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Book of Abstracts

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Section I

Fifty years of the Hulse-Taylor pulsar

Author: Paulo Freire[1]

[1] *Max Planck Institute for Radio Astronomy*

Speaker: Paulo Freire

In this talk, I will recount the original discovery of the first binary pulsar, PSR B1913+16 at the Arecibo Observatory, and the subsequent timing observations and the major results to emerge from this study, which include a precise tests of strong-field gravity, the confirmation of the existence of gravitational waves and the indication that merging neutron stars throughout the Universe are important, both as a source of heavy elements and of detectable gravitational waves. This discovery was an important motivation for the subsequent construction of gravitational wave detectors. I will then discuss the immense progress that has happened since in the field of tests of gravity theories with radio pulsars, which include much more precise tests of gravity theories with the Double pulsar (PSR J0737-3039A/B system), with a wide range of pulsar - white dwarf systems and the test of the universality of free fall with a millisecond pulsar in a triple star systems. I conclude by highlighting some exciting prospects for the near future.

Exploring the stability of rapidly rotating hybrid stars and their collapse into black holes

Authors: Christoph Gärtlein; David Blaschke; Ilídio Pereira Lopes[1]; Oleksii Ivanytskyi[2]; Violetta Sagun[3]

[1] *CENTRA-IST*

[2] *University of Wroclaw*

[3] *University of Coimbra*

Speaker: Violetta Sagun

We study rotating neutron stars with a particular emphasis on the effect of fast spin on the deconfinement phase transition in their interiors. We demonstrate the impact of increasing rotational frequencies on the maximum gravitational mass, central energy density, angular momentum, and the rise of the nonaxisymmetric instability. Utilizing observational data from the fastest-spinning millisecond pulsars with measured masses, we have further constrained the properties of the quark phase, the rise of instability against oscillations, and the star's collapse into a black hole. These results have implications for the dense matter equation of state and the boundary between the lower mass gap and massive neutron stars.

The curious case of S62: The missing classical GR test in the Galactic Center

Author: Diogo Ribeiro

Speaker: Diogo Ribeiro

The supermassive black hole at the centre of our galaxy, Sagittarius A*, is surrounded by a dense cluster of young massive stars. Amongst these stars, the precise stellar astrometry and spectroscopy of the star S2 have been used to observe the gravitational redshift signature and the prograde relativistic precession in its orbit predicted by General Relativity. Closer in, The star S62 has been approaching the central milliarcseconds of our galaxy over the last few years. Its known trajectory tells us that the star will have its closest approach to the Super Massive Black Hole in June 2025 at an angular separation of just one milliarcsecond. This is the smallest projected distance for all known stars, making S62 the most promising lensing candidate near a SMBH. In this talk, I will present the current observational data of S62, discuss the prospects of measuring its lensing in 2025 and present the current joint theoretical and observational efforts employed by the GRAVITY collaboration to perform the missing classical GR test in the Galactic Center.

Penrose process driven by magnetic reconnection

Authors: Filippo Camilloni; Luciano Rezzolla[1]

[1] *Goethe University*

Speaker: Filippo Camilloni

Magnetic reconnection is an ubiquitous astrophysical phenomenon, with a number of astronomical observations, as well as numerical simulations, that are increasingly providing evidence of interesting dynamical effects when occurring around black holes. In this talk we present a general approach to the study of a Penrose process driven by plasmoids that are produced at reconnection sites along current sheets. Our approach is meant to determine the physical conditions that make a plasmoid-driven Penrose process energetically viable, and does not rely on ad-hoc prescriptions for the kinematics of the bulk plasma, that can either be in magnetohydrodynamical or force-free regimes. Moreover the approach we exploit is genuinely multidimensional and allows one to explore configurations outside the already explored equatorial plane. We show this with a concrete example: a magnetised torus, whose portion penetrating the ergosphere, that we dub "ergobelt", naturally provides a site to self-consistently compute the occurrence of reconnection and to estimate the energetics of a plasmoid-driven Penrose process.

Penrose process from BSW collisions

Authors: Duarte Feiteira; José P. S. Lemos; Oleg B. Zaslavskii

Speaker: José P. S. Lemos

The Penrose process uses the negative energy states of the ergosphere of a black hole to extract energy and deposit it at infinity. Originally, the process was realized in the decayment of one particle into two new particles. The BSW effect uses the properties of the event horizon to generate infinite center of mass energies in the collision of two incoming particles. In this work we determine the energetics of a Penrose process of two electrically charged particles suffering a BSW collision along the radial direction at the event horizon of an extremal Reissner-Nordström black hole. Specifically, several types of radial collisions can be considered, the most interesting one is between a critical particle, i.e., a particle that has its electric charge adjusted in a particular way to the other relevant parameters, and a usual particle, as it gives a divergent center of mass frame energy locally. A divergent center of mass frame energy at the point of collision is a favorable condition to extract energy from the black hole, but not sufficient, since, e.g., the product particles might go down the hole. To understand whether energy can be extracted or not in a Penrose process, we investigate in detail a collision between ingoing particles 1 and 2, from which particles 3 and 4 emerge, with the possibility that particle 3 can carry the energy extracted far out from the black hole horizon, i.e., there is a high Killing energy transported by particle 3. One finds that the mass, the energy, the electric charge, and the initial direction of motion of particle 3 can have different values, depending on the collision internal process itself. But, the different possible values of the parameters of the

emitted particle 3 lie within some range, and moreover the energy of particle 3 can, in some cases, be arbitrarily high but not infinite, characterizing a super-Penrose process. It is also shown that particle 4 lives in its own electric ergosphere with negative energy states while it exists, i.e., before being engulfed by the event horizon, as it is required in a Penrose process. The full background for this collisional Penrose process is a d dimensional extremal Reissner-Nordström black hole spacetime with negative, zero, or positive cosmological constant, i.e., an asymptotically anti-de Sitter, flat, or de Sitter spacetime.

