IBERICOS 2021

15TH IBERIAN COSMOLOGY MEETING

29 March - 1 April 2021 (*online*)

@Coimbra University & @IST - Lisbon University

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https://ibericos2021.math.tecnico.ulisboa.pt

Ibericos15.2021@gmail.com

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IberiCOS 2021: 15th Iberian Cosmology Meeting

	Monday (29 March)	Tuesday (30 March)	Wednesday (31 March)	Thursday (1 April)	
09:00	**Welcome**	Jérôme Martin	Alessandro Melchiorri	Miguel Zumalacarregui	09:00
09:15	José Mimoso			Paolo Cremonese	09:15
09:30				Sarah Libanore	09:30
09:45	Alexey Koshelev			Miguel Conceição	09:45
10:00	Marco de Cesare	Llorenç Espinosa-Portalés	Jaime Zapatero	Ville Vaskonen	10:00
10:15	Riccardo Della Monica	Sayantan Choudhury	Carlos García-García	Carlos Frajuca	10:15
10:30	Break	Break	Break	Break	10:30
11:00	Diego Rubiera-Garcia	Javier Rubio	Yo Toda	Carlos Martins	11:00
11:15	Maria Caruana	Andreas Mantziris	Nihan Katirci	Léo Vacher	11:15
11:30	Cláudio Gomes	Aatifa Bargach	Rodrigo Calderon	Vasco Tavares	11:30
11:45	Inês Albuquerque	Sravan Korumilli	Giuseppe Fanizza	Jurgen Mifsud	11:45
12:00	Marco Calzà	Francisco Torrenti	David Figueruelo Hernán	Elsa Teixeira	12:00
12:15	Saikat Chakraborty	Kenneth Marschall	Javier Carrón Duque	Victor da Fonseca	12:15
12:30	Soumya Chakrabarti	Khalil El Bourakadi	Srikanta Panda	Rubén Arjona	12:30
12:45	Amine Bouali	Nikodem Poplawski	Bernhard Vos	Reginald Bernardo	12:45
				Snehasish Bhattacharjee	
13:00	Lunch	Lunch	Lunch	**IberiCOS 2022 announcement**	13:00
				Final remarks	
14:00	Mariam Bouhmadi-López	Federico Urban	Beatriz Pereira		14:00
14:15	Teodor Vassilev	Ricardo Ferreira	Dina Traykova		14:15
14:30	Rita Neves	Mariia Khelashvili	Rebecca Briffa		14:30
14:45	Alejandro García-Quismondo	António Manso	Jackson Said		14:45
15:00	Javier Olmedo	Catarina Cosme	Ivan de Martino		15:00
15:15	Asier Alonso-Bardaji	Ahmad Borzou	Daniele Gregoris		15:15
15:30	Marek Liska	Violetta Sagun	Marcelo Rubio		15:30
15:45	Jan Chojnacki	Valentina Cesare	Pierre Fleury		15:45
16:00	Break	Break	Break		16:00
16:30	José Senovilla	Albert Escriva	Asier Lopez-Eiguren		16:30
16:45		Encieh Erfani	José Correia		16:45
17:00		Juan Carlos Hidalgo	Ander Urio		17:00
17:15		Julian Idler	Daniel Jiménez-Aguilar		17:15
17:30	Bruno le Floch	Enrico Schiappacasse	Manuel Rosa		17:30
17:45	Sarah Uria	Víctor Boscá Navarro	Ana Rita Almeida		17:45
18:00	Vitor Bessa	Orfeu Bertolami (public talk)	Ivan Rybak		18:00
18:15	João Luís Rosa		Hilberto Silva		18:15
18:30	Ismael Gaspar				18:30
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	Monday (29 March)	Tuesday (30 March)	Wednesday (31 March)	Thursday (1 April)	
09:00	**Welcome**	Jérôme Martin	Alessandro Melchiorri	Gravitational Waves (6) *Chair: Francisco Lobo*	09:00
09:15	José Mimoso				09:15
09:30					09:30
09:45	Modified Gravity I (3) *Chair: Pedro Gil Ferreira*				09:45
10:00		Inflation I (2) *Chair: João Rosa*	CMB & LSS I (2) *Chair: João Rosa*		10:00
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10:30	Break	Break	Break	Break	10:30
11:00	Modified Gravity II (8) *Chair: David Mota*	Inflation II (8) *Chair: Andrew Liddle*	CMB & LSS (8) *Chair: Nelson Nunes*	Dark energy & varying fundamental constants (9) *Chair: Marina Cortês*	11:00
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13:00	Lunch	Lunch	Lunch	**IberiCOS 2022 announcement** **Final remarks**	13:00
14:00	Quantum Cosmology (8) *Chair: Claus Kiefer*	Dark matter (8) *Chair: Mariam Bouhmadi-Lopez*	CMB & LSS III (8) *Chair: Mar Bastero-Gil*		14:00
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16:00	Break	Break	Break		16:00
16:30	José Senovilla	Primordial black holes (6) *Chair: Javier Rubio*	Topological defects (8) *Chair: Carlos Martins*		16:30
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17:30	Mathematical Cosmology (5) *Chair: Artur Alho*				17:30
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18:00		Orfeu Bertolami (public talk)			18:00
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IberiCOS 2021
15$^{\text{th}}$ Iberian Cosmology Meeting

Book of Abstracts

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Invited speakers

John Barrow: The Man who knew infinite things "we didn't know we didn't know"

(Monday, 29 March, 09:15 - 09:45)

José Mimoso, Universidade de Lisboa, Portugal

John Barrow wrote once that "Any universe simple enough to be understood is too simple to produce a mind able to understand it" (a Groucho Marx inspired principle). In my talk I'll try to persuade you that the Universe is for sure not so simple after all, as John was close to be the epitome of a mind able to decipher the secrets of the universe, and also those of sports... Moreover, we were so fortunate that he would gladly explain his findings to us with unmatched good humor, and witticism. Sadly he was not given enough time!

Mathematics in Cosmology

(Monday, 29 March, 16:30 - 17:30)

José Senovilla, Universidad del País Vasco, Spain

After a historical introduction highlighting the original cntributions of relevant mathematicians to our present understanding of the Universe and its evolution, I will provide a (very personal) short selection of mathematical results of application and importance in Cosmology. These will include, in particular and time permitting, the question of singularities, inhomogeneous and non-singular models, remarks on the brane perspective, and the consequences of a positive (effective) cosmological constant.

The quantum origin of the galaxies

(Tuesday, 30 March, 09:00 - 10:00)

Jérôme Martin, CNRS/Institut d'Astrophysique de Paris, France

According to the theory of cosmic inflation, the large scale structures observed in our Universe (galaxies, clusters of galaxies, Cosmic Background Microwave - CMB - anisotropy...) are of quantum mechanical origin. They are nothing but vacuum fluctuations, stretched to cosmological scales by the cosmic expansion and amplified by gravitational instability. At the end of inflation, these perturbations are placed in a two-mode squeezed state with the strongest squeezing ever produced in Nature (much larger than anything that can be made in the laboratory on Earth). In this talk, we will study whether astrophysical observations could unambiguously reveal this quantum origin by borrowing ideas from quantum information theory. It will be argued that cosmic inflation is not only a successful paradigm to understand the early Universe but is also an interesting playground to discuss foundational issues in Quantum Mechanics.

Cosmologia, a ciência do Universo [*public talk, in Portuguese*]

(Tuesday, 30 March, 18:00 - 19:00)

Orfeu Bertolami, Faculdade de Ciências da Universidade do Porto, Portugal

Nesta palestra nós discutiremos as principais ideias e factos observacionais que permitem que alcancemos um entendimento fenomenológico da dinâmica do Universo. Este entendimento permite-nos, por um lado, reconstruir com algum detalhe a história do Universo, mas por outro, levantam questões de princípio de fundamental importância para a física contemporânea.

Planck evidence for a closed universe and a possible crisis for Cosmology

(Wednesday, 31 March, 09:00 - 10:00)

Alessandro Melchiorri, Università di Roma La Sapienza, Italy

We show that a combined analysis of CMB anisotropy power spectra obtained by the Planck satellite and luminosity distance data simultaneously excludes a flat universe and a cosmological constant at 99% C.L. These results hold separately when combining Planck with three different datasets: the two determinations of the Hubble constant from Riess et al. 2019 and Freedman et al. 2020, and the Pantheon catalog of high redshift supernovae type-Ia. We conclude that either ΛCDM needs to be replaced by a drastically different model, or else there are significant but still undetected systematics. Our result calls for new observations and stimulates the investigation of alternative theoretical models and solutions.

Session 1: Modified Gravity I

(Monday, 29 March, 09:45)
Chair: Pedro Gil Ferreira (University of Oxford)

Physical excitations in analytic infinite derivative gravity

Alexey Koshelev, Universidade da Beira Interior, Portugal

In my talk I will discuss a very promissing class of analytic infinite derivative gravity theories as the real candidate for quantum gravity. The theory is renormalizable and ghost-free. The main accent will be made on the analysis of the structure of the propagator around different backgrounds. An intruguing property of the varying number of physical excitations in different backgrounds will be discussed in details.

The talk is based on arXiv preprints: 2005.09550 (honorable mention in Essay in gravitation 2020), 2006.06641 (published in PRD), 2103.01945 in collaboration with Sravan Kumar, Alexei Starobinsky and Anna Tokareva and a work in progress.

Anisotropic cosmologies in modified gravity and singularity resolution

Marco de Cesare, University of the Basque Country, UPV/EHU, Spain

I will present recent results obtained in the context of anisotropic cosmological models in modified gravity theories. The emphasis will be placed on identifying general dynamical features in such theories, particularly in connection with singularity resolution, as well as shortcomings of specific models (e.g., mimetic gravity).

First, I will focus on theories where the initial cosmological singularity is resolved and replaced by a non-singular bounce, and study the propagation of (shear) anisotropies through the bounce in Bianchi I. We showed in [1] that there is a large class of modified gravity theories where the evolution of anisotropies admits a simple and universal description, which can be formulated as algebraic transition rules between Kasner exponents in the pre- and post-bounce phases (Kasner transitions). This result generalizes previous findings in loop quantum cosmology and in mimetic gravity and shows the much broader extent of their applicability.

Next, I will focus specifically on a version of mimetic gravity originally proposed by Mukhanov and Chamseddine; this model resolves the initial singularity in FLRW models, and was also argued to resolve the singularity in the Schwarzschild black-hole interior (modelled as a Kantowski-Sachs spacetime). However, using dynamical system techniques to analyze the dynamics of Kantowski-Sachs model in this theory, we showed in [2] that there is no singularity resolution in this case. Furthermore, solutions cannot be matched to a null black-hole event horizon and, therefore, do not correspond to the interior of a static and spherically symmetric black hole. This is a cautionary example about the risks of extrapolating the black-hole interior/Kantowski-Sachs isometry beyond general relativity.

Based on:

[1] MdC, E.Wilson-Ewing, “A generalized Kasner transition for bouncing Bianchi I models in modified gravity theories”, JCAP 12 (2019) 039;

[2] MdC, S.S. Seahra, E.Wilson-Ewing, “The singularity in mimetic Kantowski-Sachs cosmology”, JCAP 07 (2020) 0

A framework to test theories of gravity with black hole shadows

Riccardo Della Monica, Universidad de Salamanca, Spain

The advancement in the Very Long Baseline Interferometry (VLBI) techniques over the last decades has led to the observation of structures on the scale of the event horizon in the local Universe. The direct observation of the shadow of a black hole provides one of the most stringent tests for theories of gravity in the strong-field regime. In this work, we present a framework for the fully-relativistic numerical integration of the geodesic equations starting from an analytic expression of the metric tensor of the space-time. The implementation of ready-to-use methods to numerically compute the shadow of a black hole allows the user to test any black hole solution of the field equations and thus makes it directly applicable to any metric theory of gravity. We performed tests of our framework for a rotating Kerr black hole in General Relativity, comparing the results with the theoretically expected shadow. We then applied the same algorithm to a rotating black hole solution in the Scalar-Tensor-Vector Gravity theory to study departures from GR.

