Spanish and Portuguese Relativity Meeting

Monday, 22 July 2024 - Friday, 26 July 2024

Book of Abstracts

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Cosmological study of a symmetric teleparallel gravity model

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We study a Symmetric Teleparallel Gravity with a Lagrangian of Logarithmic form. The full model leads to an accelerated Universe and for specific values of the free parameters the Hubble rate reduces to the well known DGP model, though the evolution of the gravitational potentials are different. We consider different branches of the Logarithmic model, among which sDGP and nDGP. The phenomenology of both the background and linear perturbations is discussed, including all the relevant effects on Cosmic Microwave Background radiation (CMB) angular power spectrum, lensing and matter power spectra. To this purpose, we modified the Einstein-Boltzmann code MGCAMB. In some cases, it is possible to have a phenomenology such that the lensing auto-correlation power spectrum is enhanced and the matter power spectrum is suppressed for the same choice of parameters. These features are of interest in view of understanding the excess of lensing in CMB data and the σ_8 tension. In some cases it is possible to have a suppressed ISW tail which is a feature preferred by CMB data;

Parallel session 10 (Cosmology Beyond GR) / 6

Beyond dark matter: Constraining hyperconical-relativistic MOND-like model to galaxy cluster RAR observations

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General relativity (GR) is the most successful theory of gravity, with great observational support at local scales. However, to keep GR valid at cosmic scales, some phenomena (such as the flat galaxy rotation curves and the cosmic acceleration) require the assumption of exotic dark matter and dark energy. Similarly to the mass-luminosity relation or baryonic Tully-Fisher relation (BTFR) and the mass-discrepancy acceleration relation (MDAR), which are observed in galaxy rotation curves, the radial acceleration relation (RAR) indicates a tight correlation between dynamical mass and baryonic mass also in galaxy clusters that allows room for modified gravity theories without exotic magnitudes. Modified Newtonian Dynamics (MOND) is an alternative theory for explaining some cases of flat galaxy rotation curves by using a hypothetically constant cosmic acceleration a_0, the so-called Milgromian parameter. However, this non-relativistic model does not provide satisfactory cosmologies, and it is too rigid (with insufficient parameters) to fit the large diversity of observational phenomena. In contrast, relativistic MOND-like gravity naturally emerges from the hyperconical model, which derives a fictitious acceleration compatible with observations (Monjo 2023, Monjo and Campoamor-Stursberg 2023). This study analyzed constraints for the hyperconical model to RAR observations of 10 galaxy clusters obtained from the HIghest X-ray FLUx Galaxy Cluster Sample (HIFLUGCS, Lie et al. 2023), and of 60 galaxy rotation curves collected by McGaugh (2007, 2016). The results showed that a general relation can be fitted to most of the cases with only one or two parameters, with a significant Chi-squared p-value. These findings suggest a possible way to complete the proposed modification of general relativity at a cosmic scale.

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Parallel Session 1 (Cosmology I) / 8

AXIALLY SYMMETRIC RELATIVISTIC THIN DISKS AND SPHEROIDAL HALOS WITH MAGNETICALLY POLARIZED MATTER

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A family of relativistic models of thin disks and spheroidal haloes with magnetically polarized material source it is presented. The models are built using exact solutions of the Einstein-Maxwell equations for a conformastatic and axially symmetric spacetime, by assuming that the material content of the halo is described by a non-dissipative anisotropic fluid and that the magnetic polarization it is proportional to the magnetic field. The solutions are obtained by expressing the metric function in terms of an auxiliary function which satisfies the Laplace equation, a characteristic property of the conformastatic spacetimes, and by using the displace, cut, and reflect method, which introduces a discontinuity in the first z-derivative of the metric tensor across the plane of the disk. Once a solution to the system of equations is obtained, not only the solution of the Einstein-Maxwell equations but also the energy-momentum tensor is completely determined, which describes the matter content of the halo and the disks, as well as the variables associated with the magnetic field and the magnetic polarization. The energy densities of the disk and the halo are everywhere positive and well behaved, and their energy-momentum tensor agrees with all the energy conditions.

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TDiff scalar fields: symmetry restoration and model selection

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As a case of potential interest for the dark sector, in this talk a scalar field action that is invariant only under transverse diffeomorphism will be considered. In the first place, some gravitational properties of this minimally coupled field will be discussed in the kinetic and potential domination regimes. Then, the idea of restoring the full diffeomorphism invariance by the introduction of additional fields will be explored. The reformulation with the full symmetry allows one to analyze the gravitational properties of the theory beyond those regimes.

Parallel session 5 (Gravitational Waves) / 11

Resonance absorption of gravitational waves and modified gravity in the forthcoming LISA project

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The recent release of NANOGrav's 15-year data strongly supports the
evidence for the existence of a stochastic gravitational wave background [1]. These waves could have originated by the merging of Supermassive Binary Black Holes (SMBBHs) throughout the history of the Universe. They also have a frequency in a range that could be resonant with the orbital periods in the Solar System and, consequently, we expect them to be absorbed by binary stars and planetary systems. Some authors have proposed to use them as natural detectors [2,3]. We show that the effect on the orbital elements in the Solar System is, however, negligible and they can not be related to any orbital anomalies that could be found in the near future with the present technology. However, future interferometric experiments in space, such as the Large Interferometer Space Antenna (LISA), could allow for a change in this perspective. On the other hand, the effect on LISA produced by these impinging stochastic gravitational waves can be certainly very small in comparison to the stronger perturbations that could be caused by modified gravity models. As an example, we study the perturbations expected for small changes in the β and γ parameters for Brans-Dicke [4] and f(R) theories [5]. These perturbations alone can be nine orders of magnitude larger than the ones we can expect from the SGW's background absorption.

Consequently, we argue that LISA could not only work as a detector of gravitational waves but it can also be ideally suited for testing modified gravity theories.

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Parallel Session 1 (Cosmology I) / 12

Thermodynamics of the universes admitting isotropic radiation

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The perturbation theory of the Friedmann-Lemaître-Robertson-Walker models seems to provide a good explanation of the observed degree of inhomogeneity in the universe, but the structure and evolution of galaxies, clusters, and voids require an analysis outside of the perturbative regime. They are

often modeled by Newtonian N-body computations. However, the non-linear effects of the Einstein field equations could be critical in the structure formation, and many studies have been devoted to providing exact inhomogeneous models for studying the formation of structures and for analyzing the effect of the nonlinear inhomogeneities on the cosmic microwave background radiation.
A family of such exact inhomogeneous models is that of the conformally flat solutions of the Barnes-Stephani metrics, the Stephani universes. They can also be characterized as the space-times verifying a weak cosmological principle without any hypothesis on the energy tensor. In this talk, the thermodynamic interpretation of the Stephani Universes is studied in detail. The general expression of the speed of sound and of the thermodynamic schemes associated with a thermodynamic solution is obtained. The constraints imposed on the solutions by considering some significant physical properties are analyzed. We focus on the models in which the cosmological observer measures isotropic radiation. We consider some examples, and a solution that models an ultra-relativistic gas is analyzed in detail.

Parallel session 9 (Neutron Stars) / 15

Hybrid star phenomenology from the properties of the special point

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We study the properties of hybrid stars containing a color superconducting quark matter phase in their cores, which is described by the chirally symmetric formulation of the confining relativistic density functional approach [1]. It is shown that depending on the dimensionless vector and diquark couplings of quark matter, the characteristics of the deconfinement phase transition are varied, allowing us to study the relation between those characteristics and mass-radius relations of hybrid stars. Moreover, we show that the quark matter equation of state (EoS) can be nicely fitted by the Alford-Braby-Paris-Reddy model that gives a simple functional dependence between the most important parameters of the EoS and microscopic parameters of the initial Lagrangian. The developed approach is utilized for analyzing spinodal instability of quark matter and constructing hybrid quark-hadron EoS. Based on it, we analyze the special points of the mass-radius diagram in which several mass-radius curves intersect. Using the found empirical relation between the mass of the special point, the maximum mass of the mass-radius curve, and the onset mass of quark deconfinement, we constrain the range of values of the vector and diquark couplings of the quark matter model.With this constraint, we construct a family of mass-radius curves, which allow us to describe the black widow pulsar PSR J0952-0607 with a mass of as a hybrid star with a color superconducting quark matter core.

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Parallel session 10 (Cosmology Beyond GR) / 16

Recent Results in Conformal Killing Gravity

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Recently Harada proposed a new gravitational theory which is third order in the derivatives of the metric tensor. This has attracted some attention particularly as it predicts a late-time transition from cosmological deceleration to accelerated expansion without assuming the presence of dark-energy or a non-zero cosmological constant. This theory has become known as conformal Killing gravity (CKG).
In this talk the most general exact solutions of the CKG field equations are discussed for a number of important physical situations: homogeneous and isotropic cosmological (FRWL) models, static spherically symmetric vacuum and electrovac spacetimes, and plane and *pp*-waves.
For any metric in conformal Killing gravity it is shown that more than one matter source can generate a particular solution. For example, the addition of an arbitrary "dark-energy"source with energy-momentum tensor $T_{ab} = \lambda g_{ab}$ has no effect on the metric. In CKG one can say "dark energy does not gravitate". If the metric admits one or more Killing vectors or tensors, the ambiguity in the possible matter sources increases considerably.
Another novel feature of the theory is that there are source-less cosmological solutions. The simplest example is the static Einstein Universe which satisfies the vacuum field equations of CKG. There are also vacuum time-dependent FRWL solutions of the theory; thus providing counter-examples to a possible Birkhoff theorem in CKG.

