields responsible for inflation live on a hyperbolic field space, and present new results for scalar non-Gaussianity. On scales around the peak, we typically find that the non-Gaussianity is large and close to local in form. We discuss implications of our results for the perturbativity of the underlying theory, focusing in particular on versions of these models with potentially relevant phenomenology at interferometer scales.

Scientific Talks / 12

The Wide–Angle Power Spectrum

Authors: Chris Clarkson[1]; Pritha Paul[2]; Roy Maartens[3]

[1] *University of Cape Town*

[2] *Queen Mary University of London*

[3] *University of the Western Cape*

We examine the computation of wide-angle corrections to the galaxy power spectrum including redshift-space distortions and relativistic Doppler corrections, and also including multiple tracers with differing clustering, magnification and evolution biases. We show that the inclusion of the relativistic Doppler contribution, as well as radial derivative terms, are crucial for a consistent wide-angle expansion for large-scale surveys, both in the single and multi-tracer cases. We forecast how well upcoming surveys will be able to disentangle wide–angle relativistic effects at large scales.

Scientific Talks / 13

Can primordial black holes form without fine-tuning?

Author: Andrew Gow[1]

[1] *Portsmouth*

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.

Scientific Talks / 14

The cosmological constant is probably still zero

Author: yang Liu[None]

Co-authors: Antonio Padilla [1]; Francisco Manuel Soares Verissimo Gil Pedro [2]

[1] *University of Nottingham*

[2] *INFN - National Institute for Nuclear Physics*

We consider a wide class of four-dimensional effective field theories in which gravity is coupled to multiple four-forms and their dual scalar fields, with membrane sources charged under the corresponding three-form potentials. Four-form flux, quantised in units of the membrane charges, generically generates a landscape of vacua with a range of values for the cosmological constant that is scanned through membrane nucleation. We list various ways in which the landscape can be made sufficiently dense to be compatible with observations of the current vacuum without running into the empty universe problem. Further, we establish the general criteria required to ensure the absolute stability of the Minkowski vacuum under membrane nucleation and the longevity of those vacua that are parametrically close by. This selects the current vacuum on probabilistic grounds and can even be applied in the classic model of Bousso and Polchinski, albeit with some mild violation of the membrane weak gravity conjecture. We present other models where the membrane weak gravity conjecture is not violated but where the same probabilistic methods can be used to tackle the cosmological constant problem.

Scientific Talks / 15

Radiation from Axion Strings with Adaptive Mesh Refinement

Authors: Amelia Drew[None]; Paul Shellard[None]

Axion strings are topological defects that arise in field theories with a spontaneously broken global symmetry, such as the Peccei-Quinn mechanism in QCD. Axion strings radiate axion particles, whose spectrum depends on the dynamics of the cosmological string network. The complex dynamics of the network make both analytic modelling and numerical simulation challenging, such that an accurate prediction of the axion mass is elusive.

We present results from adaptive mesh refinement (AMR) simulations of individual, sinusoidal configurations of axion strings (Drew and Shellard 2022, 2023). We outline quantitative investigations of the massless (axion) and massive (radial) radiation, undertaken by extracting and analysing both modes on a diagnostic cylinder to determine their dependence on the string energy densitiy $\mu \propto \ln \lambda$. We also discuss the advantages and complexities of using AMR for string simulations, and outline future directions for this work.

Scientific Talks / 16

Unimodular Hartle-Hawking wave packets and their probability interpretation

Authors: Bruno Alexandre[1]; Joao Magueijo[1]

[1] *Imperial College London*

We re-examine the Hartle-Hawking wave function from the point of view of a quantum theory which starts from the connection representation and allows for off-shell non-constancy of Λ (as in unimodular theory), with a concomitant dual relational time variable. By translating its structures to the metric representation we find a non-trivial inner product rendering wave packets of Hartle-Hawking

waves normalizable and the time evolution unitary; however, the implied probability measure differs significantly from the naive $|\psi|^2$. In contrast with the (monochromatic) Hartle-Hawking wave function, these packets form travelling waves with a probability peak describing de Sitter space, except near the bounce, where the incident and reflected waves interfere, transiently recreating the usual standing wave. Away from the bounce the packets get sharper both in metric and connection space, an apparent contradiction with Heisenberg's principle allowed by the fact that the metric is not Hermitian, even though its eigenvalues are real. Near the bounce, the evanescent wave not only penetrates into the classically forbidden region but also extends into the $a^2 < 0$ Euclidean domain. We work out the propagators for this theory and relate them to the standard ones. The $a = 0$ point (aka the "nothing") is unremarkable, and in any case a wave function peaked therein is typically non-normalizable and/or implies a nonsensical probability for Λ (which the Universe would preserve forever). Within this theory it makes more sense to adopt a Gaussian state in an appropriate function of Λ, and use the probability associated with the evanescent wave present near the time of the bounce as a measure of the likelihood of creation of a pair of time-symmetric semiclassical Universes.

