XVIII Black Holes Workshop
Book of Abstracts

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Instituto Superior Técnico

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Contents

Day 1 - 1st Morning session

Ten years testing the nature of compact objects through gravitational-wave astronomy: from GW150914 to GW250114

Juan Calderon Bustillo
IGFAE, University of Santiago de Compostela

Over the past decade, gravitational-wave astronomy has transformed from a theoretical ambition into a mature observational field. Advanced LIGO, Virgo, and KAGRA have now detected hundreds of compact binary mergers, enabling breakthroughs across fundamental physics, astrophysics, and cosmology. Among the most profound advances is the ability to test General Relativity in the strong-field, highly dynamical regime. Since the first constraints obtained from GW150914, the field has progressed toward increasingly precise analyses, culminating in state-of-the-art tests using GW250114, the loudest event recorded to date. In this talk, I will discuss this scientific evolution, highlighting how our ability to probe the nature of gravity and compact objects has advanced between these two milestones, with particular emphasis on the development and maturation of black-hole spectroscopy.

Estimating the Hubble constant from the mock GW data of Einstein Telescope

Pinaki Roy
University of Warsaw

The Hubble constant is a crucial cosmological parameter that is a measure of the rate of change of the cosmic scale factor per unit cosmic scale factor i.e. $\dot{a}/a$. There is a considerable discrepancy between the measurements of the Hubble constant from standard candle observations and those from cosmic microwave background (CMB) observations. Data from gravitational wave (GW) events can provide an independent constraint on the Hubble constant. Higher the number of events, the stronger is the constraint. A tight constraint is expected to be achieved in the era of the third generation detectors such as the Einstein Telescope (ET). Without relying on any electromagnetic observation, one can either use the double black hole (BH) merger or the double neutron star (NS) merger detections to break the mass-redshift degeneracy. We present a method of estimating the Hubble parameter using

ET mock data for binary coalescence events and discuss the challenges. We assume flat cosmology in our analysis.

Binary Black Hole Initial Data with Gravitational Wave content

João Carlos Gomes Rebelo

In this talk I start by exposing the failure to capture the gravitational radiation of binary black holes in initial data used to model wave signals within numerical relativity. Currently, the most common approach involves conformally flat initial data, which successfully models the black holes but not the generated radiation in the far zone at the initial time. With this in mind, I give a possible solution based on adding radiative content derived from a Post-Newtonian approximation. This solution implies the need for a past-history evolution of the binary, which can be done with a simple Hamiltonian system derived from the Post-Newtonian Hamiltonian. The solution was implemented in the numerical relativity code Spectre, where the constructed initial data is constraint-solved within the XCTS formalism, and then evolved using a generalized-harmonic formulation. The generated radiation is then extracted using CCE. After presenting the details of the implementation, I show results of tests where the initial-data radiation was correctly evolved. I then finalize by discussing the current problems to be solved, namely the boundary conditions for the constraint solve and the matching between initial-data and evolution-generated radiation.

Impact of Magnetic Field Topology on Electromagnetic and Gravitational Waves from Binary Neutron Star Merger Remnants

Inês Rainho
Universitat de València

I will present general relativistic magnetohydrodynamic simulations of binary neutron star mergers exploring four magnetic field topologies: a dipolar pulsar-like configuration, a mixed poloidal–toroidal interior field, and two new hybrid topologies that transition from a mixed core to a pulsar-like exterior at $0.95\,R_{\mathrm{NS}}$ and $0.5\,R_{\mathrm{NS}}$. The binaries are evolved with the SLy and WFF1 equations of state and ADM masses of 2.7 and 2.6 $M_\odot$, respectively, and include an additional lower-mass SLy case producing a long-lived remnant. We analyze the post-merger dynamics and emission, focusing on gravitational-wave spectra, remnant oscillations, and convective stability. The results show (1) the first assessment of convective stability in magnetized remnants, (2) a distinct secondary gravitational-wave peak in pulsar-like configurations from nonlinear coupling of $m = 0$ and $m = 2$ modes, and (3) a strong dependence of gravitational-wave properties on magnetic topology. The latter suggests that nearby ($\lesssim 50\,\mathrm{Mpc}$) events could allow future detectors to constrain the magnetic structure of neutron stars.

Collisions of Black Holes in Einstein-Maxwell-Scalar Theory

Robin Croft
Sapienza, Università di Roma

Black Holes (BH) in Einstein-Maxwell-Scalar Theory (EMS) are a hairy BH solution who's hair is sourced by a specific coupling between electromagnetism and a scalar field. In certain finite regions of parameter space these solutions display an effective potential with a double peak (a.k.a. a well) which supports echoes. In this talk we will discuss our work (in progress) with numerical simulations of EMS BH headon collisions as a probe of gravitational wave echoes.

A finite element framework for stationary solutions in curved spacetime

Romain Gervalle
University of Aveiro

We present a new numerical framework for constructing stationary, axially symmetric solutions in curved spacetime and efficiently computing their key physical properties. The code is based on the finite element solver FreeFem, which requires the field equations to be expressed in their weak (variational) form. We introduce this formalism in the context of gravitational systems and illustrate its applications to the construction of rotating boson stars and hairy black holes. The code is parallelized to achieve fast and accurate solutions, is publicly available on Git, and can be readily adapted to new problems. We also discuss possible extensions and future developments.

A kinetic theory model for relativistic stars

Hannes Rüter
CENTRA - Instituto Superior Técnico

I present a model to evolve spherical stars within full kinetic theory by solving the relativistic Vlasov-Boltzmann equation coupled to the Einstein field equations. The Vlasov-Boltzmann equation allows to fully consistently model matter out of thermal equilibrium, overcoming the restrictions of ideal and near-ideal fluid models typically used for neutron stars. I will discuss the spectral discretisation method that helps to cope with the six-dimensional phase space of the Vlasov-Boltzmann equation. Furthermore I will present some physical results that are enabled by the model.

Twist and higher modes of a complex scalar field at the threshold of collapse

Krinio Marouda

CENTRA, Instituto Superior Tecnico

We investigate the gravitational collapse of a massless complex scalar field in axisymmetric spacetimes under a fixed azimuthal symmetry ansatz, allowing for non-zero twist and angular momentum. Extending previous work to higher angular modes, we employ the pseudospectral code bamps together with a newly developed symmetry-reduction scheme (m-cartoon method) and a twist-compatible apparent horizon finder to evolve near-critical configurations. In this talk, I will present an overview of the results reported in arXiv:2511.04649. Our analysis focuses on the role of angular momentum in shaping the picture of the threshold of collapse in axisymmetry, as well as the possibility of extremal black hole solutions emerging at the critical regime in this model.

Day 1 - 2nd Morning session

Critical collapse of gravitational wave initial data in Axisymmetry

Ananya Adhikari

CENTRA, Instituto Superior Tecnico

Extreme spacetimes at the threshold of gravitational collapse and black hole formation exhibit unique and fascinating behaviors referred to as critical phenomena. While extensive studies have been conducted on the critical phenomena of the gravitational collapse in spherical symmetry, the behavior of such spacetimes when departing from this symmetry is an intensely active field of research in numerical relativity. A principal challenge in this context is the difficulty of comparing results from different computational programs, which has hindered the ability to reach vetted and confident conclusions about the critical phenomena of vacuum spacetimes in the absence of spherical symmetry. Recently, due to improved numerical techniques and the resultant higher accuracy of simulations, it has become possible to make advancements in comparing computational results from different packages. Additionally, it has become possible to explore new families of gravitational wave initial data and tune a parameter of the system towards the threshold of black hole formation. In this talk, we present some of our recent initial efforts towards comparing results from the 'prague' and 'bamps' codes when evolving Teukolsky wave initial data in axisymmetry. We study the behavior of the system in both the subcritical and supercritical limits, and discuss the challenges that remain in finding horizons in the supercritical regimes. Additionally, we also present some initial results from evolving axisymmetric twisting Brill wave initial data, which has not been studied extensively in the past.