Session 2: Modified Gravity II

(Monday, 29 March, 11:00)
Chair: David F. Mota (University of Oslo)

Bouncing and loitering solutions in Born-Infeld gravity and its extensions

Diego Rubiera-Garcia, Complutense University of Madrid, Spain

We consider different types of non-singular universes arising in Born-Infeld theories gravity and their funcional extensions when coupled to perfect fluids and scalar fields. These non-singular solutions are of two types: bouncing solutions, where the scale factor collapses to a minimum value and then re-expands, and loitering solutions, where the cosmological evolution interpolates between an asymptotically Minkowski past and the current accelerated expansion. The role of perturbation instabilities is also discussed.

Cosmological Bouncing Solutions in $f(T, B)$ Gravity

Maria Caruana, University of Malta (Department of Physics), Institute of Space Sciences and Astronomy, Malta

Teleparallel Gravity offers the possibility of reformulating gravity in terms of torsion by exchanging the Levi-Civita connection with the Weitzenböck connection, which describes torsion rather than curvature. Surprisingly, Teleparallel Gravity can be formulated to be equivalent to general relativity for an appropriate setup. Our interest lies in exploring an extension of this theory in which the Lagrangian takes the form of $f(T, B)$ where T and B are two scalars that characterize the equivalency with general relativity. In this work, we investigate the possibility of reproducing well-known cosmological bouncing scenarios in the flat Friedmann-Lemaître-Robertson-Walker geometry using this approach to gravity. We study the types of gravitational Lagrangians which are capable of reconstructing analytical solutions for symmetric, oscillatory, superbounce, matter bounce, and singular bounce settings. These new cosmologically inspired models may have an effect on gravitational phenomena at other cosmological scales.

Stability Conditions for the Horndeski Scalar Field Gravity Model

Cláudio Gomes, CFP, University of Azores, Portugal

We constrain the viable models of Horndeski gravity, written in its equivalent Generalised Galileon version, by resorting to the Witten positive energy theorem. Other criterion for stability are also analysed, such as the attractiveness of gravity, the Dolgov-Kawasacki instability and the energy conditions. Some applications for Cosmology are discussed.

Phenomenology of a Scaling Cubic Galileon Model

Inês Sarranito Albuquerque, IA/FCUL, Portugal

The current standard model of Cosmology, Lambda-Cold-Dark-Matter (LCDM), has been known to face a series of shortcomings, both conceptually and observationally. In response, modified gravity (MG) models have been widely explored as alternative explanations for the late-time cosmic acceleration. In this talk I will present the Scaling Cubic Galileon (SCG), a Cubic Horndeski model capable of reproducing a late-time acceleration period as well as introducing new scaling solutions in the presence of cubic Horndeski interactions and a standard scalar-field kinetic term with two exponential potentials. In addition to exploring the model's background dynamics, I will present a study of its effect on large-scale structure observables, such as the matter and Cosmic Microwave Background (CMB) temperature and lensing power spectra, performed using the Einstein-Boltzmann code EFTCAMB.

Kinematic reconstructions of extended theories of gravity at small and intermediate redshifts

Marco Calzà, University of Coimbra, Portugal

n the last few decades, extensions of General Relativity have gained attention especially in view of possible breakdowns of the standard ΛCDM paradigm at intermediate and high redshift regimes. If General Relativity would not be the ultimate theory of gravity, modifying Einstein's gravity in the homogeneous and isotropic universe may likely represent a viable path toward the description of the current universe speed up. We here focus our attention on two classes of extended theories, i.e. the $f(R)$ and $f(R,G)$ paradigms, with the only requirement that the cosmological principle holds. We thus limit our treatment by only assuming the concordance paradigm is preserved at background cosmology. In so doing, we presume that each extended models reduce to the ΛCDM scenario at infrared energy regime. To do so, we involve a few classes of $F(R,G) = R + f(R,G)$ modified theories of gravity, i.e in which the Ricci scalar is explicitly reported. Hence, we parameterize the so-obtained Hubble rate by means of effective barotropic fluids, by calibrating the shapes of our curves through the most suitable dark energy parameterizations, e.g. XCDM , CP L, W P , and so forth. Afterwards, by virtue of the correspondence between Ricci and Gauss-Bonnet invariants and the redshift z, i.e. $R = R(z)$ and $G = G(z)$, we rewrite $f(R,G)$ in terms of corresponding $f(z)$ auxiliary functions. This scheme enables one to get numerical shapes for $f(R,G)$ and $f(R)$ models. Further, we fixed our priors over the free coefficients of our frameworks by means of the most recent outcomes provided by Planck's mission.

Towards a ΛCDM Universe in $f(R)$ gravity

Saikat Chakraborty, Center for Gravitation and Cosmology, Yangzhou University, China

ΛCDM model till date remains the best observationally fitting model for late time cosmology. However, this model suffers from the theoretical issue that the quantum vacuum energy, which is the only known candidate for Λ, gives from QFT calculation a value that mismatches with the observed value of Λ by orders of magnitude. This theoretical issue motivated the search for alternative late time cosmologicsl models. Among various alternative models, a broad class of models incorporate modified gravity, within which a significant subclass are $f(R)$ gravity models. A very pertinent question to ask is whether there are some $f(R)$ gravity models that can exactly mimick the ΛCDM evolution history. This question is of interest because if there are indeed such $f(R)$ gravity models, then one need to worry about a theoretical issue on Λ. In my talk I will discuss some attempts in this direction from the points of view of two frequently used mathematical treatments in theoretical cosmology: the reconstruction method and the dynamical systems approach.

Cosmic Acceleration in an Extended Brans-Dicke-Higgs Theory

Soumya Chakrabarti, Theory Division, Saha Institute of Nuclear Physics, Kolkata, India

We consider an extended scalar-tensor theory of gravity where the action has two interacting scalar fields, a Brans-Dicke field which makes the effective Newtonian constant a function of coordinates and a Higgs field which has derivative and non-derivative interaction with the Lagrangian. There is a non-trivial interaction between the two scalar fields which dictates the dominance of different scalar fields in different era. We investigate if this setup can describe a late-time cosmic acceleration preceded by a smooth transition from deceleration in recent past. From a cosmological reconstruction technique we find the scalar profiles as a function of redshift. We find the constraints on the model parameters from a Markov Chain Monte Carlo analysis using observational data.

Evolution of an effective equation of state, matter density contrast and thermodynamic equilibrium of the universe are studied and their significance in comparison with a LCDM cosmology is discussed.

Cosmological constraints of phantom dark energy models

Bouali Amine, Physics of Matter and Radiation Laboratory, Mohammed I University, Morocco

Many efforts have been put forward to discover the reason behind the phenomenon of the current accelerated expansion of the Universe. It seems that Dark Energy (DE) is one of the most successful explanations, even though the nature of the DE component still a mystery. In the context of general relativity, where the accelerated expansion is described by dark energy (DE) we extract the cosmological parameters of three phantom DE models with the help of Markov Chains Monte Carlo (MCMC). These models induce singularity and abrupt events are known as Big Rip (BR), Little Rip (LR) and Little Sibling of the BR (LSBR), respectively. We first start with a background analysis which consists to confront the theoretical models to the joined observational data i.e. supernova type Ia (SNe Ia) dataset, Planck 2018 distance priors of cosmic microwave background (CMB), baryon acoustic oscillations (BAO) and the direct measurement of the Hubble constant H(z). For model comparison, we use the corrected Akaike Information Criterion (AIC_c). As a second step, we have analysed the theoretical predictions of these models and then confront them to the most accepted model, ΛCDM.

Session 3: Quantum Cosmology

(Monday, 29 March, 14:00)
Chair: Claus Kiefer (University of Cologne)

Eddington-inspired-Born-Infeld tensorial instabilities neutralized in a quantum approach

Mariam Bouhmadi-López, Ikerbasque and University of the Basque Country, Spain

The recent direct detection of gravitational waves has highlighted the huge importance of the tensorial modes in any extended gravitational theory. One of the most appealing approaches to extend gravity beyond general relativity is the Eddington-inspired-Born-Infeld gravity which is formulated within the Palatini approach. This theory can avoid the Big Bang singularity in the physical metric although a Big Bang intrinsic to the affine connection is still there, which in addition couples to the tensorial sector and might jeopardize the viability of the model. In this paper, we suggest that a quantum treatment of the affine connection, or equivalently of its compatible metric, is able to rescue the model. We carry out such an analysis and conclude that from a quantum point of view such a Big Bang is unharmful. We expect therefore that the induced tensorial instability, caused by the Big Bang intrinsic to the affine connection, can be neutralized at the quantum level.

The little rip in classical and quantum $f(R)$ cosmology

Teodor Borislavov Vassilev, Universidad Complutense de Madrid, Spain

The little rip is a cosmological abrupt event predicted by some phantom dark energy models that are compatible with our Universe. This event can be interpreted as a big rip singularity infinitely delayed in time, although bounded structure are destroyed in a finite time in the future. In this talk I shall discuss the little rip cosmology within the scheme of alternative metric $f(R)$ theories of gravity from both classical and quantum points of view. The quantum analysis will be performed in the framework of $f(R)$ quantum geometrodynamics by means of the modified Wheeler-DeWitt equation. Furthermore, I will prove that the DeWitt criterion for singularity avoidance can be satisfied. Similar to what happens in general relativity, this result points towards the avoidance of the little rip in $f(R)$ quantum cosmology.

States of Low Energy in Loop Quantum Cosmology

Rita Neves, Universidad Complutense de Madrid, Spain

A general construction of States of Low Energy (SLE) in Friedmann-Lemaître-Robertson-Walker (FLRW) spacetimes has been defined in 2007 by Olbermann, by minimizing the mode by mode contribution to the regularized energy density. These have been shown to be an adequate choice of vacuum state for primordial perturbations if the model includes a period of kinetic domination preceding inflation. This is precisely the case in Loop Quantum Cosmology (LQC). In this talk, we will review the construction of SLE for a general FLRW model and show results and comparison with observations when applying to LQC.

Cosmological perturbations on top of loop quantum backgrounds

Alejandro García-Quismondo, Instituto de Estructura de la Materia (IEM-CSIC), Spain

In this talk, I will discuss some recent results concerning the loop quantum dynamics of isotropic cosmologies. After a brief introduction of the homogeneous case, I will examine the consequences of a regularisation ambiguity in the definition of the quantum Hamiltonian on the perturbative formalism for the introduction of inhomogeneities. Then, I will conclude by commenting on how the effective masses seen by scalar and tensor perturbations (which are key to obtain physical predictions) are affected by this ambiguity.

Anisotropic inflationary loop quantum cosmology: predictions for the CMB

Javier Olmedo, Universidad de Granada, Spain

The paradigm of slow-roll inflation provides a picture of the early universe that is in good agreement with present observations. Despite its success, most of the models studied so far rely heavily on the assumption that the universe is perfectly isotropic at early times. In this talk, I will discuss recent advances about anisotropic inflationary models in loop quantum cosmology, which have a well-defined dynamics at Planck scales. Here, gauge-invariant perturbations are Fock quantized and evolved through an anisotropic bounce. Despite anisotropies die out very rapidly just before the inflationary expansion, quantum cosmological perturbations keep memory of that anisotropic phase, and leave anomalies in the Cosmic Microwave Background (CMB). With these imprints and current data, we constrain the departure from spatial isotropy of the early universe, as well as discuss angular correlation functions that are otherwise forbidden in the standard isotropic scenario.