Scientific Talks / 18

New Insight on Neutrino Dark Matter Interactions from Small-Scale CMB Observations

Author: William Giarè[1]

[1] *University of Sheffield*

In this talk, I will discuss the possibility of using cosmological observations to constrain models that involve interactions between neutrinos and dark matter. I will show that small-scale measurements of the cosmic microwave background with a few per cent accuracy are critical to uncover unique signatures from tiny couplings that would require a much higher sensitivity at lower multipoles, such as those probed by the Planck satellite. Interestingly, analyzing the high-multipole data released by the Atacama Cosmology Telescope (both independently and in combination with Planck and Baryon Acoustic Oscillation measurements) an intriguing 1σ-preference for a non-vanishing coupling is found both fixing and varying the effective number of relativistic degrees of freedom in the early Universe. This result aligns with other CMB-independent probes, such as Lyman-α.

Scientific Talks / 19

Clockwork Cosmology

Author: Kieran Wood[1]

Co-authors: Anastasios Avgoustidis [1]; Paul Saffin

[1] *University Of Nottingham*

The clockwork mechanism has recently been proposed as a means to generate an exponentially suppressed coupling to matter from a fundamental theory of multiple interacting particles without any unnatural parameters. Applied in a gravitational setting within the framework of ghost-free multi-metric gravity, it provides us with a potential solution to the hierarchy problem, by generating a Planck scale coupling to matter from a TeV scale fundamental theory of many interacting gravitons. In this talk I will aim to do two things. First, I will present an overview of how the clockwork mechanism works in general, alongside a means to construct multi-gravity potentials such that the fundamental theory will always exhibit this clockwork effect (ones also gets the matrix encoding the masses of the gravitons for free!). Second, since a gravitational clockwork necessarily deviates from general relativity, it may possess interesting cosmological implications. As a first look at this, I will discuss the background-level cosmological solutions.

Scientific Talks / 20

Growth of structure in regularised 4D Einstein-Gauss-Bonnet

Author: Carola Zanoletti[1]

[1] *Newcastle University*

Interest in modified gravity has been rekindled by cosmologists'attempts to resolve cosmological tensions. For example, it has been suggested that parametrisations of modified structure growth can provide a better fit to large-scale structure data and can alleviate the S8 tension. In this era of precision cosmology we can successfully test these effects for modified gravity theories that so far elude detection. In the spirit of this revitalisation of modified gravity, we analyse regularised 4D Einstein-Gauss-Bonnet in the limit of a General Relativistic background, which is equivalent to a ΛCDM background with a dark relativistic degree of freedom and modified scalar perturbations. In this talk, we will look at a range of interesting behaviours displayed by this theory and probe the effect its imprint on large-scale structure may have on the standard cosmological tensions.

Scientific Talks / 21

Impact of a quantum gravity bounce on cosmological perturbations

Authors: Lisa Mickel[1]; Steffen Gielen[1]

[1] *Univesity of Sheffield*

In this talk we will explore a phenomenological avenue to connect quantum gravity to cosmological perturbations. Namely, we will discuss the impact of a modified Friedmann equation on the evolution of gauge invariant perturbation variables. Such Friedmann equations may arise from quantum gravitational theories such as Loop Quantum Cosmology (LQC) or Group Field Theory (GFT) and in these cases give a bouncing universe. To maintain generality, we employ the separate universe framework, which allows to study possible alterations independent of a description of inhomogeneities in the quantum framework. We identify two types of modifications to the Friedmann equation; one leaves the dynamics of perturbations unaltered (LQC), whereas the other can introduce a behaviour that differs from general relativity (GFT). Finally, we will examine the possibility to go beyond the separate universe framework by studying inhomogeneous quantities in GFT.

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Invited talk: Claudia de Rham