Extreme mass-ratio inspirals into Newtonian Proca stars

João Bernardo dos Santos Silva
CENTRA, Instituto Superior Tecnico

Massive bosonic fields can form self-gravitating solitonic structures, which for vector fields are known as Proca stars. For ultralight fields, these structures can describe the cores of dark matter haloes surrounding the supermassive black holes at the center of galaxies. It has been argued that future gravitational-wave detectors might be able to probe the properties of dark matter structures. So far, however, analyses considering ultralight dark matter have focused mainly on massive scalar fields. In this work, we study how Proca stars respond to a perturbing small object inspiralling within their interior, in the Newtonian limit. We consider both spherically symmetric Proca stars and the non-spherically symmetric ground state solutions. We compute the total energy lost by the inspiralling object and compare it with the case in which the bosonic star is composed of a massive scalar field. Our results show that the response of the bosonic structure depends on the nature of the underlying field and provides a first step toward fully relativistic computations of extreme mass-ratio inspirals into Proca stars. In this talk, in addition to presenting our results, I will emphasize the importance of studying such systems in the search for physics beyond the Standard Model, as well as their potential detectability by the upcoming LISA mission.

Relativistic effects in extreme-mass-ratio inspirals in scalar clouds: eccentric and inclined orbits

Qixuan Xu
CENTRA, Instituto Superior Tecnico

We study extreme-mass-ratio inspirals (EMRIs) in scalar clouds including orbital inclination and eccentricity. We also assess the importance of relativistic effects. EMRIs are binary systems in which a stellar-mass compact object spirals into a supermassive black hole, and are key sources for space-based gravitational wave detectors like LISA. Recent studies have explored EMRIs within scalar clouds formed via superradiant instabilities around rotating black holes. Building upon prior work, we extend the analysis to include the effects of eccentricity and orbital inclination on the dynamics of EMRIs in such environments. We employ a fully relativistic framework to assess how these orbital parameters influence energy loss through scalar radiation and gravitational waves.

Geodesic Chaos in Stationary Spacetimes: Numerical Study of Test-Particle Motion in a Black Hole Metric Perturbed by a Rotating Thin Disc

Claudia Caputo

Charles University, Prague

Motivated by the complex phenomena occurring in the vicinity of accreting black holes, this study revisits how additional matter distorts otherwise integrable geodesic motion. Whereas most earlier work considered static, axisymmetric configurations, real accretion discs rotate and drag the surrounding spacetime. To quantify the dynamical impact of this rotation-induced frame dragging, we examine test-particle trajectories in a Schwarzschild black hole perturbed by a rotating thin disc. High-order Runge–Kutta integration is employed to construct Poincaré sections while systematically varying the disc's specific angular momentum. Chaoticity is characterised using several Lyapunov indicators—finite-time exponents, FLI, and MEGNO—and a global estimator, the Kolmogorov–Sinai entropy, computed for each resulting phase-space portrait. Finally, we assess the potential bias introduced by the disc's idealised sharp edges, underscoring the importance of smooth-edge models in future analyses.

Extreme-mass-ratio inspirals in a relativistic accretion disc

Francisco Duque

Max Planck Institute for Gravitational Physics (Albert Einstein Institute)

In this talk, we will present a fully relativistic model for the interaction and orbital evolution of extreme-mass-ratio inspirals (EMRIs) embedded in active galactic nucleus (AGN) accretion disks. Our analysis shows that relativistic corrections can significantly modify the disk-driven torques on the EMRI in the strong-field regime, enhancing their magnitude by several orders and even reversing their sign as the orbit approaches the ISCO. These relativistic corrections also modify the radial dependence of the torque to a level that is comparable to LISA's measurement precision. Thus, observations of these systems by LISA could give unique access to the mid-plane gas physics of accretion discs, which is inaccessible to electromagnetic observations. We will end by discussing practical challenges for this in the context of the LISA global fit necessary to simultaneously extract the $\sim 10^7$ overlapping sources in the instrument's data stream.

Orbital perturbation theory in Schwarzschild space-time

Oleksii Yanchyshen

ZARM, University of Bremen / University College Dublin

The osculating elements technique provides a powerful tool for describing the motion of celestial bodies in space. The LISA mission will offer an opportunity to study gravitational waves from extreme mass ratio inspirals (EMRIs), making accurate orbital models essential. I will present a general relativistic perturbation scheme for osculating elements, describing orbits under the influence of a perturbing force in a Schwarzschild space-time, formulated in terms of Weierstrass elliptic functions. I will also give examples of "toy-model" external forces and show linearized solutions of the corresponding osculating elements equations.

There and back again: outspiralling motion in non-Kerr compact objects

Manuel Gonçalo Oliveira Mariano

Universidade de Aveiro

In Keplerian dynamics, a test body orbiting a point particle in circular motion has a monotonically increasing frequency, with decreasing radius. If a dissipative channel is introduced, such as gravitational wave (GW) emission, (say) under the quadrupole approximation, the corresponding GW strain has an ever increasing frequency with time. A similar statement holds for equatorial motion of a test particle on the Kerr manifold, except such inspiral is cut off at the ISCO, wherein stable circular orbits cease to exist and a plunge is expected. We analyse circular timelike orbits in generic spinning spacetimes and study the conditions in which exotic motion can occur, arising from non-Kerr features. In particular, we derive conditions under which an inspiral towards a compact object is naturally followed by an outspiral motion, and give concrete examples, as well as the corresponding GW phenomenology. This analysis serves both as a theoretical exploration of non-Kerrness and as an example of a concrete smoking gun of exotic spacetimes.

Radio orbiting a black hole

Filipe Pereira dos Santos
CENTRA

We study how the radiation emitted by an electromagnetic dipole is modulated when it orbits a rotating uncharged black hole. We use black hole perturbation theory, allowing for the dipole to be misaligned with the spin of the black hole, to analytically compute the frequencies excited in this setup, as well as the associated amplitudes. We then obtain the electromagnetic wave signal and energy fluxes by numerically solving the radial Teukolsky equation. Our results, which agree with the literature in the appropriate limits, show that the signal produced is extremely rich, with clear signatures of gravitational lensing, Doppler shifts, and beaming. To our knowledge, this is the first model of electromagnetic wave generation and propagation from a moving dipole source in curved spacetime developed from first principles.

Primordial Black Holes in Modified Gravity

Serdar Yildiz
KU Leuven

In this talk I will explore the nonlinear dynamics of cosmological oscillons in the early Universe and discuss whether modified gravity could trigger their collapse into primordial black holes (PBHs). Oscillons, which are long-lived and spatially localized configurations of scalar fields, naturally emerge in a broad class of inflationary models and can reach large overdensities during post-inflationary evolution. In standard General Relativity these overdensities remain subcritical and do not form black holes. I will instead consider Einstein–scalar–Gauss–Bonnet modified gravity and examine, through ongoing numerical work, how the Gauss–Bonnet coupling may alter oscillon self-gravity and influence the growth (or accelerated decay) of these overdensities. This framework aims to clarify under what conditions modified gravity might facilitate oscillon collapse into primordial black holes. The broader implications connect to dark-matter scenarios, early-Universe structure formation, and potential gravitational-wave signatures of beyond-GR dynamics.

Day 1 - 1st Afternoon session

Regular black holes without mass-inflation instability and gravastars from modified gravity

Pedro G. S. Fernandes

University of Heidelberg

In this talk, we derive regular black-hole solutions, including the Hayward metric, from four-dimensional action principles involving vector fields in addition to the metric. These black holes possess additional hair associated with the vector fields, manifesting as free integration constants that regularize the geometry. These constants can be chosen such that regular black holes of all masses are extremal. As a result, they have vanishing surface gravity and are not susceptible to mass-inflation instability. We also discover another regular black-hole metric with these properties, which constitutes a gravastar for an appropriate choice of integration constant.