Holonomy and inverse-triad corrections in non-homogeneous midi-superspace models

Asier Alonso-Bardaji, Euskal Herriko Unibertsitatea/Universidad del País Vasco, Spain

The discrete nature of spacetime predicted by loop quantum gravity may provide an answer to the singularity problems of general relativity. For example, homogeneous cosmological scenarios have been widely studied, predicting the resolution of the initial singularity. In the context of loop quantum cosmology, effective theories provide an accurate description of the evolution when compared to the full quantum dynamics. We extend these effective methods to include non-homogeneous midi-superspace models such as LTB-like and polarized Gowdy universes. For that purpose, we develop a systematic construction of anomaly-free effective constraints encoding corrections motivated by loop quantum gravity, i.e. holonomy and inverse-triad modifications.

Quantum phenomenological gravitational dynamics: A general view from thermodynamics of spacetime

Marek Liska, Institute of Theoretical Physics, Faculty of Mathematics and Physics, Charles University, Prague, Czech Republic

It is known that Einstein equations can be derived from the proportionality between entropy and horizon area. However, it is also known that when quantum gravity effects are considered, a correction to the entropy logarithmic in horizon area appears. Here, I will present quantum modified gravitational dynamics implied by this corrected entropy and discuss its main features. Furthermore, I will outline the application of the modified dynamics to cosmology, suggesting the replacement of the Big Bang singularity by a regular bounce.

Cosmological predictions from infinite classical action

Jan Chojnacki, Faculty of Physics, University of Warsaw, Poland

The destructive interference of the neighboring field configurations with infinite classical action in the gravitational path integral approach serves as a dynamical mechanism resolving the black hole singularity problem. It also provides an isotropic and homogeneous early universe without the need for inflation.

The path integral approach yields a powerful framework in the quantum theory. It emphasizes Lorentz covariance and allows for the description of non-perturbative phenomena. In the path integral, one sums over all possible configurations of a field(s) ϕ weighted by $e^{iS[\phi]}$, where $S[\phi]$ is the classical action of the theory.

In the Minkowski path integral, the classical action approaching infinity causes fast oscillations in the exponential weight and hence the destructive interference of the neighboring field configurations. Such configurations do not contribute to the physical quantities. Furthermore, in Wick rotated path integral is weighted by $e^{-S[\phi]}$, and the field(s) configurations on which the action is infinite do not contribute at all. This provides theoretical motivation for the Finite Action Principle, saying that an action of the universe should be finite. This principle has a significant impact on the nature of quantum gravity and the cosmological evolution, once the higher-curvature terms are included. In the framework of Horava-Lifshitz gravity, field configurations with finite classical action describe a universe with a homogeneous and isotropic beginning, without black hole singularities and ghost particles.

Session 4: Mathematical Cosmology

(Monday, 29 March, 17:30)
Chair: Artur Alho (IST - University of Lisbon)

Universal laws of bouncing cosmology

Bruno le Floch, Institut Philippe Meyer, École Normale Supérieure, France

Modifications to 3+1d general relativity (GR) at high curvatures can eliminate the Big Bang singularity in favor of a bounce. Abstracting away microscopic details of the bounce, the spacetime is simply a GR solution on both sides of a singularity hypersurface, with some theory-dependent "singularity scattering map" relating the asymptotic metrics on both sides. The asymptotic metric near a singularity was studied by Belinsky, Khalatnikov and Lifshitz (BKL) and they found that the time evolution at different points decouples. Motivated by this ultralocality property, we classify (in the absence of BKL oscillations) all singularity scattering maps that are ultralocal. By matching previous calculations on homogeneous spacetimes in f(R) gravity and in loop quantum cosmology with our classification we obtain a prediction for non-homogeneous bounces in these theories. Lastly, we uncover that the collision of plane gravitational waves yields cyclic spacetimes (which may have infinitely many successive singularities). This is joint work with P.G. LeFloch and G. Veneziano.

Quantum Corrections to the Bianchi II transition

Sara Fernández Uria, University of the Basque Country (UPV-EHU), Spain

A quantum state in a Bianchi II model is studied in its approach to a cosmological singularity by means of the evolution of its moments. Classically this system presents a transition between two Bianchi I models. This phenomenon is described by a very specific and well-known transition law, which is derived based on the conservation of certain physical quantities. In the quantum theory fluctuations and quantum moments of higher order of the different variables arise. Consequently, these constants of motion are modified and hence the transition rule. We focus on the so-called locally rotationally symmetric (LRS) and vacuum cases, as a first step towards a more complete study. Indeed, the main goal is to generalize this analysis to the Bianchi IX spacetime, which can be seen as a succession of Bianchi II models. Ultimately, these results may lead to a better understanding of the role played by quantum effects in the BKL conjecture.

Global dynamics of the Einstein-Euler-Yang-Mills system in flat Robertson-Walker cosmologies

Vitor Emanuel Moreira Bessa, CMAT, Portugal.

We apply a new global dynamical systems formulation to flat Robertson-Walker cosmologies with a massless and massive Yang-Mills field and a perfect-fluid with linear equation of state as the matter sources. This allows us to give proofs concerning the global dynamics of the models including asymptotic source-dominance towards the past and future time directions. For the pure massless Yang-Mills field, we also contextualize well-known explicit solutions in a global (compact) state space picture.

Dynamical system approach to hybrid metric-Palatini cosmologies

João Luís Rosa, Institute of Physics - University of Tartu, Estonia

We study the cosmological phase space of the generalized hybrid metric-Palatini gravity theory, characterized by the functions $f(R, R)$, using a dynamical system approach. We formulate the propagation equations of the suitable dimensionless variables that describe FLRW universes as an autonomous system. The fixed points are obtained for four different forms of the function f and the behavior of the scale factor is computed. We show that due to the structure of the system, no global attractors can be present and also that two different classes of solutions for the scale factor exist. Under an appropriate redefinition of the variables, we can find a solution for the scale factor that models inflation and the late-time cosmic acceleration period and for which the Hubble parameter, deceleration parameter, and time interval since the Big Bang are coherent with the observational constraints from the Planck Satelite.

Relativistic Zel'dovich Approximation and exact solution of Einsteins equations

Ismael Delgado Gaspar, Institute of Astronomy, National Autonomous University of Mexico, Mexico

We examine the relationship between the Szekeres models and the Relativistic Zel'dovich Approximation (RZA). We show that the second class of the Szekeres solutions is exactly contained within the RZA when the latter is restricted to an irrotational dust source with a flow-orthogonal foliation of spacetime. In such a case, the solution is governed by the first principal scalar invariant of the deformation field, proving a direct connection with a class of Newtonian 3-dimensional solutions without symmetry. For the second class, a necessary and sufficient condition for the vanishing of cosmological backreaction is expressed through integral constraints. Domains with no backreaction can be smoothly matched, forming a lattice model, where exact deviations average out at a given scale of homogeneity, and the homogeneous and isotropic background is recovered as an average property of the model. Although the connection with the first class of Szekeres solutions is not straightforward, this class allows for the interpretation in terms of a spatial superposition of non-intersecting fluid lines, where each world line evolves independently and under the RZA model equations, but with different associated "local backgrounds". This hints towards a possible generalization of the Lagrangian perturbation schemes to structure formation models on evolving backgrounds, including global cosmological backreaction.

[I. Delgado Gaspar and T. Buchert, Phys. Rev. D (2021)]

Session 5: Inflation I

(Tuesday, 30 March, 10:00)
Chair: João Rosa (University of Coimbra)

Long-range enhanced mutual information from inflation

Llorenç Espinosa-Portalés, Instituto de Física Teórica UAM-CSIC, Spain

In the inflationary paradigm, the stretching of quantum fluctuations originates primordial curvature perturbations that seed structure formation. This stretching is also responsible for the creation of long-range correlations that lead to an enhanced mutual information between distant regions of the universe. I will discuss the nature of this enhancement during the subsequent radiation era and its implication for primordial black holes.

The Cosmological OTOC

Sayantan Choudhury, National Institute of Science Education and Research, Bhubaneswar, India

The out-of-time-ordered correlation (OTOC) function is an important new probe in quantum field theory which is treated as a significant measure of random quantum correlations. In this paper, using for the first time the slogan "Cosmology meets Condensed Matter Physics", we demonstrate a formalism to compute the Cosmological OTOC during the stochastic particle production during inflation and reheating following the canonical quantization technique. In this computation, two dynamical time scales are involved—out of them, at one time scale, the cosmological perturbation variable, and for the other, the canonically conjugate momentum, is defined, which is the strict requirement to define the time scale-separated quantum operators for OTOC and is perfectly consistent with the general definition of OTOC. Most importantly, using the present formalism, not only one can study the quantum correlation during stochastic inflation and reheating, but can also study quantum correlation for any random events in Cosmology. We have studied the possibility of having three different types of correlators, which quantifies the random quantum correlation function out-of-equilibrium. We have also studied the classical limit of the OTOC and checked the consistency with the large time limiting behaviour of the correlation. Finally, we prove that the normalized version of OTOC is completely independent of the choice of the preferred definition of the cosmological perturbation variable.

Session 6: Inflation II

(Tuesday, 30 March, 11:00)
Chair: Andrew Liddle (University of Lisbon)

One residue to rule them all: Electroweak symmetry breaking, inflation and field-space geometry

Javier Rubio, Center for Astrophysics and Gravitation, Instituto Superior Técnico, Portugal

I will present a unified framework for the generation of the Fermi-to-Planck mass ratio in scalar-tensor theories involving a non-minimal coupling of the Higgs field to gravity. The proposed approach opens up new avenues for model building by rephrasing the usual hierarchy problem in terms of geometrical properties of the field manifold. Among other applications, this could lead to interesting synergies with α-attractor scenarios and superconformal field theories.

Cosmological implications of EW vacuum instability: constraints on the Higgs-curvature coupling from inflation

Andreas Mantziris, Imperial College London, United Kingdom

The current experimentally measured parameters of the Standard Model (SM) suggest that our Universe lies in a metastable electroweak vacuum, where the Higgs field is prone to vacuum decay to a lower state with catastrophic consequences. Our measurements dictate that such an event has not taken place yet, despite the many different mechanisms that could have triggered it in our past light-cone. The focus of our work has been to calculate the probability of the false vacuum to decay during the period of inflation and use it to constrain the last unknown renormalisable SM parameter ξ, which couples the Higgs field with space-time curvature. More specifically, we derived lower ξ-bounds from vacuum stability in three inflationary models: quadratic and quartic chaotic inflation, and Starobinsky-like power-law inflation. We also took the time-dependence of the Hubble rate into account both in the geometry of our past light-cone and in the Higgs effective potential, which is approximated with three-loop renormalisation group improvement supplemented with one-loop curvature corrections. Based on arXiv:2011.03763.

Higgs inflation with non-minimal scalar field coupling and holographic cosmology

Aatifa Bargach, LPMR, faculty of sciences Oujda, University Mohammed first, Morocco

Higgs inflation is an excellent way to connect inflationary models with known particle physics (Higgs boson) and to benefit from observational constraints of both particle physics and cosmology. In this study, we derive a Higgs inflationary model in the context of holographic cosmology, where we consider a universe filled with a Higgs field non-minimally coupled to gravity in a slow-roll regime. In this regard, we show that the background and perturbative parameters characterising the inflationary era are related to the standard one through corrections terms. We found that for the e-fold number $N \sim 58$, the spectral index, n_s, and the tensor-to-scalar ratio, r, values are 0.965 and 0.021, respectively, which are in agreement with 2018 Planck observational data. However, as soon as we move from $N \sim 58$, the model is ruled out by the current data.