Extreme mass-ratio inspirals into black holes surrounded by boson clouds

Author: Richard Pires Brito[1]

[1] *CENTRA, Instituto Superior Técnico*

Speaker: Richard Pires Brito

Boson clouds can form through superradiant instabilities of ultralight bosons around spinning black holes. The formation of boson clouds leads to a number of potentially detectable signatures, among them the possibility that they can affect the dynamics of binary black hole systems. In this talk I will review recent work aiming at studying extreme-mass-ratio systems in which a small compact object evolves around a massive black hole surrounded by a boson cloud.

Section II

The power of binary pulsars in testing Gauss-Bonnet gravity

Authors: Daniela Doneva[1]; Stoytcho Yazadjiev[1]

[1] *University of Tuebingen*

Speaker: Daniela Doneva

Binary pulsars are a powerful tool for probing strong gravity that still outperforms direct gravitational wave observations in a number of ways due to the remarkable accuracy of the pulsar timing. They can constrain the presence of additional charges of the orbiting neutron stars very precisely, leading to new channels of energy and angular momentum loss, such as scalar dipole radiation. In the present talk, I will review the existing constraints on theories beyond GR, focusing especially on the Gauss-Bonnet theories of gravity.

Black hole spontaneous scalarization in dynamical regime

Author: Stoytcho Yazadjiev[1]

[1] *Sofia University*

Speaker: Stoytcho Yazadjiev

In my talk I will discuss the black hole spontaneous scalarization in its dynamical regime within the scalar-Gauss-Bonnet gravity. Some of the basic ideas, results and astrophysical consequences will be presented.

Black holes with electroweak hair

Author: Romain Gervalle[1]

[1] *Institut Denis Poisson (Tours)*

Speaker: Romain Gervalle

In the framework of Einstein's General Relativity coupled with the Weinberg-Salam electroweak theory, we construct static, axially symmetric, and magnetically charged hairy black holes. Near the horizon, the strong magnetic field changes the structure of the electroweak vacuum, creating a ring-shaped condensate of massive W, Z and Higgs fields – an electroweak "hair". The condensate supports up to 22% of the total magnetic charge and contains loops of electric current. In the extremal limit, the horizon is surrounded in addition by a region where the Higgs field approaches zero, restoring the full electroweak symmetry. The mass of extremal solutions is less than the total charge, $M < |Q|$, which makes them energetically favored compared to the Reissner-Nordström solution with same charge, for which $M = |Q|$. As the charge increases, we observe a phase transition where the horizon geometry changes from spherical to oblate. At this point, the extremal black holes reach a size of the order of centimeters with an approximately terrestrial mass. They

may have originated from primordial black holes created in the early Universe and acquired a magnetic charge from the fluctuating ambient plasma. These black holes are appealing candidates for magnetic monopoles which do not require any new physics beyond the Standard Model and they should survive till today.

Self gravitating scalar field configurations around black holes

Author: Juan Carlos Degollado

Speaker: Juan Carlos Degollado

In this talk I will describe quasi-stationary solutions of the
Einstein-Klein-Gordon equations for a scalar field surrounding a black hole.
The solutions cover scales from; less than a Schwarzschild radius to several orders of
magnitude its value. These self gravitating gravitational
atoms are relevant in a wide range of masses, from ultralight to MeV dark
matter and for black holes ranging from primordial to supermassive.

Stability of Hairy Black Holes with scalar or Proca hair

Author: Jordan Nicoules

Speaker: Jordan Nicoules

We present some preliminary results about the stability of the Kerr Black Holes with Scalar Hair (KBHsSH) introduced by Herdeiro and Radu in 2014. These black holes admit a scalar hair, minimally coupled to gravity and solution to the massive Klein-Gordon equation, which has a harmonic dependence in time and in the azimuthal angle. This allows the metric sector to be stationary and axisymmetric. The KBHsSH can coexist with traditional Kerr Black Holes in a region of the parameter space, and should be entropically favored. On the other hand, spinning scalar Boson Stars have been shown to be unstable dynamically (Sanchis-Gual et al. 2019), which begs the question of the stability of the KBHsSH close to that limit. We thus perform fully non-linear 3D numerical evolutions to test the stability of KBHsSH, using the Einstein Toolkit numerical suite. We will present the first results that we obtained in both parts of the parameter space mentioned previously. Motivated by the qualitatively different behavior between spinning scalar and Proca Boson Stars, an ongoing line of work aims at performing similar numerical evolutions for Kerr Black Holes with Proca Hair (Herdeiro, Radu, Rúnarsson 2016).

Floating orbits and energy extraction from magnetized Kerr black holes

Author: João Sieiro dos Santos[1]

[1] *Instituto Superior Técnico, CENTRA*

Speaker: João Sieiro dos Santos

We look at the effect of including radiation in the dynamics of charged particles in circular orbit around weakly magnetized Kerr black holes. The magnetic field leads to the existence of very low frequency circular orbits in the equatorial plane. The radiation emitted by particles in these orbits can be amplified through superradiance. We show that, as a result of this amplification, particles can be frozen in floating orbits and even extract energy from the BH.