Parallel session 2 (Numerical Relativity) / 17

Improved Binary Black Hole Initial Data

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Numerical Relativity stands as a crucial tool in the identification of gravitational wave signals by constructing most of the signal templates used in the Matched Filtering Method. But this simulated collisions are still far from being perfectly realistic. In order to ensure more realistic templates I implement initial data with radiative content, utilizing Post-Newtonian descriptions of the spatial metric and extrinsic curvature in the initial time slice. The XCTS equations are solved for this data and it is then evolved using the SpECTRE code. I will describe the steps needed to construct such realistic initial data and compare the output signal with the usually evolved conformal data without gravitational waves.

Parallel session 6 (Black Holes Beyond GR) / 18

Numerical explorations of well-posedness beyond General Relativity

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Many modified theories of gravity that deviate from general relativity (GR) in the vicinity of black holes or neutron stars lack a well-posed initial value problem formulation. Numerical considerations play a crucial role in solving the modified equations. Nonetheless, performing numerical simulations is only possible when the equations are well-posed. In this talk, I will focus on a single modified

theory (scalar Gauss-Bonnet gravity) and show that considering additional interactions renders it well-posed.

Parallel session 4 (Black Holes I) / 19

The canonical ensemble of a d-dimensional Reissner-Nordstrom black hole in a cavity

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We construct the canonical ensemble of a Reissner-Nordström black hole in a cavity for an arbitrary number of dimensions. The system of a charged black hole in a cavity can be described by a partition function given by the Euclidean path integral approach, where we consider the usual Einstein-Maxwell action with the Gibbons-Hawking-York boundary term and an additional boundary term of the Maxwell tensor. The spacetime is then Euclideanized and time becomes periodic. The inverse temperature at the boundary is fixed, which corresponds to the total time length at the cavity, and the charge is also fixed, which corresponds to the flux of the Maxwell tensor at the cavity. The zero loop aproximation is performed, and the path integral is heavily simplified, which allows us to find the black hole solutions for the fixed quantities. We find that, below a critical electric charge, there are three solutions, from which two are stable. Above the critical charge, there is only one solution, which is stable. We find analytical expressions for the points where these solutions meet and for the critical charge. Regarding thermodynamics, the energy, the pressure, the entropy and the electric potential are obtained. Stable solutions correspond to the solutions with positive heat capacity at constant charge. We analyze the favorable states and compare the gravitational radius of the zero action solutions between the canonical ensemble, the grand canonical ensemble and the Buchdahl-Andréasson-Wright bound. We verify that these three gravitational radii only coincide in the chargeless case and in the extreme case.

Parallel session 3 (Cosmology II) / 20

Influence of spatial curvature in particle production during the early universe

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Observations suggest that the spatial sections of our universe are nearly flat, with spatial curvature, if present, being very small. It is proposed that any trace of curvature may have been erased during an early inflationary phase. Only at the onset of inflation, positive or negative spatial curvature may have affected spacetime dynamics. It is during this regime that cosmological particle production becomes most important, since the geometry is changing very rapidly.

In this presentation, we investigate the implications of positive or negative spatial curvature at the beginning of inflation on the abundance of gravitationally produced scalar particles after this period, which has been proved to be a viable mechanism for dark matter production.

Parallel session 10 (Cosmology Beyond GR) / 21

Field interactions from broken diffeomorphisms

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In this talk we explore the possibility of describing an interacting dark sector as result of breaking the invariance under diffeomorphism of the matter action. Particularly, we consider two scalar fields with different non-canonical minimal couplings to gravity. We consider the potential and kinetic domination regimes for each field and analyze the resulting models. Then, we focus on cases describing dark matter-dark energy interaction and compare its predictions to observations.

Parallel session 4 (Black Holes I) / 23

Hidden symmetries in the dynamics of perturbed black holes

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Perturbation theory of vacuum spherically symmetric spacetimes is a crucial tool for understanding the dynamics of black hole (BH) perturbations as well as BH scattering phenomena and the ringdown signal of binary BHs. Since the pioneering work of Regge and Wheeler it is known that the equations for the perturbations can be decoupled in terms of (gauge-invariant) master functions that satisfy 1 + 1 wave equations. However, while in the literature only few master equations are known, the full landscape of master equations was recently found, clarifying that Einstein equations actually allows for an infinite set of them. These findings pave the way to the introduction of some new hidden symmetries governing the dynamics of perturbed non-rotating BHs: Darboux covariance and the infinite hierarchy of Korteweg-de Vries (KdV) deformations of the master equation. This generates a novel connection with integrable systems that relates the physical description of the perturbed BH, such as the greybody factors, to the KdV conserved quantities.

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On cosmological clustering of Gravitational Wave events

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Traditional large-scale structure surveys estimate the power spectra from galaxy surveys where distances are estimated based on the observed redshift. But not all tracers of dark matter, such as supernovae Type Ia and gravitational wave merger events, have a measured redshift; instead, they provide an observed luminosity distance. Therefore the natural estimator would be the observed number counts in luminosity distance space. In this talk, we would review the full calculation of clustering in luminosity distance space including all light-cone effects, and establish the differences with redshift space. We will also present models for the biases that affect the observed angular power spectrum. Additionally we will discuss the implication of cosmological constraints can have in the properties of BH population responsible for GW events.

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Hubble-induced phase transitions and Higgs Vacuum Stability

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A Hubble-induced phase transition is a natural spontaneous symmetry breaking mechanism, allowing for explosive particle production in non-oscillatory models of inflation involving non-minimally coupled spectator fields. In this talk, I will discuss the impact of this effect on the evolution and stability of the Standard Model Higgs after inflation and the reheating of the Universe, characterizing its dynamics via 3+1-dimensional classical lattice simulations. Phenomenological aspects like the generation of short-lived topological defects and gravitational waves will also be discussed.

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Weak cosmic censorship with quantum-corrected black holes

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The weak cosmic censorship conjecture asserts that naked singularities cannot be generically produced when regular initial data is evolved using the classical equations of General Relativity, and assuming the matter content is physically reasonable. Whatever curvature singularities arise —if they arise —are con- cealed within black hole event horizons.
A potential violation of this hypothesis was investigated fifty years ago by Wald. In one of the versions considered, it consisted in trying to overspin an extremal rotating black hole by throwing at it a test particle with large angular momentum. Alas, what was found was that either the particle slings around the black hole or, if it falls through the horizon, it does not cause overspining. In any case, the horizon is preserved and no singularity is exposed.
In this talk I will discuss how this test of the weak cosmic censorship performs on quantum-corrected black holes recently discovered. Specifically, I will analyze the effects of dropping a test particle into an extremal quantum rotating BTZ black hole, whose three-dimensional metric captures the exact backreaction from strongly coupled quantum conformal fields.

Parallel session 2 (Numerical Relativity) / 28

A preliminary study of PN1 cross terms contribution in the evolution of EMRIs

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1 Abstract

The study of sources of gravitational waves, which includes the capture of a compact object by a supermassive black hole (an "extreme-mass ratio inspiral, EMRI"), has been approached in relativistic astrophysics with a post-Newtonian treatment (see for example [1] for a complete description). Nevertheless, such estimation is only valid in the two-body problem. From an astrophysical point of view, a binary emitting gravitational waves is usually perturbed by other contributions. This obstacle is overcome to first order using the cross terms of the post-Newtonian corrections [2]. In this talk, we present some preliminary results and implications in the detection of EMRIs.

2 Methods and Results

Our treatment implies the use of an N-body algorithm which numerically implements the calculations of the PN1 contributions to Newtonian orbits incorporating the new cross terms (a detailed description of codes used in similar scenarios can be found in [3]). For this purpose, we simulate appropriate Black Holes which orbit an EMRI.

The system's evolution should outstandingly modified by the addition of cross terms. This new approach suggests a potential need to re-evaluate the calculations and results implemented hitherto. Since present, such models have not considered cross terms, which focuses a further field of research. Our preliminary computations from the simulations, including for the first time such terms, appear encouraging and indicate important changes in the knowledge of the problem so far. In this presentation, we show this initial research and survey their probable inferences for increment our understanding of EMRIs.

3 Conclusions

The addition of PN1 cross terms in the computation of orbital evolution of EMRIs may modify the previous results and inferences about the idea we have of EMRIs and their possible detection. The investigation in this field seems to be promising. This work is been performed by our research team nowadays. We intend to expose new findings hereafter.

Acknowledgments

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Gravitational particle production and freeze-in at stronger coupling

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I discuss gravitational production of dark matter and how it hinders predictivity of non-thermal dark matter models.

Parallel session 4 (Black Holes I) / 31

Radiation reaction in magnetized black holes: can the tail term be ignored?

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We study radiation from charged particles in circular motion around a Schwarzschild black hole immersed in an asymptotically uniform magnetic field. In curved space, the radiation reaction force is described by the DeWitt-Brehme equation, which includes a complicated, non-local tail term. We studied this system in the weak field regime, where the tail term can be treated directly, and in the strong field regime, using black hole perturbation theory. Our results show that, contrary to some claims in the literature, the tail term cannot be neglected. We also report a surprising "horizon dominance effect".