A non-local framework of violating Maldacena consistency relation

Sravan Kumar Korumilli, Tokyo Institute of Technology, Japan

The well-known Maldacena consistency relation related to squeezed limit non-Gaussianity is known to be violated only in the context of beyond the single field slow-roll and/or multifield inflation. In this talk, I will present a new way of violating Maldacena consistency relation with non-local inflation driven by a single scalar field where the standard slow-roll is perfectly maintained and the curvature perturbation in super-horizon scales is conserved. The origin of the Maldacena consistency relation violation is a purely non-local effect.

CosmoLattice

Francisco Torrenti, University of Basel, Switzerland

The aim of my talk is to present CosmoLattice: a new public package for lattice simulations of classical field theories in an expanding universe. CosmoLattice was released in February 2021, and it can simulate (so far) the dynamics of scalar and gauge field theories, both Abelian and non-Abelian. In my talk I will discuss about the motivation of CosmoLattice, its basic features and functionalities, and well as future updates.

Energy distribution and equation of state after inflation

Kenneth Marschall, University of Basel, Switzerland

We discuss the energy distribution and equation of state of the universe between the end of inflation and the onset of radiation domination for observationally consistent single-field inflationary scenarios, with a potential ‘flattening’ at large field values, and a monomial shape around the origin. As a proxy for (p)reheating, the inflaton is coupled to a light scalar field with a quadratic interaction and we investigate the non-perturbative and non-linear dynamics of this system with lattice simulations. For particular cases we are able to calculate the exact number of e-folds until radiation domination, which significantly reduces the uncertainty in the inflationary observables, the spectral tilt and tensor-to-scalar ratio.

Perturbative and Non-Perturbative Process in The Early Universe

Khalil El Bourakadi, Physics and Quantum Technology Team, LPMC, Faculty of Sciences Ben M’sik, Casablanca Hassan II Univerity, Morocco

We study the two-phase scenario following inflation, where the initial step is preheating, accompanied by a step of perturbative reheating at which inflaton field decays transferring all of its energy to create relativistic particles, the interaction of these particles will evolve towards a state of thermal equilibrium with a temperature T_{re} called the reheating temperature. It is observed that the scenario of reheating normally predicts the maximum reheating temperature $T_{re} \simeq 10^{15}$ GeV, which corresponds to an almost instantaneous transition from inflation to the radiation domination era. This will naturally lead to a nonperturbative preheating. In this framework, we propose constraints on the preheating and reheating durations parameters expressed in terms of the cosmic microwave background (CMB) inflationary scalar spectral index. Furthermore, T_{re} in some models is predicted to be less than 10^{15} GeV, this scenario does not correspond to the instantaneous process of reheating. The total duration of the corresponding two steps given as $N_{pre} + N_{re}$, is modeled by an effective equation-of-state parameter w studied in the range [-1/3,1/3]. in this work we study the compatibility of polynomial and arctangent models of inflation with the observational data obtained from Planck 2018.

Universe in a black hole with spin and torsion

Nikodem Poplawski, University of New Haven, USA

We consider gravitational collapse of a spherically symmetric sphere of a fluid with spin and torsion into a black hole. We use the Tolman metric and the Einstein-Cartan field equations with a relativistic spin fluid as a source. We show that gravitational repulsion of torsion prevents a singularity and replaces it with a nonsingular bounce. Quantum particle production during contraction strengthens torsion in opposing shear.

Particle production during expansion can produce enormous amounts of matter and generate a finite period of inflation. The resulting closed universe on the other side of the event horizon may have several bounces. Such a universe is oscillatory, with each cycle larger in size then the previous cycle, until it reaches the cosmological size and expands indefinitely. Our universe might have therefore originated from a black hole existing in another universe.

Session 7: Dark matter

(Tuesday, 30 March, 14:00)
Chair: Mariam Bouhmadi-López (University of the Basque Country)

Detecting spin-2 dark matter with gravitational wave interferometers

Federico Urban, CEICO, FZU, Prague, Czech Republic

I will discuss how spin-2 dark matter, if it is ultra-light, generates a ever present signal that is akin to but distinct from a continuous gravitational wave, and that this signal could be detected with current and planned gravitational wave interferometers. In case of a null detection we would be able to place the most stringent bounds on the spin-2 Yukawa fifth force strength in the frequency ranges accessible by gravitational wave interferometers. The implementation of this type of searches for gravitational wave interferometers would therefore further our grasp of both dark matter and gravity.

The QCD axion in the CMB

Ricardo Zambujal Ferreira, IFAE, Barcelona, Spain

The QCD axion is likely the best-motivated particle beyond the Standard Model (SM) of Particle Physics. It solves the problem it was proposed for, the strong CP problem, and can also solve the dark matter puzzle.

Although its couplings to SM particles are rather weak, axions can be efficiently produced in the primordial plasma in the early universe. This yields a relic background of hot axions that leaves imprints in cosmological fossils such as the cosmic microwave background (CMB).

In this talk, I will describe the latest progress in this subject. I will present model-independent analyses of the thermal axion production through the different SM sectors (heavy quarks, Higgs, leptons) including flavour violating interactions, and discuss which regions of parameters can be probed with current and future data. I will also show the results for some benchmark models like the DFSZ axion.

The situation is quite promising, CMB-S4 can potentially probe axion masses down to the meV and it can offer a unique glance at the QCDPT.

Two-phase structure of fuzzy dark matter with three-particle interaction

Mariia Khelashvili, Bogolyubov Institute for Theoretical Physics, Ukraine

Fuzzy dark matter(FDM) model considers bosons with a mass nearly 10-22 eV as dark matter particle candidates so that de Broglie wavelength of these particles is of kiloparsec scale, comparable to the size of small galaxies (like dwarf spheroidal galaxies). Due to this feature, quantum effects play a role on macroscopic scales. In the center of DM halo particles fall into the ground state and form a central core (soliton), surrounded by an envelope of incoherent phase with an average density close to NFW profile, similarly to cold DM predictions. The macroscopic quantum features of FDM allow solving CDM model tensions with observations on the small scales. Large de Broglie wavelength prevents cusp formation in the DM halo center, so naturally provides a solution to the core-cusp tension. In the same way, it delays the structures formation and suppresses the formation of small-scale structures. On the large scales, as was shown by numerous numeric simulations, cold FDM predictions are indistinguishable from the standard cosmological model.

The model, in turn, is not free of some tensions noticed recently. These are related mainly to predicted by FDM scaling relations between DM halo parameters which follow from exact scaling symmetry of Schrodinger-Poisson equation discrepancy FDM soliton. There is also a discrepancy of an order of magnitude in FDM particle mass, required by the kinematics of galaxies and Lyman-alpha forest observation. However, the one order of magnitude difference might be explained by nonlinear baryonic physics. In the light of the FDM model successes and its slight disagreements with observations, consideration of self-interaction may be interesting for softening the mentioned tensions. The two-particle interaction is usually present in the Gross-Pitaevsky equation and thus taken into account in Bose-Einstein condensate dark matter model (which is very close to FDM). We consider the FDM model with repulsive three-particles interaction ψ^6, which is the simplest non-renormalizable term. Our investigations show that this model has the potential to address the tension between FDM scalings and galaxy kinematics observations.

From the detailed analysis of thermodynamic characteristics of FDM with three-particle self-interaction, we find the existence of two phases of dark matter (the dilute and dense phase) separated by instability region in the FDM halo soliton, and first-order phase transition between phases. The above results are published in [1].

[1]. A. M. Gavrilik, M. V. Khelashvili, A. V. Nazarenko, Bose-Einstein condensate dark matter model with three-particle interaction and two-phase structure. Phys. Rev. D 102, 083510 (2020).

(Super)-ν inflaton dark matter

António Torres Manso, University of Granada, Spain

We present the supersymmetric extension of the unified model for inflation and Dark Matter studied in Ref. arXiv:1811.02302. The scenario is based on the incomplete decay of the inflaton field into right-handed (s)neutrino pairs. By imposing a discrete interchange symmetry on the inflaton and the right-handed (s)neutrinos, one can ensure the stability of the inflaton field at the global minimum today, while still allowing it to partially decay and reheat the Universe after inflation. Compatibility of inflationary predictions, BBN bounds and obtaining the right DM abundance for the inflaton Dark Matter candidate typically requires large values of its coupling to the neutrino sector, and we use supersymmetry to protect the inflaton from potentially dangerous large radiative corrections which may spoil the required flatness of its potential. In addition, the inflaton will decay now predominatly into sneutrinos during reheating, which in turn give rise both to the thermal bath made of Standard Model particles, and inflaton particles. We have performed a through analyses of the reheating process following the evolution of all the partners involved, identifying the different regimes in the parameter space for the final Dark Matter candidate. This as usual can be a WIMP-like inflaton particle or an oscillating condensate, but we find a novel regime for a FIMP-like candidate.

Neutrino Portal to FIMP Dark Matter with an Early Matter Era

Catarina Cosme, IFIC, University of Valencia, Spain

We study the freeze-in production of Feebly Interacting Massive Particle (FIMP) dark matter candidates through a neutrino portal. We consider a hidden sector comprised of a fermion and a complex scalar, with the lightest one regarded as a FIMP candidate. We implement the Type-I Seesaw mechanism for generating the masses of the Standard Model (SM) neutrinos and consider three heavy neutrinos, responsible for mediating the interactions between the hidden and the SM sectors. We assume that an early matter-dominated era (EMDE) took place for some period between inflation and Big Bang Nucleosynthesis, making the universe to expand faster than in the standard radiation-dominated era. In this case, the hidden and SM sectors are easily decoupled and larger couplings between FIMPs and SM particles are needed from the relic density constraints. In this context, we discuss the dynamics of dark matter throughout the modified cosmic history, evaluate the relevant constraints of the model and discuss the consequences of the duration of the EMDE for the dark matter production. Finally, we show that if the heavy neutrinos are not part of the thermal bath, this scenario becomes testable through indirect detection searches.

An estimate of the mass of classic or fermionic dark matter using the observed mass model of late-type galaxies

Ahmad Borzou, Syracuse University and Baylor University, USA

We analyze observations of the mass profiles of more than 100 late-type galaxies to construct the temperature profile of their dark matter (DM) halo by assuming that (1) DM in the halos obeys either the Fermi-Dirac or the Maxwell-Boltzmann distribution, and (2) the halos are in the Virial state. We derive the mass to the temperature of DM at the center of the halos in terms of the total mass of the halo and show that the relationship is the same as the one obtained from N-body simulations of DM and also the same as the one obtained by observing the visible matter. Taking the latter as a validation of our analysis, we derive the mass to the temperature of DM at the edge of the halos and show that it is galaxy independent and is equal to mTR≃1010 in natural units. Since the observed galaxies are well separated in the sky, we conclude that DM is a thermal relic and TR in the above ratio can be expressed in terms of the temperature of the cosmic microwave background at the time that DM froze-out. We use this result to study possible cosmological scenarios. We rule out (1) non-thermal DM, (2) collisionless cold DM, (3) cold self-interacting DM that freeze-out before the radiation-matter equality. Two viable scenarios are (1) DM has a mass of 1 MeV, and has decoupled when it was relativistic, and therefore is warm; (2) DM is self-interacting and cold with a mass in the range of 10 eV$< m <$7 keV that freeze-out after the equality.

