V Black Holes Workshop

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Instituto Superior Técnico, Lisbon, Portugal

List of Abstracts

1. **Masoud Allahverdizadeh:** *Extremal Myers-Perry black holes coupled to Born-Infeld electrodynamics in five dimensions*

   We construct a new class of perturbative charged rotating black hole solutions of nonlinear Einstein-Born-Infeld theory in five dimensions with spherical horizon topology. We focus on the extremal black holes with equal-magnitude angular momenta. The perturbative parameter is assumed to be the electric charge q and the perturbations is performed up to 4th order. We also study some physical properties of these black holes. It is shown that the perturbative parameter and the Born-Infeld parameter modify the value of the physical quantities of the black holes.

2. **Richard Pires Brito:** *Tidal effects around higher-dimensional black holes*

   In four-dimensional spacetime, moons around black holes generate low-amplitude tides, and the energy extracted from the hole's rotation is always smaller than the gravitational radiation lost to infinity. Thus, moons orbiting a black hole inspiral and eventually merge. However, it has been conjectured that in higher-dimensional spacetimes orbiting bodies generate much stronger tides, which backreact by tidally accelerating the body outwards. This effect, analogous to the tidal acceleration experienced by the Earth-Moon system, would determine the evolution of the binary. Here, we put this conjecture to the test, by studying matter coupled to a massless scalar field in orbit around a singly-spinning rotating black hole in higher dimensions. We show that in dimensions larger than five the energy extracted from the black hole through superradiance is larger than the energy carried out to infinity. Our numerical results are in excellent agreement with analytic approximations and lend strong support to the conjecture that tidal acceleration is the rule, rather than the exception, in higher dimensions. Superradiance dominates the energy budget and moons "outspiral"; for some particular orbital frequency, the energy extracted at the horizon equals the energy emitted to infinity and "floating orbits" generically occur. We give an interpretation of this phenomenon in terms of the membrane paradigm and of tidal acceleration due to energy dissipation across the horizon.

3. **Kirill Bronnikov:** *Cylindrical wormholes with and without rotation*

   Wormholes connecting different universes or distant parts of the same universe can be extended in a certain direction like cosmic strings. Then, in the simplest case they can be cylindrically symmetric. We discuss the conditions under which cylindrical wormholes can be described as solutions to the Einstein equations. It has been shown that rotation, representing a vortex gravitational field, can provide a wormhole geometry without violating the standard energy conditions, but the main problem is that such geometries cannot be asymptotically flat. We try to solve this problem by invoking thin shells co-rotating with the whole cylindrical configuration.

4. **Gabriel Cardoso:** *Extremal black brane solutions in 5D gauged supergravity*

   We study stationary black brane solutions in the context of gauged supergravity in five dimensions. Using the formalism of first-order flow equations, we construct extremal black brane solutions that include Nernst branes, i.e. extremal black brane solutions with vanishing entropy density, and black branes that are the brane equivalent of black rings, whose entropy can be computed from a Cardy formula of the dual CFT.

5. **Marc Casals:** *Quantum States for Fields on Kerr*

   In the absence of a full theory of Quantum Gravity, it is widely believed that quantizing matter fields on a classical black hole background space-time gives a good description of physical phenomena

(such as Hawking radiation) when the physical scales are much larger than the Planck scales. The definition of the quantum state of the 'matter' field then becomes crucial and is neither unique nor trivial. Of particular importance is the 'Hartle-Hawking state', representing a black hole in thermal equilibrium with a bath of its own quantum field radiation. While such a state is well-defined for fields in Schwarzschild, it is ill-defined for bosons in Kerr. In this talk we will discuss the construction of various quantum states for boson and fermion fields on a Kerr background and we will show that, unlike for bosons, a Hartle-Hawking-like state can be constructed for fermions in Kerr.