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Heat kernel and Revelations

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Heat-kernel techniques provide a standard toolkit for calculating functional determinants of Laplace-type operators, facilitating the evaluation of contributions at one loop to the vacuum effective action. While typically perturbative, the coincidence limit of the heat-kernel expansion in proper-time enjoys in some cases a resummed version, paving the way for the analysis of various nonperturbative aspects of quantum field theories. I will discuss some recent results in this direction, in curved and flat spaces, and present several physically relevant applications.

Parallel session 5 (Gravitational Waves) / 33

Numerical Relativity Simulations of Dark Matter Admixed Neutron Star Mergers: Unveiling Effects on Gravitational Waves and Ejecta

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We present a novel study of the impact of asymmetric dark matter (DM) on the dynamics of binary neutron star (BNS) mergers and the associated gravitational wave (GW) signatures. Utilizing numerical relativity simulations with a recently developed framework for DM admixed BNS, we analyze not only the emitted GW signal but also the dynamical behavior of the ejected material (ejecta) during and after the merger for different particle's mass and fraction of DM. This comprehensive approach allows us to explore how the presence of DM affects the post-merger remnant's fate, potentially altering its collapse into a black hole or remaining as a massive neutron star. We focus on deviations in the GW signal and the ejecta properties compared to standard BNS mergers. This study aims to establish a connection between DM properties and the combined GW and ejecta signatures, offering a powerful tool for constraining the DM nature through future multi-messenger observations of BNS mergers.

Parallel session 8 (Black Holes II) / 34

Relativistic effects on the orbits of the closest stars to the black hole at the center of the Galaxy

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In this presentation, we investigate the detection of the spin and quadrupole moment of the black hole at the center of the galaxy called Sgr A. *These parameters affect the astrometric and spectroscopic observations of stars in the close vicinity of the black hole (S stars). Here, we consider a collection of S stars as well as putative stars that are closer to Sgr A*, and thus much more affected by the spin effects. Such stars might exist if they are too faint to have been already detected by GRAVITY. It is possible that either future observations of this instrument, or of its update GRAVITY+ that is under development, might detect such faint inner stars. In order to reach our objectives, we use different relativistic models in order to generate the orbit of S stars and analyze how they can be affected by the spin and quadrupole moment of Sgr A*. This, allows us to study the detectability of these quantities enabling us to test the no-hair theorem and thus general relativity.

Parallel session 7 (Mathematical Relativity) / 35

Algebraic classification of 2+1 spacetimes

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We present a new and effective method of algebraic classification of 2+1 geometries. It parallels the approach of Newman and Penrose, and in our work, we extend this formalism into three dimensions. The spacetimes are classified into the types I, II, D, III, N and O using appropriate scalars constructed from the Cotton tensor, which are analogous to the Newman–Penrose scalars of the Weyl tensor in 4D. We also derive the Bel–Debever criteria, together with the multiplicity of the Cotton aligned null directions (CANDs). The classification is then nicely summarized using an algorithm based on the polynomial curvature invariants. This allows us to establish equivalence with the previous method of algebraic classification developed by García-Díaz and others. Lastly, we demonstrate the practicality

of the new method on some explicit examples, such as the Robinson–Trautman spacetime with an aligned electromagnetic field.

Parallel session 9 (Neutron Stars) / 36

Neutron stars and the cosmological constant problem

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Phase transitions can play an important role in the cosmological constant problem, allowing the underlying vacuum energy, and therefore the value of the cosmological constant, to change. Deep within the core of neutron stars, the local pressure may be sufficiently high to trigger the QCD phase transition, thus generating a shift in the value of the cosmological constant. The gravitational effects of such a transition should then be imprinted on the properties of the star. Working in the framework of General Relativity, I will present a new model of the stellar interior, allowing for a QCD and a vacuum energy phase transition. I will determine the impact of a vacuum energy jump on mass-radius relations, tidal deformability-radius relations, I-Love-Q relations and on the combined tidal deformability measured in neutron star binaries.

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Kerr-de Sitter and algebraically special metrics with prescribed asymptotics in all dimensions

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We provide a classification of arbitrary dimensional $(\Lambda > 0)$-vacuum metrics corresponding to type II metrics in the Coley et al. classification of Weyl tensors, which also admit a conformal extension with a locally conformally flat boundary. These metrics are found to coincide with a previously known class that generalizes Kerr-de Sitter metrics. To identify both classes, we conduct a detailed analysis of the fall-off behavior of the Weyl tensor and its relation to the asymptotic initial data.

Parallel session 7 (Mathematical Relativity) / 38

Generalized Siklos space-times

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Siklos space-times conform an interesting class of exact solutions of General Relativity. In particular, they represent idealized gravitational waves propagating on top of anti-de Sitter space-times. In this talk, I will present a generalization of them, which are naturally called generalized Siklos space-times. I will motivate their introduction, elaborate on the curvature of these space-times and discuss some relevant physical features of them. Among other aspects, I will show that these space-times lead, in certain cases, to a superposition principle for the Einstein equations. Based on Lett.Math.Phys. 113 (2023) 5, 106 with C. S. Shahbazi and work in progress with Bernardo Araneda.

Parallel session 10 (Cosmology Beyond GR) / 40

Symmetric teleparallel gravity, numerical relativity and f(Q) cosmology

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In this presentation, we will review recent advancements in the symmetric teleparallel equivalent of general relativity (STEGR) as an alternative framework for numerical relativity. Initially, we will introduce the metric 3+1 formalism, the Hamiltonian of STEGR and the equations of motion in the 3+1 decomposition. After assessing the implications of the results in numerical relativity, we proceed to explore the search of cosmological solutions in f(Q) gravity, a nonlinear generalization of STEGR, and how new methods could help to find new sets of Friedmann equations. The new solutions are physically different from previously found ones, and are currently the subject of ongoing research.

Parallel session 7 (Mathematical Relativity) / 41

New approach to conserved charges of generic gravity in AdS

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Starting from a divergence-free rank-4 tensor of which the trace is the cosmological Einstein tensor, we give a construction of conserved charges in Einstein's gravity and its higher derivative extensions for asymptotically anti-de Sitter spacetimes. The current yielding the charge is explicitly gauge-invariant, and the charge expression involves the linearized Riemann tensor at the boundary. Hence, to compute the mass and angular momenta in these spacetimes, one just needs to compute the linearized Riemann tensor. We give two examples.

Phys. Rev. D 99, 044016 (2019)

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The self dual action: Ashtekar variables without gauge fixing

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I will discuss how to use the GNH method to study the Hamiltonian formulation of the Euclidean self-dual action. This action can be used to arrive at the complex Ashtekar formulation for Lorentzian General Relativity or a real connection formulation for Euclidean General Relativity. I will show how one can get the Ashtekar formulation for Euclidean gravity without using any gauge fixing and compare this derivation with the one corresponding to the Holst action.

Parallel session 6 (Black Holes Beyond GR) / 43

Regular primordial black hole constraint from isotropic gamma-ray background

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The literature is flourishing in exotic and theoretical black hole solutions realized in the framework of general relativity or modified gravity theories to cure the singularity affecting the vacuum solutions of general relativity.
On the other hand, the Schwarzschild solution is the standard lore when computing constraints on primordial black hole abundance arising from the isotropic diffuse gamma-ray background.
In this study, we present an extension of such constraint by considering a sample of the most common regular black hole solution. We show that the constraint changes and the so-called asteroid mass width, where primordial black holes may contribute to the totality of the dark matter, can be enlarged or closed by those non-Schwarzshild solutions.

Parallel session 6 (Black Holes Beyond GR) / 44

Black hole mergers in cubic gravity

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The evolution of the event horizon in the merger of a large black hole and a small compact object can be studied exactly in the extreme mass ratio regime by tracing back a specific set of null geodesics. While this type of analysis has already been conducted for various scenarios in General Relativity, a similar study in modified theories of gravity is still missing. We study how higher-order corrections of gravity influence the dynamics of the merger, focusing in the case where the small compact object is a black hole in cubic gravity. In particular, we determine the impact of the theory's coupling parameter on the relevant physical observables that characterize the fusion, such as the merger duration and the distortion of the small companion. We also compare our results in the limit of vanishing coupling parameter with the already known results of General Relativity.

Parallel session 9 (Neutron Stars) / 45

Ridges due to latent heat in rotating neutron stars, in GR and f(R) gravity

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We discuss "ridges" in macroscopic properties of rotating neutron stars as tell-tale signatures of first order phase transitions in the matter therein. The intensity of the nonanaliticity in the various observables angular momentum/angular frequency/ moment of inertia/ mass/ major and minor radii is proportional to the latent heat in the phase transition, and these signals could be found when the respective diagrams are well populated.

We study the changes respect to General Relativity when working with a family of modified-gravity theories which includes quadratic f(R). Interestingly, the Seidov limit (maximum latent heat in such a phase transition due to gravitational collapse) is substantially modified.

Based on Annals Phys. 459 (2023) 169487, 2307.15366 and upcoming work.

Parallel session 5 (Gravitational Waves) / 46

New windows onto nHz Gravitational Wave science with astrometry

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We present a summary of novel techniques based on astrometry science and exploiting the joint measurement from astrometric surveys and Pulsar Timing Array to constraint the production of gravitational waves in the nHz band. We address our presentation on the possibility of probing a stochastic GW background with data coming from existing and planned optical surveys, such as Gaia and LSST, showing the potentials and the limitations of those experiments in our search.