Energy Conditions in Non-Minimally Coupled Weyl Connection Gravity

Margarida Lima

CAMGSD/IST & UAzores

Non-Minimally Coupled Weyl Connection Gravity is based on the idea that the geometry of spacetime is not fully determined by the metric. Instead, it incorporates a Weyl connection with its own non-metricity vector, so that parallel transport and curvature are governed by a richer geometric structure. In this framework, the non-metricity field becomes dynamical and directly influences the gravitational sector, contributing to the field equations and modifying the effective curvature terms. This model introduces an additional force term, which can mimic both dark matter and dark energy effects, while simultaneously retaining Weyl's original motivation of unifying gravity and electromagnetism. Indeed, Schwarzschild-like and Reissner–Nordstrom-like black hole solutions exist, leading to new features, such as an additional horizon, due to the non-metricity vector. We then examine how the classical energy conditions should be formulated in the presence of Weyl's non-metricity, analyze the corresponding modifications to the Raychaudhuri equation, and discuss how these considerations can constrain the additional parameters introduced by the model.

Gravity with higher-curvature terms and second-order field equations: $f(R)$ meets Gauss-Bonnet

Andrea Pierfrancesco Sanna

INFN Sezione di Roma 1

General Relativity (GR) is expected to break down in the high-curvature regime. Beyond effective field theories with higher-order operators, it is crucial to identify consistent nonperturbative theories including higher-curvature terms. Two well-studied cases are f(R) gravity and Einstein–dilaton–Gauss–Bonnet (EdGB) gravity. The former shares GR's vacuum solutions, while the latter faces well-posedness issues in the strong-coupling regime. Combining them naturally extends EdGB gravity to include arbitrary higher-curvature terms, yielding genuinely new phenomena beyond simple superposition. Focusing on quadratic and quartic corrections, we analyze black hole solutions and discuss how higher-order terms modify their geometry and interior and affect the theory's well-posedness in the strong-field regime.

Superradiance in Einstein-Gauss-Bonnet gravity with Born-Infeld electrodynamics

Oskar Borgvall González

Instituto Superior Técnico

In string theory, a natural low energy effective action is the Einstein-Gauss-Bonnet gravity, in which a Gauss-Bonnet term accompanies the usual Einstein-Hilbert action. Born-Infeld electrodynamics arises when considering an Abelian gauge field coupled to the open bosonic string or open superstring. In this talk, we analyze the superradiant behavior of a massive, charged scalar field coupled to a spherically symmetric, charged black hole solution within this modified theory of gravity, and compare with the classical Reisnner-Nordström solution. We show how this setup gives rise to a different phenomenology than in the classical case. In particular, the absorption cross section of a charged scalar field can be unbounded from below for certain parameter ranges, a phenomenon only studied previously for the Ayón-Beato-García regular black hole. Lastly, we will analyze the presence of long-lived quasi-normal modes, whose existance is implied by resonances in the absorption cross section at specific frequencies.

New model of spontaneous scalarization of black holes induced by curvature and matter

Zakaria Belkhadria

Université de Genève/ Università di Cagliari

Spontaneous scalarization is a mechanism that allows black holes to develop a non-trivial profile of a scalar field "scalar hair" because of tachyonic instabilities, enabling tests of gravity beyond General Relativity. Motivated by stability and threshold issues in Gauss-Bonnet scalarization, we propose a new model characterized by two nonminimal couplings of the scalar field to both Gauss-Bonnet curvature and a U(1) gauge field (e.g. electromagnetic field). The presence of two distinct sources of tachyonic instability broadens the conditions for spontaneous scalarization. We track how the electric charge and the coupling constants govern the onset of the scalar field and derive new solution branches with nontrivial scalar profiles. Numerical integration shows multiple coexisting scalarized black hole solutions with adjustable thresholds, influenced by the relative strengths of curvature and matter couplings. We examine their scalar charge, horizon properties, and thermodynamic characteristics, demonstrating how the model can selectively activate or suppress scalarization phenomena. The matter source term modifies the scalarization onset and promotes stable solutions, as indicated by the evolution of the scalar charge and horizon quantities. These findings suggest an alternative approach to scalarization, may avoid the instabilities of curvature-only or matter-only models, and offer new ways to test strong-gravity effects in upcoming observations.

Instabilities of Black Holes with Resonant Hair

José Pedro Mota Valente Ferreira

Universidade de Aveiro

We study the stability of black holes with resonant scalar hair in the context of Einstein-Maxwell-scalar models. Using numerical relativity techniques, we explore the nonlinear evolution of these solutions. The results suggests that these solutions are dynamically unstable, evolving towards bald black holes through two distinct decay mechanisms. We analyze the timescales associated with these instabilities across different regions of parameter space. These findings suggest that such decay mechanisms may be a more general feature, and could be found in related models.

Stability of Hairy Black Holes with scalar or Proca hair: An update

Jordan Gaëtan Nicoules
Universidade de Aveiro

I will give an update on our results regarding numerical evolutions of hairy Black Holes, with scalar hair (BHsSH) and Proca hair (BHsPH). Those were introduced respectively by Herdeiro and Radu in 2014, and Herdeiro, Radu, Rúnarsson in 2016. These black holes admit a massive bosonic hair minimally coupled to gravity which has a harmonic dependence in time and in the azimuthal angle. This allows the metric sector to be stationary and axisymmetric. They have two noteworthy limits: boson clouds around Kerr Black Holes and spinning Bosonic Stars. The latter have been shown to be unstable dynamically in the scalar case (Sanchis-Gual et al. 2019), which begs the question of the stability of the BHsSH close to that limit, and if/how the behavior is altered while exploring the parameter space. Moreover, since spinning scalar boson stars and Proca stars have different stability properties, we may expect different outcomes for BHsSH and BHsPH. To investigate these questions, we thus perform fully non-linear 3D numerical evolutions using the Einstein Toolkit numerical suite and present the corresponding results.

Two Kerr Black Holes in Equilibrium with Self-Interacting Scalar Hair

Chen Liang
Universidade de Aveiro

Axially symmetric static double-black hole (2BH) configurations can be constructed as Weyl solutions. However, conical singularities along the symmetry axis prevent gravitational collapse of these systems. We study asymptotically flat spinning 2BHs with self-interacting scalar hair, which can be regarded as dipolar spinning boson stars (DsBSs) with two horizons, one located at the center of each component. These 2BHs are constructed based on a generalized Weyl framework. The coupling to the scalar field removes the conical singularities, yielding the 2BHs that are regular on and outside both horizons. We investigate the effect of quartic self-interactions on these configurations. Additionally, we examine DsBSs with a single horizon positioned between the two components—single Kerr black holes with self-interacting odd-parity scalar hair. As the self-coupling strength increases, these single hairy Kerr black holes become "hairier" while their horizons cannot become heavier.

Bosonic stars in the astrophysical environment

Hector Raul Olivares Sanchez

Universidade de Aveiro

Bosonic stars are among the most theoretically well-developed exotic compact objects proposed as black hole mimickers, and are motivated by several extensions to general relativity and the standard model of particle physics. Understanding their possible interactions with the astrophysical environment is essential both for assessing their viability as mimickers and to identify potential distinguishing signatures. Here we examine their observational properties in the electromagnetic channel, focusing on two scenarios: (i) a stellar-mass bosonic star in a binary system with a solar type companion, and (ii) a supermassive bosonic star at the center of a galaxy. Our results can be applied to systems such as Gaia BH1 and some of the targets of the Event Horizon Telescope.

Stability and collisions of excited spherical boson stars: glimpses of chains and rings

Marco Brito

Universidade de Aveiro

Scalar, spherically symmetric, radially excited boson stars were previously shown to be stabilized, against spherical dynamics, by sufficiently strong self-interactions. Here, we further test their stability now in a full 3+1D evolution. We show that the stable stars in the former case become afflicted by a non-spherical instability. Then, we perform head-on collisions of both (stable) fundamental and (sufficiently long-lived) excited boson stars. Depending on the stars chosen, either a black hole or a bosonic remnant are possible. In particular, collisions of excited stars result in a bosonic bound state which resembles a dynamical superposition of chains and rings, akin to the ones found as equilibrium solutions in JHEP 03, 119 (2025). These evolutions emphasize a key difference concerning the dynamical robustness of fundamental vs. excited spherical boson stars, when generic (beyond spherical) dynamics is considered.