How neutron stars can help us to constrain dark matter

Violetta Sagun, University of Coimbra, Portugal

We study an impact of asymmetric dark matter on properties of the neutron stars and their ability to reach the two solar masses limit, which allows us to present a new range of masses of dark matter particles and their fractions inside the star. Our analysis is based on the observational fact of the existence of two pulsars reaching this limit and on the theoretically predicted reduction of the neutron star maximal mass caused by the accumulation of dark matter in its interior. We also demonstrate that light dark matter particles with masses below 0.2 GeV can create an extended halo around the neutron star leading not to decrease, but to increase of its visible gravitational mass. By using recent results on the spatial distribution of dark matter in the Milky Way, we present an estimate of its fraction inside the neutron stars located in the Galaxy center. We show how the detection of a 2 Msun neutron star in the most central region of the Galaxy will impose an upper constraint on the mass of dark matter particles of ∼60 GeV. Future high precision measurements of the neutron stars maximal mass near the Galactic center, will put a more stringent constraint on the mass of the dark matter particle. This last result is particularly important to prepare ongoing, and future radio and X-ray surveys.

Dynamics of disk and elliptical galaxies in Refracted Gravity

Valentina Cesare, Osservatorio Astrofisico di Catania (INAF), Italy

We investigate the dynamics of disk and elliptical galaxies with Refracted Gravity (RG), a novel classical theory of modified gravity inspired to electrodynamics in matter, which does not resort to dark matter. The presence of dark matter is mimicked by a gravitational permittivity, a monotonic increasing function of the local mass density which depends on three universal parameters.

RG properly describes the rotation curves and the vertical velocity dispersions of 30 disk galaxies from the DiskMass Survey (DMS) with mass-to-light ratios consistent with stellar population synthesis (SPS) models, disk scale heights in agreement with edge-on galaxies observations, and permittivity parameters from individual galaxies consistent with each other, suggesting their universality. RG produces a Radial Acceleration Relation of DMS galaxies with the correct asymptotic limits but with residuals correlating with some galaxy properties and with a too large intrinsic scatter, at odds with observations. Further investigation is required to assess if this issue indicates a failure of RG or depends on the galaxy sample.

RG also models the velocity dispersions of stars and of blue and red globular clusters of the elliptical E0 galaxies NGC 1407, NGC 4486, and NGC 5846 belonging to the SLUGGS survey with mass-to-light ratios in agreement with SPS predictions, anisotropy parameters consistent with the literature, and the three permittivity parameters in agreement with each other. The permittivity parameters also present a rather good consistency with those estimated from the DMS galaxies. Given these encouraging results, RG is a theory that deserves further investigation.

Session 8: Primordial Black Holes

(Tuesday, 30 March, 16:30)
Chair: Javier Rubio (IST - University of Lisbon)

Numerical simulations of primordial black holes and universal threshold

Albert Escriva, University of Barcelona, Spain

In this talk, I will explain a new and improved numerical method to estimate the threshold value for primordial black hole formation, which is an essential information to statistically estimate the PBH abundances. Using the numerical results, I will show how to estimate analytically the threshold with a shape-dependence accurately enough for cosmological applications. Finally, I will comment on some new results regarding the accretion effect from the Friedmann background to PBHs.

Primordial Black Holes in the Excursion Set Theory

Encieh Erfani, IASBS, Iran

We study primordial black holes (PBHs) formation in the excursion set theory (EST) in a vast range of PBHs masses with and without confirmed constraints on their abundance. In this work, a new concept of the first touch in the EST is introduced for PBHs formation which takes into account the earlier horizon reentry of smaller masses. Our study shows that in the EST, it is possible to produce PBHs in different mass ranges which could make up all dark matter. We also show that in a broad blue-tilted power spectrum, the production of PBHs is dominated towards a smaller mass. Our analysis put upper limit 0.1 on the amplitude of the curvature power spectrum at length scales relevant for PBHs formation.

Production of Primordial Black Holes from complex scalar field reheating

Juan Carlos Hidalgo, Instituto de Ciencias Físicas, UNAM, Mexico

An initial phase in many models of reheating is a period of fast oscillations of the inflaton field at the bottom of the potential. Here we study the instability band arising from the complex scalar field oscillations in a quadratic potential, attractor of a variety of inflationary models, and determine the scales and conditions for Primordial Black Hole formation. The resulting mass spectrum of PBHs is such that they evaporate within the age of the universe. We determine under which conditions the left over Planck mass relics account for all of the dark matter. We show how this constraint bounds the parameters of such reheating phase, namely the Hubble scale at the end of inflation and the number of e-folds elapsed in this period.

Primordial black holes in an early matter-dominated era and stochastic inflation

Julian Leonardo Rey Idler, Universidad Autonoma de Madrid, Spain

We consider the possibility that the majority of dark matter in our Universe consists of black holes of primordial origin. We examine the effects of stochastic inflation and an early matter-dominated era on the abundance of these black holes. We show that the power spectrum of comoving curvature perturbations computed in stochastic inflation matches the result obtained by solving the Mukhanov-Sasaki equation at the linear level, even in the presence of an ultra-slow-roll phase. We also find a significant reduction in the required tuning of the parameters of the inflationary potential in the matter-dominated scenario, in contrast to the standard case of formation during radiation domination. We show that the stochastic background of primordial gravitational waves resulting from this mechanism could be detected by future space-based observatories.

Shining Primordial Black Holes

Enrico Domenico Schiappacasse, University of Jyväskylä, Finland

Primordial black holes (PBHs) are one of the oldest dark matter (DM) candidates and the possibility of their existence has been strongly revitalized since the first gravitational wave detection from LIGO-Virgo collaboration. As a result, the mixed DM scenario partially composed of a small fraction of PBHs is plausible and well motivated. In this talk, I will address implications for DM direct and indirect detection in the presence of a small fraction of DM in PBHs. Since PBHs are local overdensities in the DM distribution, they are able to act as seeds for the formation of DM structures. Dark matter minihalos around PBHs will grow during the radiation and matter-dominated eras reaching up to ∼102 times the central PBH mass. First, we consider dark minihalos composed of the QCD axion or light bosons holding a symmetry breaking energy scale sufficiently large to avoid sizeable self-annihilation within minihalos. Taking into account the effect of tidal forces in the Milky Way galaxy, we study the impact of this scenario on DM direct searches on the Earth. For an initial fraction in LIGO-motivated PBHs of about 1%, we estimate that the presence of minihalos around PBHs today could reduce by half the local dark matter background. Second, we consider dark minihalos composed of a thermal WIMP, highlighting the case of SU(2)L triplet fermion "winos". This would impact indirect searches of DM on the Earth because of the enhancement of DM annihilation within minihalos. We find that the mixed wino DM scenario is viable and determine constraints on the fraction of DM in PBHs. For the current sensitivity of indirect searches, there is a sizable chance for detecting a gamma ray signal characteristic for the wino annihilation in an individual nearby minihalo with about one solar mass central PBH. We name this unique light source as a "shining black hole".

Modelling accurately the microlensing of supernovae in a lumpy universe

Víctor Boscá Navarro, Institute for Theoretical Physics (IFT) UAM-CSIC, Spain

Needless to say that the nature of dark matter is one of the biggest questions of modern physics. The possibility that dark matter is (at least partially) made of compact objects is a very appealing idea. One way to probe compact objects, such as primordial black holes, beyond the Solar mass is via supernova lensing. In this project we model the probability density function of microlensing magnification P(A|f), given that a fraction f of dark matter is made of compact objects. We include many effects, such as the complex distribution of dark matter in haloes, the subtle effect of lens-lens coupling, the effect of the large scale structure and the finite size of sources.

Session 9: CMB and LSS I

(Wednesday, 31 March, 10:00)
Chair: João Rosa (University of Coimbra)

Geometry versus growth: internal consistency of the flat ΛCDM model

Jaime Ruiz Zapatero, University of Oxford, United Kingdom

We develop a multi-probe self-consistency test of the flat ΛCDM model with the aim of exploring potential causes of the cosmic tension. In order to do so, we divide model into two theory regimes and individually study their preferred parameter values in search for potential discrepancies. This is done by letting each regime be governed by an independent but identical set of ΛCDM parameters. We then obtain parameter constraints for each parameter set by making use of a number of cosmological observables across different redshifts. We employ data sets from the weak lensing probe KiDS-100, the large scale structure surveys BOSS, eBOSS and 6dF as well as the CMB probe Planck. Overall we observe a good agreement between the two theory regimes for all the studied combinations of data sets. Focusing on the key parameters σ_8 and Ω_m, we observe deviations between the traditionally obtained constraints and those obtained from the independent analysis of each theory regime. Most importantly, we find that moving the traditionally obtained constraints towards the region of the parameter space where the the constraints of the two theory regimes intersect would alleviate the the σ_8 cosmic tension, hinting at possible relationship between the two phenomena.

Determining the evolution of growth with current LSS and CMB data

Carlos García-García, University of Oxford, United Kingdom

The current constraints on the σ_8 parameter from the Large Scale Structure KiDS survey shows a 3σ tension with respect to its Planck CMB value. However, other surveys as DES show compatible results with Planck. In this talk I will show preliminary results of constraints on the evolution of the σ_8 parameter on time from DES galaxy clustering and weak lensing, eBOSS quasars and the Planck CMB convergence field. I will compare the $\sigma_8(z)$ ΛCDM evolution constraints with two different $\sigma_8(z)$ data driven reconstructions and check their compatibility. In a near future, we aim to compare these with the constraints from KV450 weak lensing, DECaLS and CMB convergence field, which should allow us to see at what moment the σ_8 evolution departs from Planck's value.

Session 10: CMB and LSS II

(Wednesday, 31 March, 11:00)
Chair: Nelson Nunes (University of Lisbon)

Extra components consistency in the Hubble tension and BBN

Yo Toda, Hokkaido University, Japan

The standard ΛCDM cosmological model now seems to face some puzzles. One of the most serious problems is the so-called Hubble tension; the values of the Hubble constant obtained by local measurements look inconsistent with that inferred from CMB. Although introducing extra energy components such as the extra radiation or early dark energy appears to be promising, such extra components could alter abundance of light elements synthesized by Big Bang Nucleosynthesis (BBN). We perform Monte Carlo simulation to evaluate the effect of those extra component scenarios for solving the Hubble tension to the BBN prediction.

Simple-graduated dark energy and spatial curvature: Do the simplest negative energy densities alleviate the H_0 tension?

Nihan Katırcı, Istanbul Technical University, Turkey

In the first part of this talk, I will review the Hubble tension and then describe some theoretical efforts to alleviate it—as well as the discrepancy with the BAO Lyman-α data - via the dark energy models that yield negative density values in the past. I will then discuss a recent work with two minimal extensions of the ΛCDM model, together or separately, can realize such a scenario: (i) The spatial curvature, which, in the case of spatially closed universe, mimics a negative density source, (ii) Simple-graduated dark energy, which promotes the null inertial mass density of the usual vacuum energy to an arbitrary constant - if negative, the corresponding energy density decreases with redshift similar to the phantom models, but unlike them crosses below zero at a certain redshift. I will close the talk by presenting the results when these are constrained using the latest observational data.

A negative cosmological constant in the dark sector?

Rodrigo Calderon, University of Montpellier, France

Following theoretical (high-energy physics) considerations, we explore the possibility that our Universe contains a negative cosmological constant, dubbed λ, on top of an additional component X accounting for the late-time accelerated stage of expansion. In this talk, I will present some of the cosmological implications of introducing λ. In particular, we will assess the viability of such models when considering Baryon Acoustic Oscillations, SNeIa and CMB (geometrical) measurements. We estimate the Bayesian evidence in various cosmological scenarios through a nested sampling of the parameter space, and compare it to base-ΛCDM for model selection. We will briefly comment on their capability to address the current Hubble tension when a high-H_0 is taken into account.