Parallel session 11 (Quantum Gravity) / 47

True and coordinate singularity resolution in the planar AdS Black Hole

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One of the main motivations for developing a quantum theory of gravity is to resolve classical singularities. In many cosmological models, various quantum gravity theories have successfully replaced the Big Bang singularity with a "big bounce". However, black hole spacetimes have historically

received less attention. In this talk, we focus on the Wheeler–DeWitt quantisation of one of the simplest black hole models: the planar AdS black hole.

I will begin by comparing the quantisation of the AdS black hole spacetime to the flat FLRW universe with a free massless scalar field. Following this, I will show how both the black hole singularity and the horizon coordinate singularity are resolved in the quantum theory, emphasising the role played by unitarity. Finally, I will discuss future research directions in this field. This talk is based on a WIP soon to appear on arXiv.

Parallel session 12 (Modified Gravity) / 48

Isospectrality and non-birefringence in the effective field theory extension of GR

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Two universal predictions of general relativity (GR) are the propagation of gravitational waves (GW) along null geodesics and the isospectrality of quasinormal modes (QNM) in Schwarzschild and Kerr black holes. However, in extension of GR one generally finds that QNMs are no longer isospectral and that the GW propagation is no longer geodesic and that it exhibits birefringence — polarization-dependent speed. We study these effects in a general effective-field-theory extension of GR with up to eight-derivative terms and show that there is a unique Lagrangian that gives rise to isospectral QNMs in the eikonal limit. Furthermore, this is also the only Lagrangian that gives rise to a polarization-independent dispersion relation for GWs, and hence is the only non-birefringent theory. We argue that both properties are related through the eikonal perturbations/light ring connection. Finally, we note that this unique theory is the quartic-curvature correction arising from string theory and argue that other stringy corrections may share similar properties.

Parallel session 10 (Cosmology Beyond GR) / 49

Can relativistic effects explain galactic dynamics without the need for dark matter?

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In a growing number of recent works, it has been claimed that “gravitomagnetism” and/or non-linear general relativistic effects can play a leading role in galactic dynamics, partially or totally replacing dark matter. Using the 1+3 “quasi-Maxwell” formalism (and generalizing it for null geodesics), we show, on general grounds, such hypothesis to be impossible. We demonstrate that (i) the observed gravitational lensing effects rule out any galactic model (linear or non-linear) based on gravitomagnetism, and (ii) the non-linear contributions to the gravitational field actually weaken gravitational attraction, thereby only aggravating the need for dark matter. I shall also briefly dissect the misunderstandings at the origin of the recently proposed relativistic “galactic” models, most notably the Balasin-Grumiller solution, which serves as an archetypal example for the two key observations above.

Parallel session 9 (Neutron Stars) / 51

I Love Q, but δM too

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The I-Love-Q relations refer to the existence of various approximate equation of state-independent relations involving the moment of inertia, Love number, and quadrupole moment. These relations have an interesting applicability in observational astrophysics since they allow the inference of two quantities within the I-Love-Q trio out of a third one alone. However, the quantities involved in the I-Love-Q relations are normalized by the parameter M_0, which arises in the usual perturbative analytical approach as the mass of the background configuration. However, since M_0 is not the mass of the rotating star M_S, it is not an observable quantity, and therefore the applicability of the relations to actual observations gets tainted. This problem is usually overcome by taking M_0 to be the mass of the star – an approximation that can, in some scenarios, be too risky. In this talk, I will explain how to extract the value of M_0 using an extended version of the universal relations, which includes additional relations involving $\delta M \propto M_S - M_0$, and analyze the extent to which the use of these extended relations provides a more precise inference of the properties of the star, and its equation of state.

Parallel session 4 (Black Holes I) / 52

Monte Carlo methods for stationary solutions of general-relativistic Vlasov systems

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I will discuss a Monte Carlo method designed to compute stationary solutions of the general-relativistic Vlasov equation describing a gas of non-colliding particles. Our method consists of three elements: 1) selecting a set of parameters of individual trajectories, which correspond to assumed properties of the distribution function (e.g., initial, asymptotic or boundary conditions), 2) solving geodesic equations for the selected sample of parameters, 3) implementing a suitable coarse-graining scheme, which yields approximations to observable quantities (particle current density, energy momentum tensor). I will discuss difficulties associated with problems 1) and 3), providing a collection of examples related with stationary accretion models in the Schwarzschild spacetime. This general discussion will be based on the paper: Phys. Rev. D 108, 124057 (2023). In a sequel of this talk, Adam Cieślik will show an application to the accretion of the collisionless gas onto moving black holes.

Parallel session 4 (Black Holes I) / 53

Monte Carlo methods for stationary solutions of general-relativistic Vlasov systems: Planar accretion onto a moving Schwarzschild black hole

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I will present the results of a Monte Carlo simulation of a planar accretion of the relativistic Vlasov gas onto a moving Schwarzschild black hole. The gas is assumed to be in thermal equilibrium at infinity, where it obeys the Maxwell-Jüttner distribution. Monte Carlo results consistently confirm the analytically derived exact expressions for particle current density in all examined cases. This simulation methodology builds on the approach developed last year for a stationary Schwarzschild black hole: Phys. Rev. D 108, 124057 (2023). I will elucidate the modifications necessary for setting up the simulation for the complexities introduced by black hole motion. This presentation is a follow-up to Patryk Mach's talk, which covers the theoretical foundations of the Monte Carlo method.

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Greybody factors of string-corrected black holes

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We compute analytically greybody factors for asymptotically flat spherically symmetric black holes with stringy higher derivative corrections in d dimensions in the high frequency limit. Our calculations include both the eikonal limit —where the real part of the frequency of the scattered wave is much larger than the imaginary part —and the highly damped case —where the imaginary part of the frequency is much larger than the real part —, addressing the emission of gravitons and test scalar fields, and yielding full transmission and reflection scattering coefficients.

Parallel session 2 (Numerical Relativity) / 56

Electrically charged numerical simulations on hyperboloidal slices

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Gravitational wave radiation is only unambiguously defined at future null infinity: the location in spacetime where light rays arrive and where global properties of spacetimes can be measured. Within the context of numerical relativity we set up simulations reaching future null infinity by using hyperboloidal slices, as opposed to traditional Cauchy slices that reach spacelike infinity. Extending previous work in spherical symmetry, the Einstein-Maxwell-Klein-Gordon system is evolved on hyperboloidal slices, allowing to model gravity coupled to electromagnetism and a complex massless scalar field. This allows us to simulate the evolution of a charged scalar field and/or a Reissner-Nördstrom (electrically charged) black hole, where this last scenario serves as a useful toy model for a rotating (Kerr) black hole. We will report on current progress on these charged evolutions, where we retrieve their emitted signals at future null infinity as they would be seen by detectors on Earth.

Parallel session 5 (Gravitational Waves) / 57

Propagation and emission of gravitational waves in the weak-field limit within the Palatini formalism

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In the era of gravitational waves physics, when detections of wave fronts are increasing in number, sensitivity, frequencies and distances, gravitational physics has entered a period of maximum activity and brilliance. This has opened a new window where General Relativity can be challenged in both weak and strong-field regimes. For this reason, modified theories of gravity have been proposed, such as f(R) theories, which consider a gravitational action that depends on a function of the scalar curvature f(R), rather than the scalar curvature R itself, or the Palatini formalism, in which the affine connection is (a-priori) assumed to be independent to the metric.

In this talk, I will focus on the analysis of gravitational waves propagation and emission in the weak-field regime for gravitational f(R) theories within the Palatini formalism. Our results show that gravitational waves propagation in vacuum matches General Relativity predictions as well as the functional form of the multipolar expansion when considering weak sources. However, a rescaling of the gravitational constant arises, which affects the energy radiated by the gravitational waves emission.

Parallel session 3 (Cosmology II) / 58

Axion-like dark energy: late rather than early

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Dynamical models where the dark energy component is given by a canonical scalar field are known as quintessence models. In this work, we propose an axion-like potential which emerges from physically motivated considerations. The potential naturally satisfies the necessary conditions for tracking behaviours (alleviating the cosmic coincidence problem); i.e., once we fix our potential, no matter which initial condition is chosen, all the trajectories will converge to the same path. It also explains the late-time acceleration of the Universe through an almost effective cosmological constant, as a result of the non-null value of the potential at the minimum. We distinguish two cases: in the first one the field has not yet reached the minimum of the potential, while in the second case the field is currently oscillating around the minimum.
We study the dynamical system and the cosmological perturbations of the model. We then obtain the matter power spectrum and $f\sigma 8$ and compare them with the ΛCDM ones. Finally, we present the cosmological constraints of our model using observational data through an MCMC approach.

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Black holes in effective field theories –dynamics and new observational signatures

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Black holes in effective field theories, such as scalar-Gauss-Bonnet theory, offer interesting alternatives to the Kerr solution that can be tested observationally. In the present talk, we will discuss some of the most interesting examples of such beyond-Kerr black holes. Special attention will be paid to the progress in studying their dynamics in cases when they are isolated and when put in a binary. Such studies shed light on the nonlinear stability and potential loss of hyperbolicity of beyond-Kerr black holes from a theoretical perspective. On the other hand, they are the ultimate tools to predict gravitational wave emission of black hole coalescence that can deviate significantly from GR, especially in the nonlinear phase of the merger.