From Scalar Clouds around Black Holes to Boson Stars

Daniel Neves
CFisUC

We study, for the first time, the evolution of a scalar cloud bound to an evaporating black hole. Our simulations of the associated Schrödinger-Poisson system for non-relativistic and spherically symmetric clouds reveal that a scalar cloud may (partially) survive as a self-gravitating boson star if the black hole evaporates adiabatically until its mass becomes less than one half of the cloud's mass. This yields a novel mechanism for boson star formation and shows that, as previously conjectured, bosonic dark matter production by light primordial black holes may result in micro-boson stars with very large occupation numbers, greatly enhancing their potential detectability even for very weakly interacting dark matter particles.

On the uniqueness of the Kerr-(A)dS metric as a type II(D) solution in six dimensions

Marcello Ortaggio
Institute of Mathematics, Czech Academy of Sciences

We present the classification of six-dimensional Lambda-vacuum spacetimes which admit a non-degenerate multiple Weyl aligned null direction with a generic optical matrix, and subject to an assumption on the asymptotic fall-off of the Weyl tensor. The most general metric is specified by one discrete and three continuous parameters, it is of type D, and belongs to both the Kerr-Schild and the general doubly-spinning Kerr-NUT-(A)dS classes. In passing, we comment on its Kerr-Schild double copy.

Day 1 - 2nd Afternoon session

Lagrangian reverse-engineering for regular black holes

Ana Bokulić
University of Aveiro

Before turning to the quantum gravity framework, it is worth exploring the possibility of black hole regularisation using classical matter fields. Nonlinear modifications of Maxwell's theory, collectively known as nonlinear electrodynamics (NLE), are among the potential candidates for resolving black hole singularities. A commonly used approach for generating regular black hole solutions is the "reverse-engineering" procedure, which enables the reconstruction of an electromagnetic Lagrangian starting from a chosen metric. However, this method often leads to physically unrealistic Lagrangians that are either inconsistent with Maxwell's weak field limit or exhibit other limitations. In this talk, we present a regular, magnetically charged black hole, for which the reverse-engineered NLE Lagrangian reduces to the Euler-Heisenberg theory in the weak field limit [arXiv:2311.17151].

Constraints on regular black holes with nonlinear electromagnetic fields

Ivica Smolić
Department of Physics, Faculty of Science, University of Zagreb

We know, both from high-energy experiments and from quantum field theoretic predictions, that Maxwell's electromagnetism is not a complete description of electromagnetic phenomena in nature, and that one needs to consider its extensions, the so-called nonlinear electromagnetic (NLE) theories. Over the past quarter century, significant effort has been devoted to the study of gravitating electromagnetic fields. The search for regular black holes with NLE fields has produced numerous candidates, each exhibiting certain virtues but often accompanied by notable drawbacks. In this talk, we shall discuss recent results that place severe constraints on this objective, either through inconsistency with Maxwell's weak field limit [arXiv:2206.07064] or through restricted relations between black hole mass and charges [arXiv:2510.23711].

From Stars to Regular Black Holes

Aitor Vicente-Cano
ICCUB - University of Barcelona

It has been recently shown that the Schwarzschild black hole singularity is generically resolved in $D \geq 4$ spacetime dimensions by the introduction of certain string theory-inspired infinite towers of higher-curvature corrections to the Einstein-Hilbert action. In such theories, Birkhoff's theorem holds, and the collapse of matter has been shown to lead to the formation of regular black holes.

In my talk, I will present two idealized spherically symmetric configurations of matter within this framework. The first corresponds to the analogue of the Oppenheimer–Snyder collapse of dust stars in these theories, where the final stage is an eternal cycle of collapse, bounce, expansion, and re-collapse, repeating indefinitely instead of ending in a singularity. The second case involves static stars; specifically, I will show, using plots, how the maximum compactness limit for constant-density stars — i.e., Buchdahl's limit — is modified by higher-curvature corrections, together with other new exotic bounds that appear within this framework.

Collisional Penrose process and the black hole's environment

Filip Hejda
CENTRA, IST, Lisbon & CEICO, FZU, Prague

Although Penrose process has been a popular example of a mechanism to extract energy from black holes since its discovery, the understanding of its astrophysical context remains far from settled. This is underscored by the recent appearance of various high-profile works debating whether corotating or counterrotating accretion disk can provide feeding mechanism for high-energy particle collisions or considering a plasmoid-driven variant of the Penrose process. However, presence of accreting plasma around black holes is also accompanied by electromagnetic fields. Various models show that interaction of a black hole with a surrounding magnetic field leads to charge accretion, which will further alter the workings of the Penrose process for charged microscopic particles. While influence of electromagnetic field has been studied extensively for particle disintegrations by Dadhich and collaborators and and also for particle collisions in the limit of fine-tuned processes around extremal black holes admitting arbitrarily small charge [PhysRevD.105.024014], a lot of interesting cases still has not been covered. The purpose of this talk is to present the ongoing work to fill this gap.

General approach to BSW effect: nonequatorial particle motion and presence of force

Oleg Zaslavskii

V. N. Karazin National University, Kharkov, Ukraine

If two particles move towards a black hole and collide in the vicinity of the horizon, under certain conditions their energy $E_{c.m.}$ in the center of mass frame can grow unbounded. This is the Banados-Silk-West (BSW) effect. Usually, this effect is considered for extremal horizons and geodesic (or electrogedesic) trajectories. We study conditions under which this effect appears in a more general context, namely when both general geometric (such as generic axially symmetric rotating black holes) and dynamic factors (such as an action of force of a generic nature) are taken into account. Our analysis is valid for a horizon of any kind (nonextremal, extremal and ultraextremal). Our general classification of possible trajectories that include so-called usual, subcritical, critical and ultracritical ones shows when the BSW effect is present. We find when the finiteness of a force and the BSW effect are compatible with each other. It is shown that nonequatorial motion does not alter our main conclusions. Authors: H. V. Ovcharenko and O. B. Zaslavskii.

Backreaction effects in a recursive Penrose process in Reissner-Nordström-AdS black hole spacetimes

Duarte Feiteira

University of Helsinki

The Penrose process for the decay of electrically charged particles in a Reissner-Nordström-anti-de Sitter black hole spacetime is studied, considering backreaction effects on the black hole's mass and electric charge. It is considered a recursive decay process, imposed by the presence of a reflective mirror or the AdS outer turning point. The effects of backreaction on the black hole itself and the consequences on the recursive Penrose process are studied for these two confinement methods.

On Folding Calabi-Yau Diagrams in M-theory and Black Holes

Adil Belhaj

Mohammed V University in Rabat

We discuss five-dimensional supersymmetric black branes in the context of the M-theory compactification on a special Calabi-Yau manifold called tetra-quadric, being realized as complete intersections of homogeneous polynomials in certain projective spaces. Combining colored graph theory and outer-automorphism group action techniques, we study the tetra-quadric Calabi-Yau diagram leading to new features. Using a procedure referred to as folding, we reveal that M-theory black branes on the tetra-quadric Calabi-Yau manifold can be reduced to known compactifications with lower dimensional Kähler moduli spaces.

Day 2 - 1st Morning session

Understanding the black hole ring-down using numerical relativity

Xisco Jimenez Forteza
Universitat de les Illes Balears

The black hole ring-down phase, describing the relaxation of a perturbed black hole into its stationary state, provides a unique window into the dynamics of spacetime and the nature of gravity in the strong-field regime. In this work, we investigate the ring-down process using numerical relativity simulations, focusing on the extraction and characterization of quasi-normal modes (QNMs) from the late-time evolution of perturbed black holes. By solving the relevant wave equations on curved backgrounds, we explore the interplay between the near-horizon dynamics and the asymptotic gravitational waveform. Our results elucidate how the amplitude and frequency content of the ring-down encode information about the black hole's mass, spin, and potential deviations from general relativity. This study contributes to a deeper theoretical understanding of gravitational wave signals observed by LIGO–Virgo–KAGRA and supports the use of ring-down analysis as a probe of black hole spectroscopy.