Axisymmetric Bosonic Stars: bifurcations with spherical bosonic stars

Authors: Chen Liang; Carlos Herdeiro; Eugen Radu

Speaker: Chen Liang

We study the bifurcation phenomena between spherical and axisymmetric bosonic stars. By numerically solving for the zero-modes of spherical bosonic stars under specific axially symmetric perturbations, we discover that excited state spherical bosonic stars bifurcate into two types of axisymmetric bosonic stars under $\ell = 2$ perturbations, with matter distributions resembling chains and rings, respectively. Meanwhile, $\ell = 4$ axisymmetric perturbations lead spherical scalar bosonic stars to bifurcate into a new type of axisymmetric bosonic stars, exhibiting a mixed chain-like and ring-like matter distribution, which we refer to as gyroscope-like. Additionally, for the first time, we have constructed chains of scalar bosonic stars with 7 constituents and their corresponding ring-like scalar bosonic stars. Our results provide an explanation for the bifurcations in bosonic stars from the perspective of perturbations, and by analyzing physical quantities such as quadrupoles and energy densities, we systematically discuss the impact of axisymmetric perturbations on spherical bosonic stars.

Section III

Self-interactions can (also) destabilize bosonic stars

Author: Marco Brito[1]

Co-authors: Carlos Herdeiro ; Nicolas Sanchis-Gual ; Etevaldo Costa ; Miguel Zilhão

[1] *Universidade de Aveiro*

Speaker: Marco Brito

We study the dynamical stability of Proca-Higgs stars, in spherical symmetry. These are solutions of the Einstein-Proca-Higgs model, which features a Higgs-like field coupled to a Proca field, both of which minimally coupled to the gravitational field. The corresponding stars can be regarded as Proca stars with self-interactions, while avoiding the hyperbolicity issues of self-interacting Einstein-Proca models. We report that these configurations are stable near the Proca limit in the candidate stable branches, but exhibit instabilities in certain parts of the parameter space, even in the candidate stable branches, regaining their stability for very strong self-interactions. This shows that for these models, unlike various examples of scalar boson stars, self-interactions can deteriorate, rather than improve, the dynamical robustness of bosonic stars.

Numerical relativity surrogate models for exotic compact objects: the case of head-on mergers of equal-mass Proca stars

Author: Raimon Luna[1]

[1] *University of Aveiro*

Speaker: Raimon Luna

We present several high-accuracy surrogate models for gravitational-wave signals from equal-mass head-on mergers of Proca stars, computed through the Newman-Penrose scalar ψ4. We also discuss the current state of the model extensions to mergers of Proca stars with different masses, and the particular challenges that these present. The models are divided in two main categories: two-stage and monolithic. In the two-stage models, a dimensional reduction algorithm is applied to embed the data in a reduced feature space, which is then interpolated in terms of the physical parameters. For the monolithic models, a single neural network is trained to predict the waveform from the input physical parameter. Our model displays mismatches below 10−3 with respect to the original numerical waveforms. Finally, we demonstrate the usage of our model in full Bayesian parameter inference through the accurate recovery of numerical relativity signals injected in zero-noise, together with the analysis of GW190521. For the latter, we observe excellent agreement with existing results that make use of full numerical relativity.

Spherical hyperboloidal evolutions in Generalized Harmonic Gauge

Author: Christian Peterson Bórquez

Speaker: Christian Peterson Bórquez

In this talk I will present successful numerical evolutions of the Generalized Harmonic Gauge formulation of General Relativity using hyperboloidal coordinates within the Dual-Foliation formalism, restricted to spherical symmetry. I will show how we can recover the expected physics at future null infinity from first principles. I will end by discussing formally singular terms appearing in the equations and how to deal with them.

Charged Scalar Field, Charged Black Holes, Charged Hyperboloidal Slices, What Else?

Authors: João Álvares; Alex Vañó-Viñuales[1]

[1] *Instituto Superior Técnico, CENTRA*

Speaker: João Álvares

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.

Modeling Relativistic Stars within Einstein-Vlasov-Boltzmann Theory

Author: Hannes Rüter[1]

[1] *CENTRA, Departamento de Física, Instituto Superior Técnico, Universidade de Lisboa*

Speaker: Hannes Rüter

Relativistic stars are typically modelled as ideal fluids. In this talk I discuss the numerical construction of solutions for spherical, relativistic stars at finite temperature 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 ideal fluid stars given by the Tolman-Oppenheimer-Volkoff solution.

Binary Black Holes in Circumbinary Disks as Multimessenger Sources

Authors: Inês Andrade Rainho; Milton Ruiz[1]; Roman Gold[2]; Ziri Younsi[3]

[1] *Universitat de València*

[2] *Ruprecht-Karls-Universität Heidelberg*

[3] *Mullard Space Science Laboratory, University College London*

Speaker: Inês Andrade Rainho

Astrophysics has undergone a transformative shift, fueled by groundbreaking observations such as the Event Horizon Telescope's imaging of the supermassive black holes M87 and SgrA and the advent of gravitational wave astronomy. These achievements underscore the need for advanced theoretical modeling to connect observations with the underlying physics. This talk explores the potential of binary black holes immersed in gaseous environments as sources of multimessenger signals, from fully relativistic magnetohydrodynamics (GRMHD) simulations to general relativistic radiative transfer (GRRT).