Parallel session 9 (Neutron Stars) / 60

Non-Parametric Constraints on the Neutron Star Equation of State with Multi-messenger Data

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The behaviour of extremely dense cold nuclear matter is still an open question due to intrinsic modelling difficulties of such extreme environments as the hearts of Neutron Stars (NS), but also to the non-trivial connection between the macroscopic observables and microscopic behaviour. In this work, we utilize the now substantial amount of astrophysical data provided by NS observations, along with constraints from chiral effective field theory(χEFT) and perturbative QCD (pQCD) theoretical calculations to directly constrain the NS Equation of State (EoS). To this end, we employ a non-parametric EoS prior construction with Gaussian Processes that is trained on 75 theoretical EoSs with varying phenomenology and creates both a model-agnostic and model-informed prior. These priors are then utilized in a Bayesian updating scheme by first performing a complete analysis of the BNS event GW170817 with minimal assumptions, and then sequentially adding information from the other NS data streams along with theory constraints. Besides providing standard constraints, such as the pressure at twice nuclear saturation density $P(2\rho_0) = 3.64^{+0.40}_{-0.29} \times 10^{34}$ *dyne* cm^{-2} for the model agnostic prior, our methodology also aims to constrain EoS properties such as phase transitions and differentiation between quark, hyperonic or hadronic models.

Parallel session 12 (Modified Gravity) / 61

Perturbations of bimetric gravity on most general spherically symmetric spacetimes

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In this talk I will present a formalism to study linear perturbations of bimetric gravity on any spherically symmetric background, including dynamical spacetimes. The setup is based on the Gerlach-Sengupta formalism for general relativity. Each of the two background metrics is written as a warped product between a two-dimensional Lorentzian metric and the round metric of the two-sphere. Using the tensor spherical harmonics allows us to use a compact and covariant description of the perturbative equations both on the Lorentzian manifold and on the two-sphere, which is valid for any coordinate choice. Finally, as an interesting application, I will specialize the obtained equations to a general nonbidiagonal background with a static physical metric, where the analytical form of the background can be solved up to a function that satisfies a nonlinear partial differential equation.

Parallel Session 1 (Cosmology I) / 62

A class of tilted cosmological solutions to the near equilibrium Einstein-Boltzmann system

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The aim of this work is to construct a class of self-consistent cosmological solutions to the combined Einstein-Boltzmann system, consisting of Einstein's equations and the Boltzmann equation. The Boltzmann equation is first rewritten in tetrad form, using a frame comoving with the fluid. In this way, the integrations with respect to the momenta become the same as in flat spacetime, and hence are independent of the metric.
For the collision term we use a relativistic BGK-type kinetic theory model, [1], which generalizes the term to a form suitable for using a particle (Eckart) frame, [2], together with its extension to polyatomic gases, [3].
Then, on using the Chapman-Enskog expansion to first order, a near equilibrium configuration, consistent with the Eckart theory, is constructed. This is used to calculate the energy-momentum tensor, from which the bulk and shear viscosity coefficients are read off, as well as to determine the particle current density, from which the coefficient of heat conductivity is found.
The so constructed energy-momentum tensor is then used to find self-consistent solutions to the Einstein-Boltzmann system with viscosity and heat flow. For this we consider a class of homogeneous and tilted locally rotationally symmetric cosmological models of Bianchi type VIII, and hence extend an earlier work, [4], where Robertson-Walker cosmologies were studied. The equations are rewritten as an integrable system of first order ordinary differential equations, suitable for numerical integration. The time evolution of some of the models are then studied, with focus on the dissipative terms.

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Cosmology with the Einstein Telescope

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Gravitational waves opened a new avenue to explore the Universe and to understand its evolution. Here, I will show the potential of third-generation gravitational wave detectors, such as the Einstein telescope in studying the underlying cosmological model and measuring the cosmological parameters with unprecedented accuracy on the Hubble constant which will aim to solve the well-known Hubble tension.

Parallel session 6 (Black Holes Beyond GR) / 64

Regular black holes from pure gravity

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I will show via an explicit construction how an infinite tower of higher-curvature corrections generically leads to the resolution of the Schwarzschild singularity in any spacetime dimension D≥5. The theories we consider have two key properties that ensure the results are general and robust: (1) they provide a basis for (vacuum) gravitational effective field theory in five and higher-dimensions, (2) for each value of the mass, they have a unique static spherically symmetric solution. I will present several exact solutions of the theories that include the Hayward black hole and others similar to the Bardeen and Dymnikova ones. Unlike previous constructions, these regular black holes arise as vacuum solutions, as we include no matter fields whatsoever in our analysis. Additionally, their thermodynamics properties can be studied in a completely universal and unambiguous way.

Parallel Session 1 (Cosmology I) / 65

New parameterisations of Dark-Energy and applications to Quintessence

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We introduce new parameterisations of dark-energy which continuously deform the special ΛCDM model. In addition, we provide the functional form of the parameters when dark-energy is described by thawing and tracking quintessence models.

Parallel session 7 (Mathematical Relativity) / 66

News tensor on null hypersurfaces

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There is growing interest in understanding the radiative properties of particular classes of null hypersurfaces in space-time, such as weakly isolated horizons, from the viewpoint of the structure available at the conformal boundary of asymptotically flat space-times. In this work, a covariant definition of news tensor is given for general null hypersurfaces with arbitrary cosmological constant in 4 space-time dimensions. For the case of vanishing cosmological constant, this treatment yields the expression (in arbitrary conformal gauge) of the relevant components of Weyl tensor in terms of the news at infinity, and a generalised transport equation for the Geroch tensor. The differences between null hypersurfaces in the bulk and null infinity are reviewed. In particular, it is argued that this sort of characterisation of gravitational radiation by means of a news tensor only works for particular bulk cases, whereas its validity is more general at infinity when the cosmological constant vanishes.

Parallel session 11 (Quantum Gravity) / 67

The trans-Planckian problem in loop quantum cosmology

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One of the criticisms of the inflationary paradigm is that scales that are observable today were trans-Planckian at the onset of inflation. This questions the validity of standard results regarding the primordial power spectrum. Standard cosmology also ignores pre-inflationary dynamics, since it loses predictability close to the initial singularity. Loop Quantum Cosmology (LQC) is an approach to the quantisation of cosmological models. It provides effective pre-inflationary dynamics where the big-bang singularity is resolved in terms of a quantum bounce, that connects a contracting epoch of the Universe with an expanding one. In this talk, we investigate the trans-Planckian problem in two models of LQC. We find that one of the models avoids the issue altogether by generating less e-folds of inflation, such that the observable modes never become transplanckian. On the other hand, the other model suffers from this problem, as observable modes become transplanckian during a time when they lose adiabaticity, making their primordial power spectrum susceptible to changes due to trans-Planckian physics.

Parallel session 11 (Quantum Gravity) / 68

Hawking partners in evaporating black holes

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Understanding the quantum information aspects of fields in gravitational collapse scenarios remains an open issue to date. Here, we present a conservative QFT study about the entanglement structure of the Hawking effect in evaporating black holes. For this purpose, first we review the known concept of Hawking partners, as being the field modes that are entangled with, and thus purify, the thermal radiation. Then, we show how the definition of these partners can be generalized to any case where the temperature of the radiation increases over time according to the semiclassical evaporation process. Our explicit computation allows us to study the relative location of radiation and partner modes at past null infinity. These results point to the inevitable need of a quantum gravity description of the high curvature regions of spacetime in order to know the evolution and ultimate fate of the Hawking partners.

Parallel session 12 (Modified Gravity) / 69

On Perturbative Constraints for Vacuum High Order Theories of Gravity

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In the realm of General Relativity (GR) and extended theories of gravity, obtaining solutions for scenarios of physical interest is a highly intricate challenge. By employing the formalism of mathematical perturbation theory within the GR framework, we have developed a systematic method to compare solutions in modified gravity theories with the field equations of GR. Within this context, we demonstrate that, for a significant class of $f(R, R_{\mu\nu}R^{\mu\nu})$ functions in vacuum, solutions in extended fourth-order gravity theories do not yield additional effects beyond those predicted by GR's perturbation theory. However, models characterized by terms of the form $f(R, R_{\mu\nu}R^{\mu\nu}, R_{\mu\nu\sigma\delta}R^{\mu\nu\sigma\delta})$ exhibit distinctive contributions not present in GR. We assert that fundamental limitations exist, explaining why solutions of certain $f(R, R_{\mu\nu}R^{\mu\nu})$ models can deviate from their GR counterparts, indicating non-connected solutions or non-analytic behavior. Conversely, in the models $f(R, R_{\mu\nu}R^{\mu\nu}, R_{\mu\nu\sigma\delta}R^{\mu\nu\sigma\delta})$, the solutions seamlessly connect with those of GR. This distinction highlights the nuanced interplay between higher-order curvature terms and their impact on gravitational dynamics, offering new insights into the landscape of modified gravity theories.

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Evolution of creases on the event horizon of a black hole merger

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The event horizon of a dynamical black hole is generically nonsmooth. The types of nonsmooth structures that can arise on the event horizon of a dynamical black hole have been recently classified 2303.15512. The most important type of nonsmooth structures were found to be crease points and caustics. In this talk, I will discuss how creases and caustics arise and evolve on the event horizon of a black hole merger. The study is carried out in the (strict) extreme mass ratio limit, for which constructing the event horizon reduces to finding a null hypersurface that asymptotes to a Rindler horizon in the Kerr spacetime. The construction allows for a quantitive study of geometrical properties of the crease set and a comparison with the predictions of an exact local model. Based on work with Maxime Gadioux and Harvey Reall.