How to play a black hole

Lucía Vélez Tartajo
Center of Gravity, Niels Bohr Institute

Black hole spectroscopy is a vibrant field of research with significant potential to uncover new physics. Despite its importance and development over the last years, very little is known about how the different characteristic modes of black holes, called quasinormal modes, are excited, and how this relates to the physics of light rings. In this project we study the excitation of the quasinormal modes as function of the initial data, trying to find how this excitation depends on the different parameters of the initial conditions or even on the coordinate systems used.

Quasinormal modes and excitation factors of Kerr black holes

Leart Sabani

Center of Gravity, Niels Bohr Institute

Theoretical understanding of the characteristic oscillations of a perturbed black hole, also referred to as quasinormal modes (QNMs), is crucial to interpreting the late stage of binary black hole mergers that we now routinely observe in gravitational wave detectors. In this talk I will introduce a new approach, based on the generalized Sasaki-Nakamura formalism, to compute the QNM spectra and their excitation factors (QNEFs), for scalar, electromagnetic, and gravitational perturbations. Using this approach, QNM wave functions remain finite at the horizon and spatial infinity.

Quasinormal Ringing of Kerr Black Holes from an Equatorial Plunge

Laura Pezzella

Gran Sasso Science Institute

Quasinormal modes (QNMs) are the characteristic complex frequencies that govern the ringdown phase of a black hole merger. While their frequencies depend only on the properties of the remnant, the strength with which different modes are excited is determined by the merger dynamics and remains poorly understood. Improving our knowledge of QNM excitation is key to maximizing the science return of black hole spectroscopy with current and future gravitational-wave detectors. In this talk, I will examine the excitation of QNMs of Kerr black holes by a point particle plunging from the innermost stable circular orbit along a critical equatorial trajectory. Using the frequency-domain Sasaki–Nakamura formalism, we compute the excitation coefficients of individual modes and analyze how they vary with the final black hole spin. I will present trends that identify which modes dominate the ringdown as the spin increases, clarifying the connection between plunge dynamics and QNM excitation. These results provide new insight into the relative mode amplitudes expected in realistic merger scenarios, with implications for parameter estimation and precision tests of general relativity.

Black Hole Ringdown Amplitudescopy

Francesco Crescimbeni
Sapienza, University of Rome

Black hole ringdowns in extensions of General Relativity (GR) generically exhibit two distinct signatures: (1) theory-dependent shifts in the standard black-hole quasinormal modes, and (2) addi- tional modes arising from extra fundamental fields – such as scalar, vector, or tensor degrees of free- dom – that can also contribute to the gravitational-wave signal. As recently argued, in general both effects are present simultaneously, and accurately modeling them is essential for robust tests of GR in the ringdown regime. In this work, we investigate the impact of extra field-induced modes, which are often neglected in standard ringdown analyses, on the interpretation of gravitational-wave sig- nals. To provide some concrete examples, we focus on dynamical Chern-Simons and Einstein-scalar- Gauss-Bonnet theories, well-motivated extensions of GR, characterized respectively by a parity-odd and a parity-even coupling between a dynamical scalar field and quadratic curvature invariants. We show that including extra field-induced modes improves the bounds on these theories compared to standard spectroscopy and also allows for equally constraining complementary tests not based on quasinormal mode shifts. Our analysis highlights the relevance of incorporating extra field-induced modes in ringdown templates and assesses their potential to either bias or enhance constraints on GR deviations.

Exploring Amplitude and Tail Properties in the Ringdown Using Numerical Linear Perturbation Theory

Alejandro Svyatkovskyy Kholyavka
University of the Balearic Islands

The ringdown phase of perturbed black holes provides a clean theoretical window into the strong-field regime of General Relativity. After a disturbance, the gravitational-wave signal is dominated at intermediate times by a superposition of quasi-normal modes (QNMs), whose frequencies and damping times depend only on the mass and spin of the black hole. In this work, we study how different types of initial perturbations affect the excitation of these modes. We consider two representative families: head-on–type Gaussian profiles, in which the width controls the balance between high- and low-frequency components, and quasi-circular–type Gaussians modulated by an orbital frequency, mimicking inspiraling binaries. Our analysis shows a strong dependence of the late-time behaviour on the structure of the initial data. Narrow, localized profiles preferentially excite high-frequency content and tend to suppress the development of power-law tails, whereas broader or frequency-modulated perturbations enhance low-frequency components and give rise to clearer tail decays consistent with Price's law. We quantify the onset of the tail regime and extract decay exponents in excellent agreement with theoretical predictions. Finally, by examining the interplay between fundamental and overtone

QNMs and their transition into the tail phase, we identify characteristic signatures that may serve as useful diagnostics for numerical-relativity simulations.

Solving the Teukolsky Equation with Spectral Methods

Tiago Pedro Moura Valente
CENTRA - Instituto Superior Técnico (ULisboa)

General Relativity is to this date the best theory of gravity we have and probing the very nature of Black Holes is possible through events such as Gravitational Waves. In our work we describe our time-domain solver of the 1+1D homogeneous Teukolsky equation, an equation that encodes the physics of linear perturbations in Kerr spacetime. We solve it in hyperboloidal slices to be able to extract the signals at future null infinity without the need for extrapolation. To do so we developed a code that employs two different kinds of spectral methods: a known pseudo-spectral scheme with collocation and a novel fully spectral scheme without collocation. With this second approach we obtain more accurate late-time power-law tails, as well as their decay rates, and we have achieved results for negative spin-weights without the use of quad precision that many suggest is necessary. Our results are in agreement with analytical and empirical generalizations of Price's Law for Kerr Black Holes. The time-integrator that we use is implicit and it shows advantages relative to the more usual explicit integrators mainly in terms of efficiency, but possibly also in terms of accuracy whenever we introduce source terms into the equation. Thus, our work marks a first step to solve the full Teukolsky system and thus evolve Extreme-Mass Ratio Inspirals simulations more accurately and efficiently.

Teukolsky by Design: A Hybrid Spectral-PINN solver for Kerr Quasinormal Modes

Alexandre Pombo
Institute of Physics of the Czech Academy of Sciences

We introduce `SpectralPINN`, a hybrid pseudo-spectral/physics-informed neural network (PINN) solver for Kerr quasinormal modes that targets the Teukolsky equation in both the separated (radial/angular) and joint two-dimensional formulations. The solver replaces standard neural activation functions with Chebyshev polynomials of the first kind and supports both soft – via loss penalties – and hard – enforced by analytic masks – implementations of Leaver's normalization. Benchmarking against Leaver's continued-fraction method shows cumulative (real+imaginary part) relative frequency errors of $\sim 0.001\%$ for the separated formulation with hard normalization, $\sim 0.1\%$ for both the soft separated and soft joint formulations, and $\sim 0.01\%$ for the hard joint case. Exploiting our ability to solve the joint equation, we add a small quadrupolar perturbation to the Teukolsky operator, effectively rendering the problem non-separable. The resulting perturbed quasinormal modes are compared against the expected precision of the Einstein Telescope, allowing us to

constrain the magnitude of the perturbation. These proof-of-concept results demonstrate that hybrid spectral-PINN solvers can provide a flexible pathway to quasi-normal spectra in settings where separability, asymptotics, or field content become more intricate and high accuracy is required.

Non-selfadjoint dynamics in black hole hyperboloidal foliations: quasinormal mode expansions and non-modal transients

Jérémy Besson

AEI Max Planck, IMB Université Bourgogne Europe

Evolution systems driven by non-normal operators present dissipative dynamical features absent in conservative systems. The general framework for the study of such non-conservative systems is given in terms of i) the spectral theory of non-selfadjoint operators and ii) its transient non-modal analysis. They constitute complementary spectral and time-domain descriptions of the non-conservative dynamics. For example, in a gravitational setting, the choice of a hyperboloidal slicing casts the dynamics of scattered fields on a background spacetime (with outgoing boundary conditions, e.g. black holes) into an evolution problem whose infinitesimal time generator is a non-selfadjoint operator. In this talk, we focus on the so-called Keldysh expansion of the resolvent that permits to express time-evolved fields as quasinormal mode expansions — with quasinormal frequencies characterised as eigenvalues of the non-selfadjoint operator (see point i above) — and, if time permits, we will present non-modal transients (ii above).