Gravitational waves and primordial black holes from supercooled phase transitions

Author: António Morais[1]

[1] *University of Aveiro*

Speaker: António Morais

We discuss strongly supercooled first-order phase transitions in conformal neutrino mass U(1) models. These transitions can generate a detectable stochastic gravitational wave background (SGWB) observable in a wide range of frequencies by LIGO, LISA, and the Einstein Telescope. Strong supercooling can also lead to primordial black hole (PBH) formation if the transition is sufficiently long-lasting. We explore the conditions under which an observable SGWB could be associated with PBHs constituting all dark matter, and discuss possible connections to the underlying high-energy physics.

Section IV

Figuring out the ancestors of LIGO-Virgo black holes

Author: Juan Calderon Bustillo[1]

Co-authors: Ania Liu [2]; Carlos Araujo-Alvarez [3]; Henry W.Y. Wong [2]

[1] *University of Santiago de Compostela*

[2] *The Chinese University of Hong Kong*

[3] *Canary Institute for Astrophysics*

Speaker: Juan Calderon Bustillo

Pair-instability supernova (PISN) prevents black-hole formation from stellar collapse within the approximate mass range $M \in [65, 130]M_{\odot}$. Such black holes may form hierarchically through merging ancestral black holes, whose properties determine those of the "child" one: mass, spin, and recoil velocity. Crucially, the child will leave its host environment if its "birth recoil" exceeds the corresponding escape velocity, preventing further mergers. I will present a Bayesian framework to obtain the masses and spins of the putative parents of the components black holes of LIGO-Virgo observations, as well as their putative birth recoil. With this, I will discuss the viability of such component black-holes as hierarchically formed depending on the properties of the host environment, focusing on the primary component of GW190521, which squarely populates the PISN gap.

Looking for ultralight scalars with LIGO-Virgo-KAGRA binaries

Author: Rodrigo Vicente

Speaker: Rodrigo Vicente

New ultralight (pseudo)scalar particles arise generically in extensions to the Standard Model. If their de Broglie wavelength is larger than the radii of compact objects (like black holes and neutron stars) they can form large-density halos around these objects, resembling a gravitational (hydrogen) atom. Building up the "gravitational chemistry": when their de Broglie wavelength is larger than the separation distance of compact binaries, they can form global states resembling a gravitational (ionized dihydrogen) molecule. In this talk, I will show that the current observations from the LIGO-Virgo-KAGRA collaboration can already be used to place stringent constraints on the presence of ultralight bosons around compact binary coalescences.

Wet Eccentric Extreme-Mass-Ratio Inspirals

Author: Francisco Duque[1]

[1] *Max Planck Institute for Gravitational Physics*

Speaker: Francisco Duque

In this talk, we discuss the evolution of eccentric, equatorial extreme-mass-ratio inspirals (EMRIs) immersed in the accretion disks of active galactic nuclei. We will see how single gravitational-wave

observations from these systems could provide measurements with ~ 10% relative precision of, simultaneously, the disk viscosity and mass accretion rate of the central supermassive black hole. This is possible when the EMRI transitions, within the observation time, from supersonic to subsonic motion relative to the disk gas, for eccentricities e >~ 0.025-0.1. The estimate of the accretion rate would assist in the identification of the EMRI's host galaxy, or the observation of a direct electromagnetic counterpart, improving the chances of using these sources as cosmological sirens. Our work highlights the rich phenomenology of binary evolution in astrophysical environments and the need to improve the modelling and analysis of these systems for future gravitational-wave astronomy.

Gravitational waves and galaxies cross-correlations: a forecast on GW biases for future detectors

Authors: Chris Clarkson[1]; José Fonseca[2]; Stefano Zazzera[3]; Tessa Baker[4]

[1] *University of Cape Town*

[2] *Institute of Astrophysics and Space Sciences*

[3] *Queen Mary University of London*

[4] *Institute of Cosmology and Gravitation*

Speaker: José Fonseca

Gravitational waves (GWs) have rapidly become important cosmological probes since their first detection in 2015. As the number of detected events continues to rise, upcoming instruments like the Einstein Telescope (ET) and Cosmic Explorer (CE) will observe millions of compact binary (CB) mergers. These detections, coupled with galaxy surveys by instruments such as DESI, Euclid, and the Vera Rubin Observatory, will provide unique information on the large-scale structure of the universe by cross-correlating GWs with the distribution of galaxies which host them. In this paper, we focus on how these cross-correlations constrain the clustering bias of GWs emitted by the coalescence of binary black holes (BBH). This parameter links BBHs to the underlying dark matter distribution, hence informing us how they populate galaxies. Using a multi-tracer approach, we forecast the precision of these measurements under different survey combinations. Our results indicate that current GW detectors will have limited precision, with measurement errors as high as ~ 50%. However, third-generation detectors like ET, when cross-correlated with LSST data, can improve clustering bias measurements to within 2.5%. Furthermore, we demonstrate that these cross-correlations can enable a percent-level measurement of the magnification lensing effect on GWs. Despite this, there is a degeneracy between magnification and evolution biases, which hinders the precision of both. This degeneracy is most effectively addressed by assuming knowledge of one bias or targeting an optimal redshift range of 1 < ⊠ < 2.5. Our analysis opens new avenues for studying the distribution of BBHs and testing the nature of gravity through large-scale structure.

Measuring the spacetime of SMBH with pulsar timing

Author: Zexin Hu

Speaker: Zexin Hu

Future observations with next-generation radio telescopes are expected to discover radio pulsars closely orbiting around Sagittarius A*(Sgr A)*, the supermassive black hole (SMBH) at our Galactic Center (GC). Such a system can provide a unique laboratory for measuring the spacetime of SMBH and testing gravity theories. We provide a numerical timing model for the pulsar-SMBH systems based on the post-Newtonian (PN) equation of motion and use it to explore the prospects of measuring the BH properties with pulsar timing. We forecast the measurement precision of BH spin and quadrupole moment and thus the test of the No-hair theorem in GR. We further investigate the possibility of probing the vector charge of Sgr A* in the bumblebee gravity model.