Parallel Session 1 (Cosmology I) / 71

Elastic interactions in the dark sector and massive neutrinos

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Cosmological models that incorporate an elastic interaction within the dark sector at the linear order have emerged as a promising solution to address the σ8 tension. This interaction works by preventing the clustering of dark matter, thereby alleviating the tension. A key question in these scenarios is whether there is a potential degeneracy between this dark sector interaction and the impact of massive neutrinos, which also contribute to the suppression of structures at late times. In this study, we explore the possibility of such a degeneracy and provide evidence that the effects of the elastic interaction and massive neutrinos do not exhibit strong correlations.

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Quasinormal mode spectrum of the AdS black hole with the Robin boundary condition

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We study the quasinormal mode (QNM) spectrum of an asymptotically AdS black hole with the Robin boundary condition at infinity. We consider the Schwarzshild-AdS$_4$ with the flat event horizon as the background spacetime and study its scalar field perturbation. Denoting leading coefficients of slow- and fast-decay modes of the scalar field at infinity as ϕ_1 and ϕ_2, respectively, we assume a linear relation between them as $\phi_2 = \cot(\theta/2)\phi_1$, where θ is a constant called the Robin parameter and periodic under $\theta \sim \theta + 2\pi$. In a certain range of the Robin parameter, there is an instability driven by the boundary condition. We also find the holonomy in the QNM spectrum under the parametric cycle of the boundary condition: $\theta = 0 \to 2\pi$. After the one-cycle, n-th overtone of the QNM moves to $(n-1)$-th overtone. The fundamental tone of the QNM is swept out to the infinity in the complex plane.

Parallel session 3 (Cosmology II) / 73

Schwinger pair production in de Sitter: Regularizing negative conductivities

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Within the context of particle interactions during inflation, both from an inflationary but also dark sector model building perspective there is great interest in analyzing the effects of particle creation by electromagnetic fields in a de-Sitter background. Notably in the current literature, there is an open discussion arising from the appearance of negative conductivities when the masses of the charged particles are smaller than the Hubble rate. We address how to properly regularize and renormalize the current of charged scalar or fermions using, dimensional regularization, Pauli Villars and a "running"adiabatic subtraction regularization. We seem to correct the anomalous predictions in previous works.

Parallel session 9 (Neutron Stars) / 74

Modeling Relativistic Stars within Einstein-Vlasov-Boltzmann Theory

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Relativistic stars are typically modelled as ideal fluids, which in spherical symmetry leads to the Tolman-Oppenheimer-Volkoff (TOV) solutions. In this talk I discuss the construction of solutions for spherical, relativistic stars within full kinetic theory. In this case matter is described by the Vlasov-Boltzmann equation, which allows for a more realistic description of stars that is valid beyond the hydrodynamic limit. I discuss the new physical effects occuring in this model and compare with the TOV solutions.

Parallel session 11 (Quantum Gravity) / 75

Particle creation with numerical hyperboloidal evolution

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In quantum field theory particle pairs can be spontaneously excited out of the quantum vacuum by a dynamical spacetime or background. Well-known examples include Hawking radiation by collapsing stars, or particle creation by accelerated mirrors. Although this topic is well-understood from a theoretical viewpoint, only few explicit examples can be calculated in full closed form using analytical methods. In this work we explore this phenomenon using numerical techniques instead, and simulate the scattering of a massless scalar field from past null infinity to future null infinity with a set of effective potentials. As radiation (revealing the creation of particles) is only unambiguously defined at null infinity, this evolution naturally resorts to ingoing and outgoing hyperboloidal slices – spacelike slices that reach past and future null infinity, respectively. By comparing the field's spectra there, we aim to ascertain the appearance of new frequency modes, which indicates the creation of particles. These numerical experiments are executed in spherical symmetry on a Minkowski spacetime background with a stationary, radially-dependent potential, as well as with a time-dependent potential that serves as a toy model and mimics the dynamics of the non-stationary regime of gravitational collapse. This presentation will report on the progress achieved so far.

Parallel session 3 (Cosmology II) / 76

The inflation trilogy and primordial black hole dark matter

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

Parallel session 2 (Numerical Relativity) / 77

Reference metrics on hyperboloidal slices for free evolution

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Gravitational wave radiation is only unambiguously defined at future null infinity - the location in spacetime where light rays arrive and where global properties of spacetimes can be measured. Reaching future null infinity is thus very important for extracting correct waveforms. A convenient way to include it in numerical relativity simulations is via hyperboloidal foliations, which can be tackled using conformal compactification. Current efforts in this approach rely on a 4D time-independent background reference metric for the calculation of the source functions in the gauge conditions, which are a crucial part of the implementation. So far, this 4D reference metric was taken to be that of Minkowski spacetime as foliated by a constant-mean-curvature slice. This work aims to generalise this choice by considering other slicing options, constructed via the height function method. I will report on current progress and the options considered so far.

Parallel session 3 (Cosmology II) / 78

Non-linear dynamics of axion inflation

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Axion inflation is one of the leading models for a successful realization of the inflationary paradigm. I will address the issue of the strong backreaction regime in the abelian axion inflation scenario, extending results from 2303.17436 and ongoing work. I will do a revision of the mild and strong backreaction regimes, during and at the end of inflation, and also show how they can be distinguished in terms of dynamics and lengthening of the inflationary period, as well as, the helical imbalance. I will also highlight the ultraviolet sensitivity of the model in the case of larger couplings and the challenges it presents for the accurate capture of the dynamics.

Parallel session 12 (Modified Gravity) / 79

Static and spherically symmetric vacuum spacetimes with non-expanding principal null directions in $f(R)$ gravity

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In this work we characterize all the static and spherically symmetric vacuum solutions in $f(R)$ gravity when the principal null directions of the Weyl tensor are non-expanding. In contrast to General Relativity, we show that the Nariai spacetime is not the only solution of this type when general $f(R)$ theories are considered. In particular, we find four different solutions for the non-constant Ricci scalar case, all of them corresponding to the same theory, given by $f(R) = r_0^{-1}\ lvertR - 3/r_0^2$ $rvert^{1/2}$, where r_0 is a non-null constant. Finally, we briefly present some geometric properties of these solutions.

Parallel session 2 (Numerical Relativity) / 80

Black-hole ringdown and their progenitors: from numerical Relativity to tests of GR

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Black-hole ringdowns from binary coalescences encode information about the final state of the remnant through their modes of oscillation, and about their progenitors through the degree of excitation of different modes. We present novel surrogate fits for the excitation amplitudes of black-hole ringdowns from quasi-circular binaries. They are calibrated to numerical relativity simulations and make use of parametric-free regression algorithms, which provide functional flexibility and automatic estimates of the fitting uncertainties. We apply our results to test the consistency of detected black-hole ringdowns with the predictions of GR and with the assumption of quasi-circularity.

Parallel session 2 (Numerical Relativity) / 82

Hyperboloidal evolution in Numerical Relativity: the case of Generalized Harmonic Gauge

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In this talk I will discuss the implementation of hyperboloidal coordinates in the Generalized Harmonic Gauge (GHG) formulation of General Relativity within the Dual-Foliation formalism. This approach allows us to include future null infinity in the computational domain, while keeping standard methods for the evolution of the strong field region. First I will mention the asymptotic properties of the metric in GHG, and how these depend in the choice of gauge. I will show numerical results of spherically symmetric evolutions with a massless scalar field as matter content as a first step towards the application of hyperboloidal evolution in GR without symmetry assumptions.

Parallel Session 1 (Cosmology I) / 83

Archimedes Experiment: the Weight of Quantum Vacuum

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The Archimedes experiment investigates the interaction between zero-point quantum fluctuations of the electromagnetic field and gravity, placing itself into one of the most longstanding discussions

in physics: the Cosmological Constant problem.
Using a highly sensitive suitably designed beam balance, Archimedes will measure the force exerted by the gravitational field on special samples suspended from the balance arms in which the vacuum energy is modulated in time by exploiting superconducting transition; the transition turns them into a stack of Casimir cavities, expelling not-allowed EM modes.
If the vacuum energy does interact with gravity, an upward force acts on the cavity and can be interpreted as the lack of weight of the expelled EM modes. The expected torque generated by this modulation is of the order of $10^{-13}\ Nm/\sqrt{Hz}$, therefore a very sensitive beam balance has been designed.
The final setup of the Archimedes experiment is now fully installed, and the first sensitivity measurement in vacuum is expected by the end of 2024, while the final measurement of the weight of the vacuum fluctuations weight is expected within 2026.

Parallel session 6 (Black Holes Beyond GR) / 84

Toward regular black holes in sixth-derivative gravity

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Higher-derivative terms are relevant in several approaches to quantum gravity. For instance, they occur in the perturbative quantization of Einstein gravity, and they can be used to construct (super-)renormalizable quantum gravity models. In this talk, we discuss the problem of whether higher derivatives could already resolve black hole singularities at classical level. To this end, we present spherically symmetric static solutions of the most general sixth-derivative gravity using series expansions. We prove that the only solutions of the complete theory, i.e., with generic coupling constants, that possess a Frobenius expansion around the origin ($r = 0$) are necessarily regular. Moreover, by expanding around $r = r_0 \neq 0$ we identify solutions with black-hole horizons. Families of singular solutions emerge only for specific branches of the theory (i.e., imposing particular constraints on the coupling constants). These results suggest that there is an important difference between higher-derivative gravity models with 4 and 6 derivatives in what concerns the space of spherically symmetric static solutions.