Day 2 - 2nd Morning session

Spectroscopy of Accelerated Black Holes

Francisco Lourenço Silva
Faculdade de Ciências da Universidade de Lisboa (FCUL)

In this presentation, we study the spectroscopic properties of accelerated black hole spacetimes, described by the C-metric. In particular, we compute the shadow radius, the greybody factors, and the quasinormal modes (QNMs) in the eikonal limit for a test scalar field in this background. We argue that these results remain valid for perturbations of other spins, differing only at the next-to-leading order in the QNM frequency. Both the charged and uncharged cases are considered, and the final expressions are written solely as functions of the black hole's acceleration, mass, and charge. We further show that, although acceleration breaks the spherical symmetry of the spacetime, the correspondence between QNMs in the eikonal limit and circular lightlike geodesics still holds. Joint work with Filipe Moura.

A greybody-factor approach to modeling black hole ringdown

Romeo Felice Rosato
Sapienza, University of Rome

The quasinormal mode spectrum plays a crucial role in modeling post-merger ringdown signals in binary coalescences, encompassing both black holes and ultra-compact horizonless objects. However, quasinormal modes are highly sensitive to small deformations of the system and only describe the linear response within a limited and imprecisely defined timeframe after the merger. Motivated by a recently discovered connection between greybody factors and post-merger black-hole signals, we investigate greybody factors as gravitational observables, providing a complementary and robust alternative to quasinormal modes. We show that greybody factors remain stable under small perturbations and are unaffected by several ambiguities that undermine the reliability of the QNM-based description. Moreover, we test this greybody-factor–based framework against a broad selection of numerical-relativity waveforms from the SXS catalog, focusing on comparable-mass coalescences with generic spins. By extracting and fitting the frequency-domain ringdown signal across the catalog, we analyze how the model parameters vary throughout the binary parameter space. This enables us to assess the domain of validity of

the greybody-factor model, identify systematic trends linked to binary parameters, and evaluate its potential applicability as an alternative ringdown parametrization in gravitational-wave data analysis. Based on: https://arxiv.org/abs/2406.01692, https://arxiv.org/abs/2501.16433, forthcoming works.

Stability and ringdown analysis of the $\mathcal{W}$-soliton

Marco Melis

Sapienza, University of Rome

Among the large variety of exotic compact objects, $\mathcal{W}$-solitons stand out as smooth, horizonless geometries in five-dimensional supergravity that carry the same mass and charges as four-dimensional Reissner–Nordström-like black holes, yet replacing the horizon with a Kaluza–Klein bubble. Their quasinormal modes reveal how far such microstate candidates can mimic true black holes. For test scalar perturbations, the spectrum is governed by a single unstable photon sphere, producing a clean, short-lived ringdown with no echoes or long-lived modes from stable light rings. Time-domain evolutions show a BH–like waveform, but with shifts in frequencies and damping times over a wide range of charges. These deviations are compatible with current bounds and potentially resolvable by near-future ringdown spectroscopy, offering a concrete target for testing smooth BH microstates with gravitational waves.

Echoes of the Black Hole Microstructure

Alexandru Dima

Università "Sapienza" di Roma

The LIGO-VIRGO-KAGRA observations are so far compatible with the Kerr black hole paradigm, though they cannot rule out entirely the existence of black hole mimickers. These are ultra-compact objects that reproduce some observable properties of black holes, while possibly predicting characteristic signatures such as non-trivial tidal deformability and/or repeated gravitational wave echoes in the ringdown. An interesting class of compact objects called "topological solitons" consists in regular and horizonless solutions to five-dimensional Einstein-Maxwell theory, which resemble static black holes upon reduction to four dimensions. These mimickers can also serve as a classical toy model for black-hole microstate geometries constructed in the "fuzzball" program. In this talk we will present our latest results concerning the linear response of topological solitons with a focus on their characteristic spectrum, gravitational wave echoes and (linear) stability.

Effective Quantum Spacetimes From Functional Renormalization Group

Mirko Pitzalis

University of Cagliari and INFN Sezione di Cagliari

We construct effective spacetime geometries by self consistently deforming the classical Schwarzschild-de Sitter solution. This has been done in the context of the Functional Renormalization Group Asymptotic Safe program by exploring how quantum modifications induced by the running of the Newton and Cosmological constants impact the infrared and ultraviolet regimes of the modified solution. The quantum corrections, stemming from the flow of the coupling constants, give rise to two new regimes. Firstly, a phase transition AdS/dS occurs in the UV regime, when the mass of the object exceeds a critical threshold. Secondly, we predict the formation of horizons whenever the mass of the object is of the order of the Planck mass.

Thermodynamics of hot curved space in the canonical ensemble and black hole nucleation

Tiago Vasques Fernandes

CENTRA, Instituto Superior Técnico

We consider the canonical ensemble of self-gravitating radiation perfect fluid inside a cavity, through the Euclidean path integral approach in the zero loop approximation. We first restrict the path integral to the hypersurface where the Einstein constraints are satisfied, allowing us to obtain the solution that extremizes the action and its stability along such hypersuface. We obtain that the solution should obey the TOV equation while both thermodynamic stability and mechanical stability can be envisioned by a single differential condition. We have computed the modes obeying the stability condition, showing that there is a thermodynamic stable branch of the solution. With the stable solution, the free energy of the system is obtained, from which the entropy, the pressure and the energy can be calculated. We then study the possible phase transitions between the stable self-gravitating radiation and York's stable black hole solution. We show that there is a phase transition from the radiation phase to the black hole phase depending on the scale of the cavity, thus having black hole nucleation.

Canonical ensemble of a self-gravitating matter thin shell in a cavity in AdS space

Francisco José Gandum Mexia Pinheiro
CENTRA, Instituto Superior Técnico

We consider the canonical ensemble of a spherically symmetric, self-gravitating thin shell of hot quantum matter in a space with a negative cosmological constant and a finite boundary. We employ the Euclidean path integral approach to quantum gravity via York's framework to determine, in the zero-loop approximation, the partition function. The whole analysis promptly yields the mechanics and the thermodynamics of the system and 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 Euclidean action of the shell solution with the black hole to study the possible phase transitions between these thermodynamic states. Under reasonable conditions, we find a first-order phase transition: at sufficiently low temperatures, the hot shell is favored, while at higher temperatures, the black hole dominates the ensemble.

Gravitational collapse at the boundary

Pau Solé Vilaró
ICCUB - University of Barcelona

Holography has successfully been used to study the dynamics of strongly coupled gauge theories as they evolve over time in a fixed spacetime. However, in these cases the metric on the field theory side is taken to be non-dynamical. This implies that the framework is not suitable to be used in dynamical contexts, such as in cosmology or astrophysics, thereby limiting the potential of the correspondence. In this work, we attempt to extend the holographic framework to the most dramatic dynamical scenario possible: a gravitational collapse. We construct a model and present a procedure to simulate a gravitational collapse from an ideal fluid on the boundary in an FLRW background. The fluid/gravity correspondence is then used to approximate the corresponding bulk metric data dual to the simulated collapse. Finally, the bulk causal structure is studied, revealing the dynamical formation of a black funnel as the initial planar black hole is gradually perturbed, eventua lly reaching the boundary and opening up to relax into the characteristic funnel shape. The entropy density at the boundary is identified with that obtained using the area density of the apparent horizon in the bulk.

Love Numbers in Confining and Deconfining AdS Phases

Jéssica Gonçalves
Institute of Cosmos Sciences - University of Barcelona (ICCUB)

The Hawking–Page phase transition between the AdS-soliton and the AdS black brane provides a holographic realization of a confinement–deconfinement transition, with the soliton favoured at low temperatures and the black brane dominant at high temperatures. Understanding how these two phases respond to deformations of the boundary geometry sheds light on the linear response of the dual plasma. Tidal Love numbers provide a quantitative measure of this response by characterizing the change in the stress-energy tensor induced by boundary metric perturbations. In this talk, I will give an overview of the setup, computation and present some results for the static tidal Love numbers of the AdS-soliton and the AdS black brane with a compactified spatial dimension, commenting on the implications for the dual field theory.