Section V

A simulation pipeline for nearly circular supermassive black hole binaries

Author: Hector Olivares[1]

[1] *Universidade de Aveiro*

Speaker: Hector Olivares

Simulation-based modeling has played a crucial role in the interpretation of very long baseline interferometry (VLBI) observations and gravitational wave detections. The experiments planned for the next dacades may deliver the first multimessenger observations of supermassive binary black holes (SMBBHs), bringing new challenges for numerical simulations. In this talk, we will discuss our efforts to build a simulation pipeline comprising general relativistic magnetohydrodynamic (GRMHD) simulations and general relativistic radiative transfer (GRRT) calculations. This pipeline is largely based on publicly available tools, making use of the spectral solver Kadath for the spacetime, the GRMHD code BHAC, and the GRRT code BHOSS. Our technique takes advantage of the the approximate helical symmetry of binary black hole spacetimes in advanced stages of the inspiral, reducing the computational cost associated to numerical relativity and GRMHD simulations, and allowing to evolve systems for long times, while accurately capturing general reltivistic dynamics. We will show the current status of the framework and discuss some applications to modeling SMBBH phenomenology.

Improvements on Casimir Wormholes

Author: Remo Garattini

Speaker: Remo Garattini

We describe the connection between a traversable wormhole and the Casimir effect. With the help of an equation of state we also discuss different forms of solutions related to the Casimir source. The effect of including an electromagnetic field, temperature and rotations to the original energy density are also discussed.

Spectroscopy of magnetized black holes and topological stars

Author: Marco Melis

Co-authors: Alexandru Dima [1]; Paolo Pani [1]

[1] *Sapienza University of Rome & INFN Roma1*

Speaker: Marco Melis

Among the various BH mimickers, fuzzballs provide a picture of classical BHs where the horizon emerges as a coarse-grained description of regular and horizonless microstates. However, the study of their stability and the corresponding spectral analysis is still rather involved.
On the other hand, Einstein-Maxwell theory in five dimensions admits magnetized black strings and

topological solitons, that upon four-dimensional compactification reduce to magnetized black holes ad topological stars (TSs). These solutions, while containing several ingredients of the aforementioned microstate geometries, are more tractable than the latter and constitute a useful toy model. We provide an analytical and numerical study of the stability and spectroscopy of these solutions under gravitational, electromagnetic and scalar perturbations, computing the quasi-normal modes (QNMs) spectrum in the full parameter space. We find that ultracompact topological stars exhibit long-lived trapped modes that give rise to echoes in the time-domain response.

Event horizon of a black hole merger in cubic gravity

Authors: Antonia M. Frassino; David Duarte Cesar Lopes; Jorge V. Rocha; João M. Dias; Valentin D. Paccoia

Speaker: David Duarte Cesar Lopes

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 derivative 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.

Black Hole Solutions in Non-Minimally Coupled Weyl Connection Gravity

Authors: M. Margarida Lima; Cláudio Gomes

Speaker: M. Margarida Lima

Schwarzschild and Reissner-Nordstrøm black hole solutions are found in the context of a non-minimal matter-curvature coupling with the Weyl connection, both in vacuum and in the presence of a cosmological constant-like matter content. This special case of non-metricity leads to black hole solutions with non-vanishing scalar curvature. Moreover, vacuum Schwarzschild solutions differ from the ones from a constant curvature scenario in f (R) theories with the appearance of a coefficient in the term linear in r and a corrected "cosmological constant". Non-vacuum Shwarzschild solutions have formally the same solutions as in the previous case with the exception being the physical interpretation of a cosmological constant as the source of the matter Lagrangian as not a simple reparametrization of the f (R) description. Reissner-Nordstrøm solutions cannot be found in vacuum, but only in the presence of matter fields, such that the solutions also differ from the constant curvature scenario in f (R) theories by the term linear in r and corrected/dressed charge and cosmological constant.

Rotating black holes in Einstein-Maxwell-dilaton theory

Authors: Etevaldo dos Santos Costa Filho[1]; Carlos Herdeiro; Eugen Radu

[1] *Universidade de Aveiro*

Speaker: Etevaldo dos Santos Costa Filho

The charged, rotating black holes (BHs) in Einstein-Maxwell-dilaton theory are known in closed form for two particular values of the dilaton coupling constant γ, while the solution with arbitrary γ is known in the limit of slow rotation, only. The spinning, charged BHs in this work are found by solving non-perturbatively the field equations, numerically. We present an overview of the parameter space of the solutions for several values of γ together with a study of their basic geometric and some phenomenological properties.

Section VI

Fifty years of Hawking radiation

Author: Tiago Vasques Fernandes

Speaker: Tiago Vasques Fernandes

In 1974, Hawking published a letter in Nature that initiated new and important lines of researches in gravitational physics. Using quantum field theory in a spacetime with collapsing matter, he obtained that black holes radiate as black bodies at a given temperature which depends on the black hole parameters, now known as the Hawking temperature. The detailed version of the Hawking radiation was published in 1975 in the journal Communications in Mathematical Physics. Bekenstein's earlier hypothesis that black holes are thermodynamic objects was thus put on firm ground. This outstanding work of Hawking, whose 50th anniversary we celebrate in the XVII Black Holes Workshop, constitutes one of the landmarks in the foundation of current frontiers of research, namely, quantum field theory in curved spacetimes, semiclassical gravity, and black hole thermodynamics. In this talk, I will give a review of Hawking radiation and a survey of the research that sprouted from this seminal work in its fifty years. I will venture into the challenges that are reserved for us in this area in the next fifty years.