Parallel session 8 (Black Holes II) / 85

Critical gravitational collapse in elastic matter models

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Critical collapse in general relativity is a topic with a rich history. In the case of perfect fluids in spherical symmetry, the critical solution at the threshold of black hole formation is known to be continously self-similar, a property that allows to compute the critical exponent by using renormalization group techniques and solving a system of ODEs forming a boundary value problem. I will discuss how this picture extends to the case of critical collapse with elastic materials.

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Numerical study of the Hawking and dynamical Casimir effects

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In this presentation we will explore, with the help of analytical and numerical tools, the dynamics of a quantum free field enclosed in a cavity with moving boundaries. The nontrivial dynamics of the mirrors yields to mode-mixing and particle production. We will then discuss how to simulate the Hawking effect and some intriguing phenomena associated with the dynamical Casimir effect.

Parallel session 11 (Quantum Gravity) / 87

Kruskal-plus-reservoir: a toy model for spinfoam effects on the low-energy gratitational field

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The quantum nature of matter leads to the exploration of quantum features of the spacetime as a dynamical frame. In this line, the geometry has been theorized to be subject to quantum fluctuations that would constitute a spacetime foam structure at the Planck scale. In this contribution we propose an effective toy model on a Kruskal spacetime to analyze the low-energy effects of the spinfoam structure on the macroscopical description of gravitational field. In order to do so, we model the spinfoam as a thermal bath, following the analogy established by J. Garay in [1], and, employing a reduced Hamiltonian formalism for the Kruskal spacetime, we construct a system-plus-reservoir model where the macroscopic geometry and the foamlike structure are bilinearly coupled.

References

[1] Garay, L. (1998). "Space-time foam as a quantum thermal bath". *Phys. Rev. Lett.*, 80, 2508–2511.

[2] V. Calzada, P., Bargueño, P. & Miret-Artés, S. "Kruskal-plus-reservoir: a toy model for spinfoam effects on the low-energy gravitational field" (To be submitted).

Parallel session 8 (Black Holes II) / 88

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

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We perform the numerical simulation of primordial black hole formation from a nonspherical profile of the initial curvature perturbation ζ. We consider the background expanding universe filled with

the perfect fluid with the linear equation of state $p = w\rho$ ($w = 1/3$ or $1/5$), where p and ρ are the pressure and the energy density, respectively. The initial condition is set in a way such that the principal directions of the second derivatives of ζ and $\triangle\zeta$ at the central peak are misaligned, where $\triangle$ is the Laplacian. In this setting, since the linearized density is proportional to $\triangle\zeta$, the inertia tensor and deformation tensor $\partial_i\partial_j\zeta$ are misaligned. Thus tidal torque may act and the spin of a resultant primordial black hole would be non-zero in general, although it is estimated to be very small from previous perturbative analyses. As a result, we do not find a finite value of the spin within our numerical precision, giving support for the negligibly small value of the black hole spin for $1/5$
$lesssim w$
$lesssim 1/3$. More specifically, our results suggest that the dimensionless PBH spin s is typically so small that $s \ll 0.1$ for w
$gtrsim 0.2$.

Parallel session 8 (Black Holes II) / 89

The Galactic Center as a gravitational laboratory

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The centre of the Milky Way has been subject of an intense observational program throughout the last thirty years, leading to exhibit the existence of a point source supermassive object named Sagittarius A*(Sgr A*). While stars orbiting around it are accelerated by gravity up to speeds of 10.000 km/s, Sgr A*moves at less than 1 km/s. The kinematic properties of such stars, called S-stars, set up its mass to about 4 million solar masses, concentrated in a region of only six light hours. The study of the motion of these stars and the potential future discovery of pulsars orbiting Sgr A* allows to probe the gravitational field of a supermassive black hole in a regime that had never been explored before. In this talk I will discuss the new avenue opened by such observations to test alternative to the classical Schwarzschild black hole model.

Parallel session 8 (Black Holes II) / 90

Twist-free axisymetric critical collapse of a complex scalar field

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It has been thirty years since the breakthrough paper of M. Choptuik on critical phenomena in the gravitational collapse of a real massless scalar field in spherical symmetry. This celebrated paper led to a rich exploration of different extreme spacetimes in numerical relativity, which persistently question the weak cosmic censorship conjecture, contribute to our understanding of spacetime singularities, as well as construct new avenues for the mathematical relativity community.
One would naively expect that the phenomena witnessed by Choptuik would generalize to full 3+1

dimensions. However, recent research has indicated that the standard picture of critical phenomena in gravitational collapse changes once symmetry is dropped, for instance, in the case of vacuum collapse of gravitational waves. In our work, we examine the gravitational collapse of a massless complex scalar field minimally coupled to GR, for the first time using a pseudospectral code (bamps), in spherical symmetry and beyond. We report deviations from Choptuik's solution and show evidence aiming to bridge our understanding of Choptuik's threshold and the vacuum threshold of collapse.

In this talk, I am going to highlight the main results of our recently published paper: https://doi.org/10.1103/PhysRevD.1

Parallel session 5 (Gravitational Waves) / 92

Gravitational wave fluxes for a spinning particle in the Hamilton-Jacobi formalism

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Extreme mass-ratio inspirals (EMRIs) are one of the most intriguing sources of gravitational waves. An EMRI binary consists of a stellar mass compact object falling into a supermassive black hole. Thanks to such a large disparity in scales, we can model these binaries, in first approximation, as a point particle (the "secondary") free-falling into the spacetime generated by the more massive companion. Corrections to the dynamics arise from radiation-reaction effects and the smaller body's spin.

In particular, the secondary spin introduces new degrees of freedom, and significantly affects the statistical accuracy of the other parameters, like the masses and the spin of the heavier object. Thus, including the secondary spin in the EMRI waveform is important to avoid biases on the inferred parameters.

In this talk, I will present a new method to compute fast and accurate gravitational waveform for extreme mass-ratio binaries with a spin-precessing secondary. Previous work in the literature directly solved the equations of motion for a spinning body, the MPD equations, in their original 2nd-order form.
Instead, we solve the MPD equations reduced to first-order form, which were derived using the Hamilton-Jacobi formalism. In this way, we can compute the trajectories very efficiently and accurately for generic orbits.
Moreover, we provide the spin-corrections to the frequencies in terms of one-dimensional integrals of Jacobi elliptic integrals. With the spin corrections to the trajectories at hand, we finally computed the EMRI waveform amplitudes and fluxes for generic orbits including, for the first time, the spin precession of the secondary.

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Neutron decay anomaly, dark matter and neutron stars

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The discrepancies in measurements of the lifetime of the neutrons could be resolved considering an extra neutron decay channel into dark matter, with a branching ratio of the order of O(1%). Although the decay channel into a dark fermion χ plus visible matter has been already experimentally excluded, a dark decay into a dark matter fermion plus either a scalar or dark photon remains still a possibility. In particular, a model with a fermion mass $m_\chi \approx 1$ GeV and a scalar $m_\phi \approx 1-2$ MeV could provide not only the required branching ratio to explain the anomaly but also a good dark matter candidate with the right thermal abundance today, and being consistent with neutron stars physics.

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Two-fluid formalism and phenomenology of the dark matter admixed neutron stars

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A two-fluid formalism for curved space-time and phenomenology of the dark matter admixed neutron stars Accumulation of a sizable amount of dark matter in the interiors of neutron stars can significantly modify the observational properties and merger dynamics of these relativistic objects. We propose a two-fluid formalism for the description of a mixture of baryon matter and dark matter existing in curved space-time. The formalism is applied to solving the problem of relativistic hydrostatics and establishes a rigorous scaling between the microscopic parameters of the components, i.e. chemical potentials of baryon matter and dark matter. Furthermore, the formalism is extended to studying gravitational perturbations of the hydrostatic system in order to define the corresponding Love numbers giving direct access to tidal deformability of the dark matter admixed neutron stars. The scenarios of non-interacting fermionic and self-interacting bosonic dark matter are considered in order to constrain the parameters of the dark matter particles. Phenomenological consequences related to the observational mass-radius curves and thermal evolution on neutron stars are also discussed.

Parallel session 5 (Gravitational Waves) / 95

Gravitational waves from boson star mergers

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We provide results of the gravitational wave energy emitted by head-on collisions of equal-mass solitonic boson stars. Our numerical simulations span a two-dimensional parameter space, where a range of values for the central amplitude of the star is considered for different values of the solitonic constant. We report gravitational wave energies emitted by the merger of fluffy (less compact) boson stars that are up to an order of magnitude higher than those emitted by a binary black hole merger. The interplay between our control parameter - the distance separating the stars dictating

the time of merger - and the multiple extrema present in the solitonic potentials considered provide a surprisingly rich phenomenology. For certain values of the solitonic constant, the gravitational wave energy exhibits striking needle-sharp features across some range of central amplitudes, whilst in other regions of the parameter space it can drop discontinuously towards the value emitted by a binary black hole merger. An interpretation of all these results will be provided in the talk.