Day 2 - 1st Afternoon session

Modeling X-ray Reflection Spectra from Returning Radiation in Black Hole Binaries

Kostas Kourmpetis

Institute of Cosmos Sciences - University of Barcelona (ICCUB)

X-ray reflection spectroscopy is a powerful tool for exploring the innermost regions of accreting black hole systems. The X-ray spectra of black hole X-ray binaries (XRBs) typically consist of three components: thermal emission from the accretion disk, Comptonized emission from a hot corona, and a reflection component resulting from the illumination of the disk by the corona. Modeling the reflection features provides key information about the black hole's spin and disk's parameters. A phenomenon known as returning radiation (i.e. disk emission that is bent back onto it by the black hole's strong gravity), can significantly affect the reflection spectra, particularly for sources in the high-soft state. However, current XSPEC reflection models do not fully account for this effect. We present a new reflection model that self-consistently includes returning radiation. To isolate its effects, we adopt a standard disk-corona configuration but disable the corona, allowing the reflection spectrum to arise solely from returning radiation, including higher-order reflections. Compared to widely used models such as relxillNS, our model naturally produces a harder high-energy reflection spectrum without requiring a Comptonized component. Our results demonstrate that returning radiation alone can account for the observed reflection features of XRBs in the soft state and should therefore be considered an important component. Including returning radiation in spectra modeling also enables us to explore its impact on black hole spin measurements and test General Relativity in the strong-field regime.

Flares from SgrA*: Dynamical probes for the accretion flow around supermassive black holes

Diogo Ribeiro

Max Planck Institute for Extraterrestrial Physics

The Galactic Centre represents the closest and best laboratory to study the environment around supermassive black holes. Sagittarius A*, the ultra-compact object at its centre, gives us a privileged view of the dynamics of moving stars and accreting gas around it. Over the last decades, we have established that the highly variable NIR emission of SgrA* must be associated with the accretion flow around it. With the advent of the GRAVITY interferometer in 2015, we have now repeatedly and consistently measured the motion of this flow. In this talk, I will report on the current polarimetric and astrometric measurements of NIR Flares obtained with the GRAVITY instrument and showcase the theoretical modelling performed by the GRAVITY Collaboration to interpret the observations. I will highlight how we constrain the spin orientation of the accretion flow, how it hints at the spin of SgrA* and how the alignment of this spin with other structures in the GC gives us a picture of the accretion history of Sgr A*.

Shadows of black holes and ultra-compact objects in the strong-field astrophysics era

Diego Rubiera-Garcia

Complutense University of Madrid, Spain

The observations made by the Event Horizon Collaboration regarding the image of the accretion flow around the supermassive objects at the heart of the M87 and Milky Way galaxies report a bright ring of radiation enclosing a central brighness depression. This finding, which is in qualitative agreement with the expectations from numerical simulations based on a Kerr black hole, has provided us with a new tool to test strong-field astrophysics of black holes via the new field of "shadows". In this talk I will report on the main theoretical, astrophysical and numerical ingredients behind this finding, and ellaborate on its possibilities via the shadows of modified black holes and ultra-compact objects.

Binaries in the Galactic Centre

Rodrigo Pereira da Silva
CFisUC & CENTRA/FEUP

The Galactic Center hosts a population of massive stars orbiting near the central supermassive black hole, collectively known as the S-cluster. Unlike massive stars found elsewhere in the Galaxy, which commonly reside in binary systems, the S-cluster appears to lack such companions. This discrepancy may reflect observational limitations or the effects of strong dynamical interactions near the supermassive black hole. We explore the stability and survivability of binary systems in this extreme environment. The implications of our results for the formation history and dynamical evolution of stars in galactic nuclei and may guide future observational searches for hidden companions in the GC.

Constraints on Dark Matter Structures around Gaia Black Holes

Nuno Gonçalo Pereira Portela Branco
CFisUC

We demonstrate that Gaia's detection of stars on wide orbits around black holes opens a new observational window on dark matter structures – such as scalar clouds and dark matter spikes – predicted in a range of theoretical scenarios. Using precise radial velocity measurements of these systems, we derive state-of-the-art constraints on dark matter density profiles and particle masses in previously unexplored regions of parameter space. We also test the black hole hypothesis against the alternative of a boson star composed of light scalar fields.

Testing bosonic dark matter through white dwarf mass measurements

Jorge Castelo Mourelle
Instituto de Ciencias Nucleares, Universidad Nacional Autónoma de México

Mass estimates of white dwarfs via electromagnetic methods, often differ from those obtained through gravitational redshift measurements, in some cases with discrepancies ranging in 5–15% across independent datasets. Although many of the discrepancies reported in large spectroscopic surveys and confirmed by high-precision techniques such as astrometric microlensing and wide-binary analyses may be attributable to thermal effects, model uncertainties or measurement errors prevent a complete description of some of the observations. Here, we explore an alternative explanation based on the presence of a gravitationally coupled bosonic scalar field that contributes to the stellar mass while remaining electromagnetically invisible. We construct stationary, static mixed configurations consisting of a white dwarf that presents a bosonic scalar field (dark matter) component, forming a composite

white dwarf–boson star system. We explore families of solutions showing that a scalar field fraction of $f_{\mathrm{DM}} \sim 5$–15% to the mass contribution can account for the observed redshift excess. Our models provide a physically motivated explanation for the mass bias, might offer new observational signatures, and allow us to place preliminary constraints on the mass and compactness of the scalar field configuration. Finally, using our theoretical framework in combination with Bayesian model selection we provide plausible bounds for the mass of the constituent (ultralight) bosonic particle.

Ways of seeing: Hypershadows of 5D black holes

João Pedro de Araújo Novo

Universidade de Aveiro

What does a black hole look like? In 1 + 3 spacetime dimensions, the optical appearance of a black hole is a bidimensional region in the observer's sky often called the black hole shadow, as supported by the EHT observations. In higher dimensions this question is more subtle and observational setup dependent. Previous studies considered the shadows of higher dimensional black holes to remain bidimensional. We argue that the latter should be regarded as a tomography of a higher dimensional structure, the hypershadow, which would be the structure "seen" by higher dimensional observers. As a case study we consider the cohomogeneity-one Myers-Perry black hole in 1 + 4 dimensions, and compute its tridimensional hypershadow.

Backreaction of perturbations around a stable Light Ring

Pedro Cunha

Universidade de Aveiro

Light rings (LRs) - closed circular orbits of null geodesics - are key features of both black holes and horizonless ultracompact objects. While unstable LRs are relevant for the observation of black hole images, stable LRs have been suspected to trigger instabilities, namely in exotic compact objects that could mimic black holes. The underlying mechanism behind this instability remains poorly understood, but a key missing piece is how the backreaction of a perturbation around the stable LR modifies the surrounding spacetime. In this talk, some progress in this direction is discussed by examining a conceptually simple, yet instructive, toy model: continuum-shell stars, supported solely by tangential pressures. Using both analytical and numerical methods, we show how perturbations around the stable LR deepen the geodesic potential and shifts its location inward, potentially amplifying any instability associated with the LR. By then extending the analysis to more general stars with nonzero radial pressure, we find that the same phenomenon can be expected to persist under reasonable assumptions.

Scalar field scattering from a Schwarzschild-de Sitter black hole

Marco de Cesare

Scuola Superiore Meridionale (SSM)

I will discuss the scattering problem for a massless scalar field in a Schwarzschild-de Sitter geometry. A rigorous application of the method of matched asymptotic expansions allows us to solve analytically the low-frequency s-wave dynamics, and connect the scalar's evolution in the proximity of the black-hole horizon with that on cosmological scales. The scattering coefficients, greybody factors, and Wigner time delay are computed explicitly. We consider both small and large black holes (relative to the cosmological horizon), extending previous studies confined to the small black-hole regime. In addition, for small black holes we perform a calculation that remains agnostic about the relative size between the ratio of the geometry's horizons and the scalar's frequency in units of the black-hole radius. When the two are comparable, we find that the greybody factor is symmetric under the exchange of the scalar frequency and the cosmological horizon radius. Based on arxiv:2511.09168 , in collaboration with M. Miranda and A.P. Porfyriadis.