Hubble constant measurement in light of forthcoming high-redshift surveys

Giuseppe Fanizza, IA/FCUL, Portugal

Forthcoming surveys will extend the understanding of cosmological large scale structures up to unprecedented redshift. According to this perspective, we present a fully relativistic framework to evaluate the impact of stochastic inhomogeneities on the determination of the Hubble constant. To this aim, we work within linear perturbation theory and relate the fluctuations of the luminosity distance-redshift relation, in the Cosmic Concordance model, to the intrinsic uncertainty associated to the measurement of H_0 from high-redshift surveys ($0.15 \leq z \leq 3.85$). We first present the detailed derivation of the luminosity distance-redshift relation 2-point correlation function and then provide analytical results for all the involved relativistic effects, such as peculiar velocity, lensing, time delay and (integrated) Sachs-Wolfe, and their angular spectra. Hence, we apply our analytical results to the study of high-redshift Hubble diagram, according to what has been recently claimed in literature. Following the specific of Euclid Deep Survey and LSST, we conclude that the cosmic variance associated with the measurement of the Hubble constant is at most of 0.1%. Our work extends the analysis already done in literature for closer sources, where only peculiar velocity has been taken into account. We then conclude that deep surveys will provide an estimation of the H_0 which will be more precise than the one obtained from local sources, at least in regard of the intrinsic uncertainty related to a stochastic distribution of inhomogeneities.

Alleviating σ_8 tensions with elastic interactions in the dark sector

David Figueruelo Hernán, University of Salamanca, Spain

In this work, we consider elastic interactions in the dark sector that can be described phenomenologically by an interaction dictated by the relative velocity between the two interacting components, modifying only the perturbations but not the background. We present the case of Dark Energy-Dark Matter and Dark Energy-Baryons interactions. We show how a non-altering background interaction can have imprints in observables like the power spectrum or it can alleviate the tension on the σ_8 parameter, and the possible effects on the bias or on the relative velocity. Moreover, we demonstrate how current data sets can detect the interaction at $\sim 3\sigma$ level of confidence and how future surveys like JPAS can improve such confidence level.

A novel Cosmic Filament catalogue with SDSS data

Javier Carrón Duque, University of Rome Tor Vergata, Italy

In this talk I will present a new catalogue of Cosmic Filaments obtained from the latest Sloan Digital Sky Survey (SDSS) public data. In order to detect filaments, we implement a version of the Subspace-Constrained Mean-Shift algorithm, boosted by Machine Learning techniques. This allows us to detect cosmic filaments as one-dimensional maxima in the galaxy density distribution. Our filament catalogue uses the cosmological sample of SDSS, so it inherits the same sky footprint (aside from small border effects) and redshift coverage. In particular, this means that, taking advantage of the quasar sample, our filament reconstruction covers redshifts from $z = 0.05$ up to $z = 2.2$, making it one of the deepest filament reconstructions to our knowledge. The catalogue provides the position and uncertainty of each detection. We assess the quality of the detections with several metrics, which show improvement with respect to previous public catalogues found with similar methods. We also detect a highly significant correlation between our filament catalogue and galaxy cluster catalogues detected with independent observations (Planck and Atacama Cosmology Telescope). Finally, I will comment on how this kind of catalogue can be used to extract physical information about cosmic filaments by studying their correlation with observables such as the gravitational lensing of the Cosmic Microwave Background or the Sunyaev-Zeldovich effect.

Parity in Planck full-mission CMB temperature maps

Srikanta Panda, Utkal University, Vani Vihar, Odisha, India

Isotropy of the universe via the Cosmological principle is one of the fundamental assumptions of modern cosmology. Hence Cosmic Microwave Background (CMB) sky is expected to preserve spatial symmetries. CMB ushered in the precision era in cosmology. Consequently it facilitated tests of this otherwise simplifying assumption of isotropy of cosmos. Multiple studies of CMB data in that direction indicated instances of isotropy violation. Here we search for evidence of a parity preference in the latest full-mission CMB temperature maps from ESA Planck probe. Specifically, we probe (a)symmetry in power between even and odd multipoles of CMB, which corresponds to a particular parity preference under inversion, in Planck 2015 angular power spectrum measurements. We also assess any specific preference for mirror parity (a)symmetry, by analyzing the power contained in $l + m =$ even or odd mode combinations.

BAO with SKA intensity mapping: an oblique hope

Bernhard Vos, Universidad Autónoma de Madrid, Spain

Baryonic Accoustic Oscillations (BAO) is a relic from the early Universe imprinted in the Large-Scale Structure (LSS) of the Universe that can be used as a standard ruler. Our study will focus on the presence of BAO signal in a SKA neutral hydrogen (HI) intensity mapping-like survey. That is, we use the integrated 21 cm line of HI without resolving galaxies. We start by creating a HI catalogue based on the Semi-Analytic model of Galaxy Evolution (SAGE) applied to the UNIT simulations and studying its relation to dark matter halos. We then applied a Gaussian smoothing in the plane perpendicular to the line of sight to simulate the telescope beam effect. We also include the effect of foreground subtraction by damping the largest modes on the radial direction. We study the anisotropic 2-point correlation function and how it is affected by the aforementioned observational effects, with a particular focus on BAO. We find that even though both the purely radial and angular BAO are erased, we can recover a BAO signal on the oblique modes.

Session 11: CMB and LSS III

(Wednesday, 31 March, 14:00)
Chair: Mar Bastero-Gil (University of Granada)

Redshift drift cosmology: ELT vs Cosmic Accelerometer

Beatriz Gamboa Pereira, IA/CAUP, Centro de Astrofísica da Universidade do Porto, Portugal

The redshift drift of objects following the Hubble flow provides us with a unique (but still unfulfilled) opportunity to watch the universe expand in real time, and in a model-independent way. In this contribution we provide a comparative analysis of the constraining power of these measurements for various cosmological scenarios. We aim to identify the main trade-off between the latest facilities proposed in the Astro 2020 white papers (specifically, the Cosmic Accelerometer) and the canonical ELT approach, focusing on parameters such as experiment time, spectroscopic sensitivity, and redshift of the measurements.

Theoretical priors for shift-symmetric Horndeski models

Dina Traykova, University of Oxford, United Kingdom

Current attempts at constraining theories which lead to late time accelerated expansion often assume broad uniform priors for their fundamental parameters. In this talk I will present the findings of a work on deriving a more restricted and correlated set of priors for the phenomenological parameters of the shift-symmetric model of scalar-tensor theories, the dark energy equation of state, w, and the one relevant for this model Horndeski parameter, α_B. I will summarise what functions we find to be a good fit for these parameters and how those were obtained, what were some of the complications that had to be addressed and how including these priors into the analysis with data leads to much tighter constraints on some of the parameters of the model.

Constraining Teleparallel Gravity through Gaussian Processes

Rebecca Briffa, Institute of Space Sciences and Astronomy, Department of Physics, University of Malta, Malta

The Gaussian processes (GP) is applied in order to impose constraints on teleparallel gravity and its $f(T)$ extensions. I use available $H(z)$ observations from (i) cosmic chronometers data (CC); (ii) Supernova Type Ia (SN) data from the compressed Pantheon release together with the CANDELS and CLASH Multi-Cycle Treasury programs; and (iii) baryonic acoustic oscillation (BAO) datasets from the Sloan Digital Sky Survey. For the involved covariance functions, I consider four widely used choices, namely the square exponential, Cauchy, Matérn and rational quadratic kernels, which are consistent with one another within 1σ confidence levels. Specifically, I use the GP approach to reconstruct a model-independent determination of the Hubble constant H_0, for each of these kernels and dataset combinations. These analyses are complemented with three recently announced literature values of H_0, namely (i) Riess $HR_0 = 74.22 \pm 1.82$ kms^{-1}Mpc^{-1}; (ii) H0LiCOW Collaboration $HHW_0 = 73.3 + 1.7 - 1.8$ kms^{-1}Mpc^{-1}; and (iii) Carnegie-Chicago Hubble Program $HTRGB_0 = 69.8 \pm 1.9$ kms^{-1}Mpc^{-1}. Additionally, I investigate the transition redshift between the decelerating and accelerating cosmological phases through the GP reconstructed deceleration parameter. Furthermore, I reconstruct the model-independent evolution of the dark energy equation of state, and finally reconstruct the allowed $f(T)$ functions. As a result, the ΛCDM model lies inside the allowed region at 1σ in all the examined kernels and datasets, however a negative slope for $f(T)$ versus T is slightly favored.

Reconstructing teleparallel gravity with cosmic structure growth and expansion rate data

Jackson Levi Said, University of Malta, Malta

Cosmology beyond ΛCDM expresses measurable deviations from each other at perturbative level such as in terms of growth data which is a result of scalar cosmological perturbations. In this work, we used a combined approach where Hubble data together with redshift–space–distortion $f\sigma_8$ data are used together to reconstruct a teleparallel gravity Lagrangian via Gaussian processes. Gaussian processes have been used in recent works in the literature to model-independently reconstruct gravitational theories beyond ΛCDM using cosmological observations. Here, a new approach is used in which growth data is used to reconstruct the theoretical Lagrangian which may lead to more realistic theoretical proposals within the teleparallel gravity context.

Constraining $f(R)$-gravity with S2-star

Ivan de Martino, Universidad de Salamanca, Spain

The GRAVITY Collaboration detected the orbital precession of the S2 star around the central supermassive black hole, providing yet another proof of the validity of the General Relativity. The departure from the Schwarzschild precession is encoded in the parameter f_{SP} which multiplies the predicted general relativistic precession. Such a parameter results to be $f_{SP} = 1.11 \pm 0.19$, which is consistent with General Relativity ($f_{SP} = 1$) at 1σ level. Nevertheless, this parameter may also hide the effect of modified theories of gravity. Thus, we consider the orbital precession due to the Yukawa-like gravitational potential arising in the weak field limit of $f(R)$-gravity, and we use the current bound on the f_{SP} to constrain the strength and the scale length of the Yukawa-like potential. No deviation from GR are revealed at scale of $f''(R) < -8.59 \times 10^{-9}$ AU^{-2} with the strength of the Yukawa potential restricted to $f'(R) = 0.98^{+0.26}_{-0.13}$. Our constraint rules out $f(R)$ models whose second derivatives is substantially different from zero. Nevertheless, models having higher-order derivatives different from zero are still possible and deserve further studies.

On the different quantifications of backreactions in inhomogeneous cosmology

Daniele Gregoris, Jiangsu University of Science and Technology, China

The success of the ΛCDM model comes with the price of introducing the dark energy whose physical properties are still mysterious; furthermore, linear perturbation theory applied to a Friedman universe cannot account for the existence of some astrophysical structures which should have formed in the early universe (like some large quasar groups and filaments). Therefore, it has been argued that weakening the Copernican principle by introducing some cosmological models which are homogeneous only on large (but not on small) length scales may tame some of these open problems. Inhomogeneous cosmological models are characterized by their backreaction that is the deviation from their maximally-symmetric counterpart with the same energy content, and this quantity essentially measures the effects that spatial inhomogeneities (e.g. astrophysical structures) have on the global dynamics of the spacetime. In my talk, I will define the kinematical, dynamical and observational backreactions and point out that no simple connections among them have been discovered so far because although one can be vanishingly small the others can nevertheless be relevant. In light of this claim, I will quantify these three types of backreactions in a specific inhomogeneous cosmological model based on a regular lattice of black holes commenting on how the time-reversal, discrete, and locally rotational symmetries affect these estimates.