Parallel session 7 (Mathematical Relativity) / 96

Symmetry reduction of gravitational Lagrangians

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Co-authors: Charles Torre ; Guillermo Frausto ; Ivan Kolář

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Derivation of the Schwarzschild solution by substituting a spherically symmetric ansatz for the metric directly into the Einstein-Hilbert action instead of the Einstein field equations is known as the Weyl trick. Although it is a violation of the variational principle, surprisingly, this trick gives the correct result, which was later justified by the principle of symmetric criticality (PSC), first studied rigorously by Palais and later by Fels and Torre. PSC imposes two conditions on the infinitesimal symmetry group action (it should be stressed that these conditions are independent of the gravitational theory in question), and when satisfied, it allows one to symmetry-reduce any Lagrangian and guarantees that its field equations are fully equivalent to the reduced field equations.

We analyze all possible symmetry reductions of Lagrangians that yield fully equivalent field equations for any 4-dimensional metric theory of gravity. Specifically, we present a complete list of 44 infinitesimal group actions obeying PSC. We identify the corresponding invariant metrics and analyze their simplest form allowing for a successful symmetry reduction of Lagrangians. It turns out that PSC is satisfied not only by the infinitesimal symmetry group action of the Schwarzschild black hole, but also by, for example, the Taub-NUT solution, FLRW cosmologies, or NHEK geometry.

Parallel session 6 (Black Holes Beyond GR) / 97

Non-singular scale-dependent black hole and some properties

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In this talk, we will study the shadow, the greybody bounding, and the QNMs of a non-singular black hole in 4-dimensional spacetime in the context of scale-dependent gravity. Our focus is on determining constraints on the scale-dependent parameter, which serves as a descriptor for the scale-dependent solution with respect to the classically observed shadow radius. We also perform an analytical computation of the weak deflection angle using the Gauss-Bonnet theorem, as well as an analytical computation of the rigorous bounds of the Greybody factor (for scalar fields and photons). Scalar quasinormal modes are also investigated.

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Constraining 3-form dark energy models

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In the present talk, we reanalise 3-form dark energy (DE) models. Those models are well known to have a phantom-like behaviour. In particular, they may lead to an abrupt late-time cosmological event which is known as the little sibling of the Big Rip (LSBR) much smoother than a Big Rip singularity. We will present cosmological constraints on the model using Planck, DESI, Pantheon+, SH0ES and DESY1. The combined dataset suggests a scenario where 3 form climbed the potential at 2<z<4, successfully bridging late time and early time datasets. As the result the infamous H_0 tension is relieved from 5 sigma in the LambdaCDM model to 3 sigma in the 3 form model, without sacrificing the sigma-8 tension.

Parallel session 12 (Modified Gravity) / 99

Black holes in Lorentz-violating Gravity

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I will discuss black holes in the context of Einstein–aether and khronometric gravity —two closely related alternative theories of gravity that allow violations of local Lorentz invariance. Since these theories admit faster-than-light propagation, metric horizons are generically permeable and it is not clear whether proper black holes can exist; surprisingly, in some cases they do, thanks to the appearance of a new kind of "universal"horizon. I will review past and recent results on the topic, with a particular emphasis on rotating solutions.

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The abundance of primordial black holes

Author: Cristiano Germani[1]

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In this talk I will give an overview of the non-linear statistics of primordial black holes pointing out the importance of using the compaction function as the statistical variable.

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Gravitational Waves at Pulsar Timing Arrays and the Early Universe

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The recently reported evidence for Gravitational Waves (GWs) in PTA datasets leaves the question of whether the signal is astrophysical or coming from the Early Universe, in the latter case originating from physics beyond the Standard Model. In this talk I provide an overview of PTA results and discuss their relevance for the fundamental physics. Features of cosmological GW backgrounds that can help in addressing the origin of the signal will be discussed, as well as well-motivated scenarios that can be probed at PTAs.

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Gravitational microlensing with extended dark matter structures [remote]

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Many models of dark matter feature small scale substructure in the form of sub haloes, boson stars, or miniclusters. In this talk, I will describe how gravitational microlensing can be used to probe such models. In particular, I will explain how existing techniques used to constrain point-like objects (such as primordial black holes) can be adapted to find constraints on several different extended objects, using data from EROS-II, OGLE, and Subaru-HSC experiments. For particular mass distributions, such as those expected from boson stars, optical effects such as caustics imply a unique shape of the light curve, which may be looked for using machine learning methods. I will explain under what circumstances positive detections of such objects can be made and describe an ongoing analysis for their detection using the Vera Rubin Observatory's Legacy Survey of Space and Time.

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Space-time symmetry breaking and the mystery of dark matter

Author: João Magueijo[1]

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If 4D diffeomorphism invariance were to break down to 3D diffeomorphisms on the leaves of a preferred foliation something dramatic would happen to the Universe, even after full 4D diffeo symmetry is restored. The usual algebra of constraints of General Relativity
would feel the symmetry breaking effects for ever after the end of the symmetry breaking phase in the form of a leftover violation of the Hamiltonian constraint. We show that this violation can be seen as a form of dark matter, with the Dirac algebra and the geodesic nature of the foliation determining whether this is something almost equivalent to cold dark matter, or an entirely new beast altogether. Scenarios where this early tragedy in the life of the Universe comes to pass include the mainstream Horava-Lishitz gravity model but also theories with evolution in the laws of physics (in terms of global time variables generalizing 4-volume time in unimodular theories), or any other theory with global or Machian interactions. We provide examples of astrophysical implications.

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Searching for fifth forces and modifications of gravity

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Light scalar fields are often considered as part of explanations for dark energy and dark matter. They also appear in theories in which gravity is modified on cosmological scales. If the scalar field theory has a screening mechanism, the fifth forces that the scalar mediates can be significant in the cosmological vacuum but suppressed on Earth and in the solar system. I will discuss how this gives rise to novel signatures that could enable us to detect fifth forces, but also the challenges involved in making accurate theoretical predictions for these non-linear theories.

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Navigating the Perils of Affinesia

In this talk I will review some of the pathologies that typically arise in modified gravity theories. I will adopt a geometrical perspective to modifications of GR taking the Geometrical Trinity of Gravity as starting point and will mainly focus on teleparallel theories. In particular, I will discuss the unavoidable presence of ghosts in the so-called f(Q) theories. To end with a positive message, a class of ghost-free theories in the symmetric teleparallel framework that is based on a TDiff symmetry will be introduced.

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Merge many times

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The mergers we observe with LIGO and Virgo are ultimately driven by the emission of energy and angular momentum via gravitational waves. However, relativity alone is not sufficient to explain how compact objects pair and merge. For instance, black-hole binaries of ˜10Msun orbiting at separations >˜10Rsun will take more than a Hubble time to merge under gravitational radiation reaction. Additional mechanisms of astrophysical nature are needed to explain the LIGO/Virgo events. Conceiving plausible scenarios for the formation and evolution of binary black holes is a major industry in the field and still presents considerable challenges. But challenges reveal opportunities for discovery! I present an update on the formation-channel problem in gravitational-wave astronomy with a specific focus on hierarchical black-hole mergers. These provide, in my opinion, an orthogonal, but at the same time complementary, direction to the usual "field vs clusters"debate.

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Black hole binaries in an expanding Universe

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According to the Λ-Cold Dark Matter (ΛCDM) model, a positive cosmological constant explains the accelerated expansion of the Universe. We start by constructing a static solution of general relativity with a positive cosmological constant that consists of two (or more) static black holes whose gravitational attraction is balanced by the cosmic expansion of the de Sitter background. Then, we extend our analysis and establish the existence of stationary, spinning black binaries in a de Sitter universe and analyse their properties (there is no quadrupole momenta, no radiation). We consider identical black holes with either aligned or anti-aligned spins which maximize the spin-spin repulsion or attraction, respectively. We discuss the prospect that spin-spin interactions can stabilize the binaries. Our solutions establish continuous non-uniqueness in general relativity without matter (we have several solutions with the same cosmological entropy and angular momentum) for the first time in four dimensions. They evade assumptions of mathematical theorems that would otherwise rule out their existence. They also provide initial data for the spinning binary merger problem (when orbital angular momentum is added).

Parallel session 12 (Modified Gravity) / 108

On the torsion, nonmetricity & gauge invariance in the formulation of the gravitational field equation as an equation of state and in the laws of black hole thermodynamics

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This project has as its general objective the extension of the classical formulation of gravity, considering it not only as a geometric theory, but as a consequence of the laws of thermodynamics applied to accelerated observers. The general case involving curvature, torsion and non-metricity will be addressed, in the context of gauge theories of gravity, with emphasis on the complete generalization of Lovelock's theorem in four dimensions. Specific objectives include obtaining the generalized version of T. Jacobson's result, which identifies the gravitational interaction as a consequence of thermodynamics on Riemannian manifolds, considering not only curvature, but also torsion and non-metricity. Furthermore, we seek to completely generalize Lovelock's theorem in an arbitrary number of dimensions for non-Riemannian geometries. The results obtained in these two objectives will be compared to evaluate their implications. The project also proposes to search for analytical and numerical solutions of black holes for the class of theories of gravity that belong to both the generalized version of T. Jacobson's result and the generalized version of Lovelock's theorem in four dimensions, and that are also aligned with the gauge theories of gravity. The laws of black hole dynamics will be determined for this class of theories and the relationship between these laws and the laws of thermodynamics will be investigated. In summary, this project addresses a novel perspective on gravity, exploring its connection with the laws of thermodynamics and proposing significant generalizations within the framework of gauge theories, thus contributing to the advancement of the understanding of gravitational physics in broader contexts.