Dynamics of the Interior of Black Holes

Andrzej Radosz

Wroclaw University of Science and Technology

It is rather well-known that the interior of Schwarzschild black hole (SBH) may be regarded as a cosmological model. Its spatial part has a topology of a hyper-cylinder, $R^1 \times S^2$: it expands along the homogeneity axis R^1 and contracts perpendicularly to this axis, S^2. The dynamical properties of the interior of the Kerr BH (KBH) are much more complex and much less-known. We argue that in this case there exists a special class of (resting) observers who are not dragged by rotating interior of KBH. Applying the signals (null geodesics), exchanged among those un-dragged observers one can analyse the properties of the interior of KBH - in such a way the dynamics of that cosmological model is described. Some interesting features in common for the interior of Schwarzschild and Kerr BHs are indicated. Namely, the critical Doppler, red/blue shifts as the results of the presence of the outer SBH and outer and inner, KBH, horizons are found.

Incomplete knowledge leads to sick extremals

Etevaldo dos Santos Costa Filho
Universidade de Aveiro

Recent studies indicate that smooth extremal black hole horizons are not generic. Evidence from different matter content and from higher-dimensional theories shows that the extremal limit typically develops singular behavior at the horizon. We contribute to this picture by numerically constructing families of stationary, axisymmetric solutions—both non-extremal and extremal—in Einstein–Maxwell–dilaton/axion theories. Whenever the extremal limit is regular, we extract and analyze the near-horizon extremal geometry (NHEG). Using the entropy-function formalism, we show that regular rotating attractors with dilatonic/axionic hair at generic couplings exist only for a specific electric–magnetic charge combination. On the global side, we construct asymptotically flat, rotating extremal black holes that interpolate to this NHEG branch, and we verify that the horizon data are fixed by extremization and decouple from the asymptotic moduli, in line with the attractor mechanism.

Rotating Thin Shells in Einstein-Gauss-Bonnet

João Dinis de Carvalho Álvares
CENTRA

A rotating solution in Einstein-Gauss-Bonnet gravity with a negative cosmological constant was recently found in the Chern-Simons point. Contrary to the attempts of applying a rotating thin shell in Kerr, here we show a clear and straightforward way to describe the way a rotating thin shell behaves. The inner and outer spacetimes are replicas of the same rotating metric, with different values of mass and angular momenta. We explore the parameter-space possibilities and discuss the mathematical correctness of the standard junction conditions used up until now in the Einstein-Gauss-Bonnet theory, which is still a matter of debate.

Day 2 - 2nd Afternoon session

Singularity at the demise of a black hole

Justin Christopher Feng

CEICO, FZU - Institute of Physics of the Czech Academy of Sciences

In this talk, I consider the conformal diagram for a 1+1 evaporating black hole in a "baby universe" scenario and argue that the "pinch off" point is a kind of quasiregular singularity characterized by points possessing two future-directed light cones and two past-directed light cones (in fact this spacetime is conformal to a region of the 1+1 trousers spacetime). I then discuss a Euclidean signature shift-symmetric scalar-tensor theory from which one can extract a Lorentzian structure, and show how this theory can provide a microscopic description for the aforementioned singularities. I discuss some recent developments indicating that this theory contains a tensor degree of freedom that propagates with a Lorentzian dispersion relation.

Can Kerr-NUT-(A)dS be charged in higher-dimensions?

Aravindhan Srinivasan

Charles University, Prague

Almost four decades have passed since the generalization of vacuum Kerr solutions to higher dimensions in the form of Myers-Perry black holes, yet an exact solution generalizing their charged extension (Kerr-Newman) to higher dimensions remains unknown in Einstein-Maxwell theory. Likewise, an exact solution for charged multi-NUT spacetimes in higher-dimensions is missing. In this talk, I will discuss this issue from the viewpoint of the generalized Kerr-Schild class.

Dyonic Reissner-Nordström black holes in Weyl conformal gravity

Reinosuke Kusano

University of St Andrews

We present a parametric study of the various black hole and naked singularity spacetimes in the dyonic Reissner-Nordström metric in Weyl's conformal fourth-order theory of gravity. We find analytic expressions for photon sphere radii, horizons, and extremal limits of the metric, as functions of the standard conformal gravity parameters β, γ, and κ. While a $1/r^2$ term exists in standard second-order Reissner-Nordström metrics, there is no such term in the conformal gravity equivalent; therefore, the innermost horizon is not necessarily a Cauchy horizon. In fact, we may obtain a so-called "nested black hole" structure, by which we denote a Schwarzschild-esque black hole inside another Schwarzschild-anti-de Sitter black hole. Also, in addition to a complete review of positive-mass spacetimes, we obtain a critical charge value for which we may obtain spacetimes wherein three horizons collide.

Gauss-Bonnet gravity and Robinson-Trautman spacetimes

Natalia Francisca Astudillo Neira

Charles University

Assuming the D-dimensional geometries admitting a non-twisting, shear-free, and expanding null geodesic congruence, that is, forming the Robinson-Trautman (RT) class, we study specific constraints implied by the field equations of the Einstein–Gauss–Bonnet (EGB) theory. These equations are analyzed with emphasis on the algebraic structure of the resulting solution. This is primary motivated by the fact that in four-dimensional General Relativity (GR), the RT family exhibits Weyl type II solutions (or more algebraically special subclasses), including spherically symmetric black holes and exact Weyl type N radiative spacetimes, however, in higher dimensions the admissible solutions reduce to Weyl type D. A systematic investigation of RT spacetimes in EGB gravity could provide a deeper understanding of whether the more restrictive behavior of higher-dimensional GR originates from the intrinsic geometric structure of the RT class or its combination with particular gravitational dynamics.

Black holes in the external Bertotti-Robinson-Bonnor-Melvin electromagnetic field

Marco Astorino
Laboratorio Italiano di FIsica Teorica (LIFT), Milano, Italy

An exact and analytical solution, in four-dimensional general relativity coupled with Maxwell electromagnetism, is built by means of a Lie point symmetry of the Ernst equations, the Harrison transformation. The new spacetime describes a Schwarzschild-like black hole embedded into a general external back-reacting electromagnetic field, which is the superposition of the Levi-Civita-Bertotti-Robinson and the Bonnor-Melvin ones. The relation between the two homogeneous electromagnetic fields is clarified. Conserved charges and the first law of thermodynamics are analysed. Swirling generalisations are also considered. Limits to the known metrics such as Schwarzschild-Bertotti-Robinson, Schwarzschild-Bonnor-Melvin and Bertotti-Robinson-Bonnor-Melvin are discussed.

Evolving Casimir Wormholes

Remo Garattini
Università di Bergamo

After a brief introduction describing what is a Casimir Wormhole, we consider how different physical sources can support the existence of this Traversable Wormhole even when a rotation is present. A setup for its evolution in time is also presented.

Zeldovich vacuum energy density and strong gravity with running gravitational constant

Hristu Culetu
Ovidius University

A static geometry with applications in microphysics is studied in this paper. The null and timelike radial geodesics are investigated and found to represent hyperbolae, but with different accelerations. Due to the very high acceleration, close to the maximum one ($a \approx 10^{34} cm/s^2$), a massless particle reach very quickly the velocity c. That is related to the Zeldovich [1] vacuum energy density ϵ which, using the strong gravitational constant $G_s = c\hbar/m_p^2$ instead of Newton's constant G_N, appears as $\epsilon_{vac} = m_p^4 c^5/\hbar^3$, i.e. proportional to m_p^4, where m_p is the proton mass. A similar dependence has recently been obtained by LeClair [2]. Some numerical examples are given, emphasizing the strong curvatures near $r = 1/a$. The energy-momentum tensor creating the curvatures has a positive trace and represents an imperfect fluid.

[1] Ya. B. Zeldovich, Usp. Fiz. Nauk 95, 209 (1968). [2] A LeClair, arXiv: 2509.02636.