Black holes after evaporation

Authors: David Matthew Hilditch; Valentin Boyanov

Speaker: Valentin Boyanov

We obtain and analyse dynamical solutions of the Einstein equations in spherical symmetry sourced by a classical electromagnetic field and a quantum scalar field, the contribution of the latter being encoded by the Renormalised Stress-Energy Tensor in the Polyakov approximation. The quantum state for the scalar is constructed as an "in" vacuum resulting from gravitational collapse, and the initial data for the geometry and the electromagnetic field is that if a Reissner-Nordström black hole. We analyse the rate of depletion of the trapped region, both from Hawking evaporation of the outer apparent horizon, as well as from an outward motion of the inner horizon. We also observe that a long-lived anti-trapped region forms below the inner horizon and slowly expands outward. A black-to-white-hole transition is thus obtained from purely semiclassical dynamics.

Quantum approach to radiation from falling charges into a Schwarzschild black hole

Authors: João Paulo Bessa Brito[1]; Rafael Bernar; Atsushi Higuchi[2]; Luís Carlos Bassalo Crispino[3]

[1] *Federal University of Para, Brazil*

[2] *University of York*

[3] *Federal University of Pará*

Speaker: Rafael Bernar

The detection of gravitational waves has ushered in a new era for general relativity, particularly in the study of black hole physics and other strong-field regimes. In this context, understanding the dynamics of fundamental fields near black holes is crucial. By analyzing the radiation emitted during these processes, one can extract signatures of the black hole and its surrounding matter. While a complete quantum theory of gravity remains an open challenge, quantum field theory in curved spacetimes provides an effective framework for studying quantum fields in a classical spacetime background. This approach has led to significant breakthroughs, such as the prediction of black hole radiation (Hawking radiation) and the observer-dependent nature of particles (the Unruh effect). In this work, we use quantum field theory at tree level to investigate electromagnetic radiation emitted by a charged particle in radial free fall towards a Schwarzschild black hole. This semiclassical analysis allows us to calculate one-particle emission amplitudes, which in turn yield the total energy released and the energy spectrum of the emitted radiation. We explore these quantities for particles with varying initial velocities and starting positions. Additionally, we extend our study to consider the case of a charged "string," falling into the black hole, offering further insights into this radiation setting.

Tidal Love numbers of black holes in anti-de Sitter

Authors: Antonia Frassino; Edgardo Franzin; Jorge Rocha

Speaker: Jorge Rocha

Tidal Love numbers in asymptotically flat spacetimes encode the response of compact objects to external gravitational perturbations, such as tidal fields, and impact the phase of gravitational waveforms from binary mergers. In asymptotically anti-de Sitter (AdS) spacetimes their relevance is entirely different: under the gauge-gravity duality, they are understood as linear response coefficients governing how plasmas polarize when the ambient geometry is deformed.

I will present results for the static tidal Love numbers of the Schwarzschild-AdS black hole computed using two different schemes. In contrast with their asymptotically flat counterparts, tidal Love numbers of AdS black holes do not vanish identically and they imply correlations between the polarization of the components of the plasma's stress-energy tensor and the curvature of the ambient space.

Elastic self-similar collapse

Author: Diogo Luís Farinha Gomes da Silva[1]

Co-author: Jorge Rocha

[1] *CENTRA - Instituto Superior Técnico*

Speaker: Diogo Luís Farinha Gomes da Silva

Critical phenomena in the context of general relativity is a topic that has garnered much interest in the last decades, revealing the laws governing black hole formation in the limit of small mass. To study these phenomena one can start by analyzing collapse solutions located exactly at the threshold of black hole formation, i.e., critical collapse, and apply perturbation methods. Critical collapse solutions for perfect fluids are well known and found to exhibit continuous self-similarity (CSS). In this talk I discuss the critical solutions for elastic matter models, more general, complex and realistic matter models, in spherical symmetry. I show that these solutions also exhibit CSS and how the dynamics vary and are allowed a richer profile as elasticity is introduced and tuned. I also show how elastic behavior directly contributes to the development of shock waves.

Electromagnetized Black Holes and Swirling Backgrounds in Non-linear Electrodynamics: The ModMax case

Author: Adolfo Cisterna[1]

[1] *Institute of Theoretical Physics, Charles University*

Speaker: Adolfo Cisterna

This work focuses on constructing electromagnetized black holes and vortex-like backgrounds within the framework of the ModMax theory–the unique nonlinear extension of Maxwell's theory that preserves conformal symmetry and electromagnetic duality invariance. We begin by constructing the Melvin-Bonnor electromagnetic universe in ModMax through a limiting procedure that connects the spacetime of two charged accelerating black holes with that of a gravitating homogeneous electromagnetic field. Building on this result, we proceed to construct the Schwarzschild and C-metric Melvin-Bonnor black holes within the ModMax theory, representing the first black hole solutions embedded in an electromagnetic universe in the context of nonlinear electrodynamics. While the characteristics of the Melvin-Bonnor spacetime and some of its black hole extensions have been widely examined, we demonstrate for the first time that the Schwarzschild-Melvin-Bonnor configuration exhibits an unusual Kerr-Schild representation. Following this direction, we also unveil a novel Kerr-Schild construction for the spacetime of two accelerating black holes, drawing on the intrinsic relationship between the Melvin-Bonnor spacetime and the C-metric. Finally, we expand the spectrum of exact gravitational solutions within Einstein-ModMax theory by constructing a vortex-like background that coexists with the Melvin-Bonnor universe. In this process, the Taub-NUT spacetime in ModMax has played a crucial role. We present this Taub-NUT solution in a different gauge that facilitates the comparison with the Melvin-Bonnor-Swirling case.