A roadmap for a description of viscous fluids in the Early Universe

Marcelo Rubio, Brandon University, Manitoba, Canada

In this talk we present a family of theories aiming to describe ultra-relativistic dissipative fluids. The family depends on three free constant parameters, and is able to take into account dissipative effects up to second order contributions. After presenting the theory, analyzing its stability criteria and symmetric-hyperbolicity, we present a novel numerical scheme to evolve them and how it could be possible to implement the governing dynamical equations for cosmological applications, in particular in the Early Universe. Finally, we introduce a possible chanel for considering anisotropies.

Horndeski and the Sirens

Pierre Fleury, Instituto de Física Teórica UAM/CSIC, Spain

Mergers of compact objects, such as black holes and neutron stars, have been nicknamed standard sirens, by analogy with electromagnetic standard candles, because their waveform directly gives access to their distance. When an electromagnetic counterpart is observed, such sources thus allow us to construct a Hubble diagram, just as supernovae. Recently, the gravitational-wave Hubble diagram has been argued to be a key probe of alternative theories of gravity, such as Horndeski models. In this talk, I will discuss the foundations of this idea, and its limitations when the inhomogeneities of our Universe are taken into account.

Session 12: Topological Defects

(Wednesday, 31 March, 16:30)
Chair: Carlos Martins (University of Porto)

Scaling Density of Axion Strings

Asier Lopez Eiguren, Tufts University, USA

In the QCD axion dark matter scenario with post-inflationary Peccei-Quinn symmetry breaking, the number density of axions, and hence the dark matter density, depends on the length of string per unit volume at cosmic time. The expectation has been that the string density tends to a constant, a feature of a string network known as scaling. It has recently been claimed that in larger numerical simulations the density of strings shows a logarithmic increase with time. This case would result in a large enhancement of the string density at the QCD transition, and a substantial revision to the axion mass required for the axion to constitute all of the dark matter. With a set of new simulations of global strings we compare the standard scaling (constant density) model to the logarithmic growth. We conclude that the apparent corrections to the density are artefacts of the initial conditions, rather than a property of the scaling network.

On improving string modelling

José Ricardo Correia, Instituto de Astrofísica e Ciências do Espaço / Faculdade de Ciências da Universidade do Porto, Portugal

Topological defects can be the fossil remnants of early Universe phase transitions. Depending on the symmetry broken (and thus on the details of the underlying GUT), one can reasonably expect the formation of the safest (in the sense that they should not over-close the Universe) type of topological defect: the cosmic string. Given the extra complexity and resolution necessary to simulate realistic defect networks, it is not surprising that one easily becomes computationally bottlenecked, to the point where it is difficult (if not impossible) to to simulate these objects and obtain observational constraints. In order to alleviate this problem we've developed an Abelian-Higgs simulation capable of exploiting thousands of graphical accelerators.

We then take this simulation and, with the help of Europe's fastest supercomputer (Piz Daint at CSCS), use it to improve the canonical semi-analytical model of string evolution, the Velocity dependant One-Scale model – VOS. This involves comparing it to a large number of simulations at different resolutions, lattice spacing and expansion rate, both through a minimization procedure and by using a Markov Chain Monte Carlo method. The wide range of simulations basically allow us to clarify interdependencies between different parameters and the particular sensitivity of the calibration to numerous systematic effects (such as lattice spacing or choice of velocity estimators) while also enabling us to account explicitly for the velocity dependencies of the curvature parameter (intimately connected to small-scale structure) and an energy loss function (with explicit scalar/gauge radiation term and a loop chopping term). Given an accurate enough calibration, it is then possible to draw some conclusions on the relative importance of energy loss mechanisms and the amount of small-scale structure in a network of cosmic strings, both directly tied to observational consequences of strings.

Loop decay in Abelian-Higgs string networks

Ander Urio, University of the Basque Country, Spain

The evolution of cosmic strings, in particular cosmic string loops, has been an open question for a number of years. The dynamics observed by field theory lattice simulations and by the Nambu-goto approximation do not agree, giving big differences in the lifetimes of loops, which for example affects their gravitational wave production.

In this talk we will discuss the results obtained from lattice field theory loop evolution simulations, focusing on loops produced during the evolution of an actual realistic cosmic string network. We show that those loops decay proportional to L, but with a larger proportionality constant than the decay by GW. We see no dependency on the behaviour on the string decay on the string length. Moreover, motivated by recent results that show L^2 decay for loops created by artificially setting up string configurations, we propose another method that confirms the L^2 decay. This shows that the decay proportional to L is intrinsic to network loops, and requires further investigation.

Exciting the kink

Daniel Jiménez-Aguilar, University of the Basque Country, Spain

In many field theories, solitonic solutions admit localized excitations with unnaturally long lifetimes in their spectrum of perturbations. These bound states may play a significant role in the dynamics of solitons, and in particular, they could shed light on some aspects concerning the evolution of cosmic string networks. As a starting point, we investigate the properties of this type of excitations in the simple case of the ($\lambda\phi^4$) theory in 1+1 dimensions. This talk will be devoted to a detailed characterization of the "shape mode" perturbation of the kink solution. We study its decay rate and its level of excitation in Minkowski spacetime as well as in two cosmological settings: the formation of kinks in a phase transition and the interaction of the kink with a thermal bath.

Evolution of Domain Walls in a Sine-Gordon Potential

Manuel Correia Rosa, Faculdade de Ciências da Universidade do Porto, IA/CAUP, Portugal

As the early Universe cools, it's expected to undergo phase transitions that can give rise to topological defects. If a result of these phase transitions is a discrete symmetry breaking, domain walls can form between disconnected regions of the Universe. The prototypical model to study the evolution of this type of defects uses a real scalar field confined by a double well potential. In this work we use numerical simulations to explore how domain walls evolve when the field is instead confined by a periodic potential. By optimizing the Press, Ryden & Spergel (PRS) algorythm (1989) to run on GPGPUs we were able to perform several runs very efficiently for different expansion rates (radiation, matter and rapid expansion) in lattices up to 32768^2. We characterize the density and velocity of the walls and compare them to the standard ϕ^4 model and the analytic Velocity-dependent One-Scale (VOS) model. Finally, we describe the new types of walls that form when the field explores neighbouring minima and how their evolution relates to the expansion rate.

Scaling solutions of wiggly cosmic strings

Ana Rita Almeida, IA - Centro de Astrofísica da Universidade do Porto, Portugal

Cosmic string networks arise in many theories of unification beyond the standard model. The evolution of the simplest networks is quantitatively described by the canonical Velocity Dependent One-Scale (VOS) model. However, studies of realistic strings must account for their non-trivial internal structure, including the so-called wiggles: short wavelength propagation modes found on very small scales, which impact both the network evolution and its observational consequences. In this work we study the allowed scaling solutions of a wiggly extension of the VOS model. The modeling of the network evolution relies on three main mechanisms: the universe's expansion rate, energy losses by intercommutation (including loop production), and the choice of the scale in which wiggles are coarse-grained. We consider the various limits where each mechanisms dominates, and compare the scaling solutions for each case, in order to gain insight on the roles of each mechanism in the overall behaviour. In particular we explore the non-trivial scaling solutions (other than the well-known Nambu-Goto solution), as numerical simulations suggest their existence at least in the matter-dominated era.

Dynamics and Y-junctions of superconducting (transonic) cosmic strings

Ivan Rybak, Instituto de Astrofísica e Ciências do Espaço (IA), Porto, Portugal

One dimensional topological defects, which could be produced in the early universe by a phase transition, can become superconducting for many scenarios. It is challenging to make a numerical simulation of superconducting strings, hence, to describe them a number of effective models were developed. There are only two types of string models, chiral and transonic, that have exact wave-like solution. While properties of chiral strings were extensively studied in the past, the transonic type was rather overlooked. We provide the dynamics and main properties of transonic strings, and also demonstrate that this model is valid for description of Y-junctions formation.

Cosmic Strings in Hybrid Metric-Palatini Gravity

Hilberto Silva, Instituto de Astrofísica e Ciências do Espaço, Portugal

We consider static, cylindrically symmetric interior string solutions in the Hybrid Metric-Palatini modified gravity theory, which is a combination of the metric and Palatini f(R) formalisms, unifying local constraints at the Solar System level and the late-time cosmic acceleration. For the basic theory we adopt the scalar-tensor representation. The physical properties of the string are described by an anisotropic energy-momentum tensor satisfying the condition $T_{tt} = T_{zz}$, that is, the energy density of the string along the z-axis is equal to minus the string tension. As a first step in our study we obtain the gravitational field equations in the Hybrid Metric-Palatini theory for a general static, cylindrically symmetric metric. Then we further restrict our metric by imposing the condition of the Lorentz invariance along the t and z axes, which reduces the number of unknown metric tensor components to a single function. In this case the general solution of the field equations can be obtained, for an arbitrary form of the scalar field potential, in an exact closed parametric form, with the scalar field ϕ taken as a parameter. We consider in detail several exact solutions of the field equations, corresponding to a null and constant potential, and to a power-law potential of the form $V(\phi) = V_0\phi^{3/4}$, in which the behavior of the scalar field, metric tensor component and string tension can be described in a simple mathematical form. We also investigate the string models with exponential and Higgs type scalar field potentials by using numerical methods. In this way we obtain a large class of stable stringlike solutions of the Hybrid Metric-Palatini modified gravity theory, whose basic parameters (scalar field, metric tensor, string tension) depend sensitively on the initial values of the scalar field, and of its derivative, on the string axis.

Session 13: Gravitational Waves

(Thursday, 1 April, 09:00)
Chair: Francisco Lobo (University of Lisbon)

Gravitational Wave lensing beyond Einstein's General Relativity

Miguel Zumalacarregui, Max Planck Institute for Gravitational Physics, Germany

Gravitational lensing of light is a well established test of gravity. However, little is known about how gravitational waves (GW) propagate beyond the simplest space-times in theories beyond Einstein's General Relativity (GR). I will present a framework for GW lensing beyond GR at leading order in frequency. The modified causal structure and kinetic mixing between metric and additional degrees of freedom leads to new phenomena, providing clear-cut tests that do not require an electromagnetic counterpart. I will present detailed predictions for static, spherically symmetric lenses in an quartic Horndeski theory in which novel GW lensing effects can provide tests far more stringent than the multi-messenger event GW170817. The next terms in the frequency expansion will further enrich the phenomenology of GW lensing and enable new precision tests of gravity.

Breaking the Mass Sheet Degeneracy with Gravitational Wave Interference in Lensing events

Paolo Cremonese, University of Szczecin, Poland

The mass-sheet degeneracy is a well-known problem in gravitational lensing. As the number of gravitational wave observations grows, detecting lensed events will become more likely, and to assess how the mass-sheet degeneracy may affect them is crucial. I woud like to present our work, where we study both analytically and numerically how the lensed waveforms are affected by the mass-sheet degeneracy computing the amplification factor. In particular, we differentiate between the geometrical optics, wave optics and intermediate interference regimes, focusing on ground-based gravitational waves detectors. In agreement with expectations of gravitational lensing of electromagnetic radiation, we confirm that, in the GO scenario, the mass-sheet degeneracy can not be broken with only one image. However, I will show how, in the interference regime, and in part in the wave-optics regime, the mass-sheet degeneracy can be broken with only one lensed waveform thanks to the characteristic interference patterns of the signal. Finally, I will show also quantitatively, through template matching, how well the mass-sheet degeneracy can be broken. Breaking the mass-sheet degeneracy increase the precision in the estimation of the lensing system parameters and, consequently, on the calculation of the cosmological parameters that can be inferred from these events, like e.g. H_0.