Section VII

The Godel Spacetime and Closed Timelike Curves

Author: Francisco Lobo

Speaker: Francisco Lobo

Kurt Godel in 1949 discovered an exact solution to the Einstein field equations (EFEs) of a uniformly rotating universe containing dust and a nonzero cosmological constant. It is interesting to note that the Godel spacetime generates closed timelike curves, thus posing challenges to the concept of causality. Given that causality is central to the formulation of physical theories, the prospect of time travel and the resulting paradoxes demands careful scrutiny. This presentation will address these critical issues in detail, in particular, in the context of the Godel spacetime.

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

Authors: Filipe Costa; José Natário

Speaker: Filipe Costa

In 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 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.
Realistic examples of gravitomagnetic lensing effects will be displayed for a Kerr black hole, contrasting with the Schwarzschild case, in particular in what pertains to the Einstein rings.

Stationary equilibrium torus supported by Weyssenhoff ideal spin fluid around Kerr Black holes

Author: Sergio Gimeno-Soler[1]

[1] *University of Aveiro*

Speaker: Sergio Gimeno-Soler

We present non-self-gravitating, geometrically thick torus solutions described by a Weyssenhoff ideal spin fluid in a rotating black hole spacetime. The Weyssenhoff spin fluid shares the same symmetries of the background geometry, i.e., stationarity and axisymmetry. We further assume that the alignment of the spin is perpendicular to the equatorial plane. Under this setup, we determine the integrability conditions of the general relativistic momentum conservation equation of Weyssenhoff ideal spin fluid using the Frenkel spin supplementary condition. We then present equilibrium solutions of the spin fluid torus with constant specific angular momentum distributions around Kerr black holes by numerically solving the general relativistic momentum conservation equation. Our study reveals that the isobaric surfaces of the tori get significantly modified in comparison to an ideal

fluid torus, due to the presence of the spin tensor and its coupling to the Riemann curvature tensor. We also put some constraints on the model and on the values of the s_0 parameter that controls the magnitude of the spin angular momentum of the fluid.

Static boson stars in the Einstein-Friedberg-Lee-Sirlin theory and their astrophysical images

Authors: Pedro Lucas Brito de Sá[1]; HAROLDO CILAS DUARTE LIMA JUNIOR[2]; Carlos Herdeiro; Luís Carlos Bassalo Crispino[1]

[1] *Federal University of Pará*

[2] *Federal University of Maranhão*

Speaker: HAROLDO CILAS DUARTE LIMA JUNIOR

Boson stars are non-topological solitonic solutions that stand as robust viable candidates for horizonless black hole mimickers. They are linearly stable in some regions of their parameter space, and additionally admit a robust formation mechanism dubbed as *gravitational cooling*. The pioneering work on boson star solutions dates back to 1968 with the studies of Kaup, where he obtained the boson star solutions in the context of GR in the presence of a complex scalar field with a potential without self interaction terms, known nowadays as mini-boson stars. After that, boson star solutions for different sorts of potentials were studied in the literature. We investigate the static boson star solutions in the so-called Einstein-Friedberg-Lee-Sirlin (E-FLS) theory, performing a complete analysis of the solution space in this model. We study the phenomenological aspects of E-FLS stars, for instance, by investigating the timelike and null geodesics with an emphasis on the analysis of circular timelike orbits and light rings. In order to study the astrophysical signatures of such stars, their images were obtained considering them surrounded by a geometrically thin accretion disk. Our results comprise two different models of accretion disks, namely the optically thin and optically thick disk models. We present a selection of our findings for the astrophysical images of E-FLS stars and discuss their relevance as a possible black hole mimicker.

Polarimetry imprints of hot spots orbiting boson stars

Author: João Luís Rosa[1]

[1] *University of Gdansk*

Speaker: João Luís Rosa

We use the polarized ray-tracing software GYOTO 2.0 to simulate the orbits of isotropically emitting hot spots around solitonic boson star configurations with different compacticities, and obtain the Stokes parameters describing the flux intensity and the Q-U parameters. Two observables can be built with these parameters, namely the Electric Vector Position Angle (EVPA) and the Q-U loops on the observer's screen. We produce these observables for every boson star configuration and compare them with their counterparts in the Schwarzschild spacetime. Our results indicate that these observables can be used to distinguish between a compact boson star and a black-hole, even in situations of extreme compactness for which the optical observables of black-holes are closely mimicked by the boson star.

Geodesic completeness of effective null geodesics in regular spacetimes with non-linear electrodynamics

Author: Merce Guerrero[1]

[1] *University of Aveiro*

Speaker: Merce Guerrero

We study the completeness of light trajectories in certain spherically symmetric regular geometries found in Palatini theories of gravity threaded by non-linear (electromagnetic) fields, which makes their propagation to happen along geodesics of an effective metric. Two types of geodesic restoration mechanisms are employed: by pushing the focal point to infinite affine distance, thus unreachable in finite time by any sets of geodesics, or by the presence of a defocusing surface associated to the development of a wormhole throat. We discuss several examples of such geometries to conclude the completeness of all such effective paths.