Gravitational wave mergers as tracers of large scale structures

Sarah Libanore, Università degli Studi di Padova, Italy

Clustering measurements of gravitational wave mergers in luminosity distance space can be used in the future as a powerful tool to study the Universe. Catalogs from an Einstein Telescope-like detector network can be used alone to constrain both cosmological and astrophysical parameters. The matter and energy content can be analysed once that the number distribution and bias of these events are modelled from hydrodynamical simulations. At the same time, bias constraints with respect to the underlying dark matter distribution can be drawn to disentangle the physical nature and properties of the gravitational wave sources themselves.

Being performed in luminosity distance space, gravitational wave surveys can be also combined with SNIa catalogs from future Vera Rubin Observatory. Using a multitracer approach, the uncertainties on cosmological parameter contraints can be widely reduced. I will show forecasts on cosmological and merger bias parameters, for both these approaches. Moreover I will discuss ongoing developments and interesting open issues to address in this area, including the need for further study of observational effects in luminosity distance space and the development of statistical estimators and analysis tools for a full exploitation of data in years to come.

Cosmological Density Fields and Gravitational Waves: A Statistical Learning Approach

Miguel Conceição, Universidade de Lisboa - Faculdade de Ciências, Portugal

Several cosmological and astrophysical studies rely on the generation of costly simulations to sample the parameter space of an underlying physical theory. Historically, the study of gravity and gravitational effects has been among the most important examples of such cases, and gravity has been linked to the very requirements to build the largest available computational facilities. This presentation concerns the application of machine learning methods to alleviate those requirements and to enable significantly faster sampling and inference, in two scenarios where gravity dominates at opposite scales and magnitudes, Structure Formation and Gravitational Waves.

In the Structure Formation context, we present results from a new method that uses Principal Component Analysis coupled with supervised learning, to emulate 3D N-body Dark Matter Density Fields given a set of cosmological parameters (dark matter density and redshift), with high precision and orders of magnitude improvement in runtimes while at the same time requiring far less computational resources compared to traditional N-Body techniques. For strong low-scale gravitational fields such as binary black hole mergers, we show that a similar approach provides a fast way for performing model parameter inference regarding these types of systems, using the gravitational wave information they generate, in approximated data. We believe that our methodology opens new exciting possibilities to enable fast and accurate data analysis for upcoming surveys like Euclid, LSST, and LISA.

Gravitational waves from strongly supercooled phase transitions

Ville Vaskonen, IFAE, Spain

Gravitational waves are sourced in cosmological phase transitions by bubble collisions and plasma motions. In this talk I will first describe an improved calculation of the gravitational wave spectrum from bubble collisions, and then discuss the energy budget of strongly supercooled phase transitions. I will illustrate the predictions for the gravitational wave signal in a classically conformal U(1) extension of the Standard Model.

Calibrating a Gravitational Wave Laser Interferometer Detector

Carlos Frajuca, IFSP, Brazil

In 2015, the first direct detection of gravitational waves was reported. Data analysis indicated that the waves had originated from the violent collision of two black holes, which scattered them through space–time as Einstein predicted. That detection was made possible by many advances in measurement technology, mainly vibration isolation of the detector optics, since, at 10 Hz, the motion of the laser-interferometric detector mirrors is at least one billion times smaller than the seismic motion of the ground. As well, it is difficult to lock the laser in the detection configuration in a large band of the spectrum; this was made possible by using many feedback and feed-forward control loops. However, in order to meet the many demanding requirements, more than a hundred of such active systems are included in a detector to allow locked acquisition and locked stability to, eventually, reach the desired sensitivity. In this work, challenges faced to reach some of these requirements will be described and we analyze how this scenario impacts the calibration of such detectors. In order to help reduce false alarm rates and provide data for veto systems, in this work we propose a specific kind of resonant-mass detector to operate in coincidence with laser-interferometric ones.

Session 14: Dark energy & Varying fundamental constants

(Thursday, 1 April, 11:00)
Chair: Marina Cortês (University of Lisbon)

BBN with GUTs

Carlos Martins, CAUP, Portugal

The success of primordial nucleosynthesis as a cornerstone of the Hot Big Bang model has been limited by the long-standing Lithium problem. Recent progress in experimental measurements of the relevant cross-sections also suggests a small discrepancy between the baryon fractions inferred from CMB+BAO data and from the latest BBN Deuterium adundance measurements. We use a self-consistent perturbative analysis of the effects of relevant theoretical parameters on primordial nucleosynthesis, including variations in nature's fundamental constants, to explore the Lithium problem and the Deuterium discrepancy, and its possible solutions, in the context of a broad class of GUT models. In particular, we discuss and quantify astrophysical mechanisms for Lithium depletion in stars, and present stringent (parts per million level) constraints on the value of the fine-structure constant at the BBN epoch. This work is described in Clara & Martins A&A Lett. 633 (2020) L11, Martins A&A in press, and a third paper currently under review.

Astrophysical and local constraints on string theory: Runaway dilaton models

Léo Vacher, IRAP-Institut de recherche en astrophysique et planétologie, France

One of the clear predictions of string theory is the presence of a dynamical scalar partner of the spin-2 graviton, known as the dilaton. This will violate the Einstein equivalence principle, leading to a plethora of possibly observable consequences which in a cosmological context include dynamical dark energy and spacetime variations of nature's fundamental constants. The runaway dilaton scenario of Damour, Piazza, and Veneziano is a particularly interesting class of string theory inspired models which can in principle reconcile a massless dilaton with experimental data. Here we use the latest background cosmology observations, astrophysical and laboratory tests of the stability of the fine-structure constant, and local tests of the weak equivalence principle to provide updated constraints on this scenario, under various simplifying assumptions. Overall we find consistency with the standard ΛCDM paradigm. We improve the existing constraints on the coupling of the dilaton to baryonic matter by a factor of 6 and to the dark sector by a factor of 2. At the one-sigma level the current data already exclude dark sector couplings of order unity, which would be their natural value. (from Martins et al published in Phys. Rev. D 100, 123514)

Varying Alpha Generalized Dirac-Born-Infeld Models

Vasco Capela Tavares, CAUP/FCUP, Portugal

We study the cosmological consequences of a class of Dirac-Born-Infeld models, and assess their viability as a candidate for the recent acceleration of the Universe. The model includes both the rolling tachyon field and the generalized Chaplygin gas models as particular limits, and phenomenologically each of these provides a possible mechanism for a deviation of the value of the dark energy equation of state from its canonical (cosmological constant) value. The field-dependent potential that is characteristic of the rolling tachyon also leads to variations of the fine-structure constant α, implying that the model can be constrained both by standard cosmological probes and by astrophysical measurements of α. Our analysis, using the latest available low-redshfit data and local constraints from atomic clock and weak equivalence principle experiments, shows that the two possible deviations of the dark energy equation of state are constrained to be $\log_{10}(1 + w0)V < -7.85$ and $\log_{10}(1 + w0)C < -0.85$, respectively for the rolling tachyon and Chaplygin components, both being at the 95.4% confidence level (although the latter depends on the choice of priors, in a way that we quantify). Alternatively, the 95.4% confidence level bound on the dimensionless slope of the potential is $\log_1 0\lambda < -5.36$. This confirms previous analyses indicating that in these models the potential needs to be extremely flat.

(This work was presented in https://doi.org/10.1103/PhysRevD.103.023525)

Varying constants of Nature and modified gravity

Jurgen Mifsud, University of Malta, Malta

Since a violation of the distance-duality relation is directly linked with a temporal variation of the electromagnetic fine-structure constant, we analyse modified theories of gravity characterised by a non-standard distance-duality relation. We here consider a model with a dark energy induced interaction in the electromagnetic sector, along with several well-studied $f(T)$ gravity models, where we revise the theoretical prediction of their corresponding violation of the distance-duality relationship. We then test their cosmological viability and illustrate that the respective model parameters could be constrained with the current varying fine-structure constant data set, supernovae data, and Hubble parameter measurements.

Cosmological Predictions of a Disformal Dark Sector

Elsa Teixeira, University of Sheffield, United Kingdom

One of the most important open questions in Cosmology concerns the enigmatic origin of the observed accelerated expansion of the Universe. This phenomenon is generally attributed to "dark energy", a matter/energy source whose nature is still not well understood, and that, in the simplest ΛCDM scenario, is characterised by an energy density that remains constant with the expansion. Currently, while the ΛCDM model is widely accepted as the standard model of Cosmology, it is still hunted by conceptual problems and observational tensions. The generalisation of the cosmological constant do a dynamical scalar field, together with an interaction in the dark sector, can address some of these issues, albeit lacking a compelling fundamental motivation. In this talk I will give a brief overview of interacting dark energy, with emphasis on disformal couplings and its cosmological implications. I will then focus on the general Dark D-Brane scenario, for which the interaction in the dark sector arises naturally through the induced metric on a moving brane. In particular, I will discuss the background and linear perturbation equations in this setting, together with a numerical analysis, with brief connection to observational constraints.

Testing Dark Energy Couplings

Vitor da Fonseca, Faculty of Sciences, University of Lisbon, Portugal

The acceleration of the Universe thought to be sourced by a cosmological constant is probably one of the most striking discovery in cosmology. Although the standard model fits well the available astrophysical observations, shortcomings have been paving the way to study dynamical dark energy. Rather than parametrizing the equation of state, as usual, we contemplate a simple and phenomenological parametrization of quintessence in the form of a canonical scalar field possibly coupled to dark matter. We modify the Boltzmann code CLASS to numerically predict observables, such as SNIa magnitude, CMB anisotropy and matter power spectra, enabling us to constrain the model. We find that it covers a wide range of possible dark energy evolution with a single additional parameter, and is a viable alternative to ΛCDM both at background and perturbation levels.

Exploring the nature of dark energy with Machine Learning

Rubén Arjona, Instituto de Física Teórica (IFT-UAM/CSIC), Spain

One of the most pressing mysteries in physics is the accelerating expansion of the Universe, usually attributed to a dark energy component. Machine Learning (ML) techniques will play a big role in testing accurately the standard model of cosmology, but will also help in the search for new physics and tensions in the data by placing tighter constraints on cosmological parameters. I will present a unified ML analysis of all the currently available cosmological data in order to reconstruct several key background and perturbations variables in a model-independent manner in order to explore the nature of dark energy.

Growth rate and configurational entropy in Tsallis holographic dark energy

Snehasish Bhattacharjee, Indian Institute of Technology, Hyderabad, India

In this work, we analyzed the effect of different prescriptions of the IR cutoffs, namely the Hubble horizon cutoff, particle horizon cutoff, Granda and Oliveros horizon cut off, and the Ricci horizon cutoff on the growth rate of clustering for the Tsallis holographic dark energy (THDE) model in an FRW universe devoid of any interactions between the dark Universe. Furthermore, we used the concept of configurational entropy to derive constraints (qualitatively) on the model parameters for the THDE model in each IR cutoff prescription from the fact that the rate of change of configurational entropy hits a minimum at a particular scale factor a_{DE} which indicate precisely the epoch of dark energy domination predicted by the relevant cosmological model as a function of the model parameter(s). By using the current observational constraints on the redshift of transition from a decelerated to an accelerated Universe, we derived constraints on the model parameters appearing in each IR cutoff definition and on the non-additivity parameter δ characterizing the THDE model and report the existence of simple linear dependency between δ and a_{DE} in each IR cutoff setup.

New scaling solutions in coupled vector dark energy

Reginald Christian Bernardo, University of the Philippines, Philippines

We present new scaling solutions in coupled vector dark energy models. Specifically, we use a dynamical system analysis and study the conditions for the existence of a stable fixed point corresponding to a scaling vector-dark matter era.