Section VIII

A new model of spontaneous scalarization induced by curvature and matter

Author: Zakaria Belkhadria[1]

[1] *Université de Genève / Università di Cagliari / GWSC/ INFN*

Speaker: Zakaria Belkhadria

This presentation explores scalarized black hole solutions in Einstein-Maxwell-Scalar (EMS) gravity and a newly developed model of scalarization induced by curvature and matter. Our work introduces novel solutions, with a focus on mixed scalarization phenomena. In EMS gravity, we investigate the coexistence of spontaneous and non-linear scalarization, demonstrating how their interplay is influenced by specific coupling constants, including cases where scalarization is effectively quenched. For the generalized scalarization model, we incorporate both curvature and matter couplings, addressing stability issues and modifying bifurcation thresholds. Utilizing advanced numerical methods, we analyze asymptotically flat scalarized black holes, emphasizing horizon properties, scalar field behavior, and thermodynamic characteristics such as temperature and entropy. These findings provide deeper insights into the scalarization process, its observational implications, and its role in extending our understanding of black hole solutions in modified theories of gravity.

The effect of resummation in AdS black holes.

Authors: Julian Barragan Amado[1]; Shankhadeep Chakrabortty; Arpit Maurya

[1] *Universidade de Lisboa*

Speaker: Julian Barragan Amado

The study of linear scalar perturbations in AdS_5 black holes typically reduces to the analysis of ODEs of the Heun-type. Recently, the connection coefficients of the Heun equation have been computed in terms of the Nekrasov-Shatashvili (NS) free energy of an $SU(2)$ supersymmetric gauge theory with four fundamental hypermultiplets. Using the exact form of these connection coefficients and summing over the instanton contributions of the NS function, we present asymptotic expansions in the small horizon limit for the retarded Green's function and the greybody factor in asymptotically AdS black holes. This talk is based on joint work with Shankhadeep Chakrabortty and Arpit Maurya.

The canonical ensemble of a self-gravitating matter thin shell in asymptotically AdS

Authors: Francisco José Gandum[1]; Jose P. S. Lemos; Tiago Vasques Fernandes

[1] *Instituto Superior Técnico*

Speaker: Francisco José Gandum

We consider the canonical ensemble of a spherically symmetric,self-gravitating thin shell of hot quantum matter in an asymptotically anti-de Sitter space. We employ the Euclidean path integral approach to quantum gravity via York framework to determine, in the zero loop approximation, the partition function. The whole analysis yields promptly the mechanics and the thermodynamics of the space as well as its stability. We give to the matter in the shell a barotropic equation of state, and assume that the entropy goes with a power law on the mass of the shell. We find the equilibrium shell spaces and their mechanical and thermal stability. We then compare the hot thin shell Euclidean action with the Hawking-Page black hole action in order to study the possible phase transitions between these two thermodynamic states. We find a first order phase transition, namely, for sufficiently low temperatures the hot shell state is favorable, otherwise the black hole dominates the ensemble.

A new look at energy extraction from charged black holes via particle collisions

Author: Filip Hejda

Speaker: Filip Hejda

Near-horizon, high-energy test particle collisions should be the ideal ingredient for collisional Penrose process. Thus, the observation by Bañados, Silk and West that particles coming from rest at infinity may collide with arbitrarily high centre-of-mass energy near the horizon of a maximally spinning black hole gained a lot of attention. Unfortunately, the energy that can be extracted through such an event turned out to be subject to an unconditional upper bound. On the other hand, such a bound does not exist for an analogous effect in the vicinity of a maximally charged black hole, which is however much less realistic. We remedied this impossible dilemma by combining the two variants and showing that the upper bound is absent whenever both the black hole and the ejected particle are charged, regardless of how small the black hole charge might be [PhysRevD.105.024014]. Nevertheless, this result was still limited to extremal black holes, and thus we generalise the analysis to subextremal cases. In the present talk, we focus on the simplified case of Reissner-Nordström spacetime. We found that with deviation from extremality, the possibility of significant energy extraction remains, whereas the possibility to produce new particles with arbitrarily high mass is severely hindered. This indicates that collisional Penrose process can in principle be responsible for production of powerful cosmic rays, but is unlikely to serve as a probe of new particle physics.

Observational properties of hot-spots orbiting relativistic fluid spheres

Authors: Hanna Liis Tamm[1]; João Luís Rosa[2]

[1] *University of Tartu*

[2] *University of Gdansk*

Speaker: Hanna Liis Tamm

In this work we analyze the observational properties of relativistic fluid spheres when orbited by isotropically emitting sources, known as hot spots, and comment on the polarizational imprints. We consider fluid star configurations in four different regimes of compacticity, from the Buchdahl limit to non-ultra compact solutions, thus obtaining fluid stars with qualitatively different geodesic structures and observational properties. We show that the observational properties for fluid stars at the Buchdahl limit are qualitatively similar to the ones for the Schwarzschild black hole, whereas for more dilute configurations one can find observational properties similar to other fundamentally different models e.g. bosonic star configurations with and without self interactions. For solutions with a radius in the range $2.25M < R < 3M$, where M is the total mass of the fluid star, the presence of a

light-ring (LR) pair, which becomes degenerate at R=3M, leads to the appearance of additional observational signatures e.g. secondary images and LR contributions, which allow one to distinguish these models from their black-hole counterparts. Fluid star configurations supported by thin shells are also analyzed and it is proven that the stability of the inner LR is increased for these solutions, resulting in a non-differentiable extremum in the effective potential of the photons. Our results suggest that compact fluid star configurations provide a suitable and physically relevant alternative to the black-hole scenario in accordance with the current generation of observational experiments.