6. **Juan Carlos Degollado:** *Long-lived scalar field dark matter clouds around supermassive black holes*

   Classical scalar fields have been proposed as possible candidates for the dark matter component of the universe. Given the fact that super-massive black holes seem to exist at the center of most galaxies, in order to be a viable candidate for the dark matter halo a scalar field configuration should be stable in the presence of a central black hole, or at least be able to survive for cosmological time-scales. In the present work we consider a scalar field as a test field on a Schwarzschild background, and study under which conditions one can obtain long-lived configurations. We show that there exist configurations that can remain surrounding a black hole for large time-scales. In particular, ultra-light scalar field dark matter around super-massive black holes can survive for cosmological times.

7. **Óscar Dias:** *Superradiance and Black Holes with a Single Killing Field*

   Superradiance can extract energy from a black hole and, in an asymptotically global AdS background, it drives the black hole unstable. The onset of superradiance also signals a bifurcation to a new family of AdS black holes in a phase diagram of stationary solutions. We construct non-linearly the rotating hairy black holes and boson stars associated to scalar superradiance. These hairy solutions give the first examples of black holes with only a Killing field: the black holes are neither stationary nor axisymmetric, but are invariant under a single Killing field which is tangent to the null generators of the horizon. We discuss the role of these solutions in a full time evolution of the superradiant instability.

8. **Hugo Ferreira:** *Quantum effects on Warped AdS3 Black Holes in 3D Topologically Massive Gravity*

   3D gravity allows us to study aspects of General Relativity and quantum gravity in a simpler technical setting which retains much of the conceptual complexity of the 4D version. However, pure Einstein gravity has no local degrees of freedom in 3D. Topologically Massive Gravity is a deformation of pure Einstein gravity which adds a gravitational Chern-Simons term and includes propagating gravitons. For many years several attempts at finding a stable vacuum solution for this theory were made and it has been recently established that the Anti-de Sitter (AdS3) solution is unstable for almost all values of the coupling constant of the Chern-Simons term. Warped AdS3 solutions are recent candidates for a stable vacuum solution. In this talk I first classically describe these solutions and the black hole spacetimes one can obtain from them. In addition, I describe scalar field perturbations on these black hole backgrounds and progress towards determining the renormalized stress energy tensor for the Hartle-Hawking vacuum state.

9. **Antonino Flachi:** *Geo-Thermal Effects and Strongly Interacting Fermions*

   With the intent of exploring how the interplay between boundary effects and chiral symmetry breaking may alter the thermodynamical behavior of a system of strongly interacting fermions, we study the Casimir effect for the set-up of two parallel layers using a four-fermion effective field theory at zero density. This system reveals a number of interesting features. (1) While for infinitely large separation (no boundaries), chiral symmetry is broken/restored via a second order phase transition, in the opposite case of small (and, in general, finite) separation the transition becomes first order, rendering effects of finite size, for the present set-up, similar to those of a chemical potential. (2) Appropriately moving on the separationtemperature plane, it is possible to generate a peculiar behavior in the temperature dependence of the thermodynamic potential and of the condensate, compensating thermal with geometrical variations. A behavior similar to what we find here has been predicted to occur in bilayer graphene. (3) Chiral symmetry breaking induces different phases (massless and massive) in the Casimir force separated by critical lines.

10. **Carlos Herdeiro:** *Inelasticity in the collision of shock waves*

    The collision of two D-dimensional equal energy Aichelburg-Sexl shock waves is discussed. Using a method first developed by D'Eath and Payne we compute the metric in the future light cone of the collision perturbatively. To first order perturbation theory we find that the inelasticity is given by a remarkably simple pattern. We set up a framework for computing this quantity to higher orders and discuss, in particular, the second order result as well as the limitations of the method.

11. **José P. S. Lemos:** *Magnetic monopoles and nonminimal magnetic black holes*

    We discuss new solutions of nonminimally extended Einstein-Yang-Mills equations with a cosmological constant and a gauge field of the Wu-Yang magnetic type. It is a six-parameter family of exact solutions. The parameters are three nonminimal coupling constants introduced phenomenologically, a parameter that is related to the magnetic charge, the asymptotic mass of the object, and a cosmological constant. We focus on the properties of regular nonminimal black holes (spherically symmetric static objects with metric functions and curvature invariants regular everywhere), and nonminimal regular stars (objects without horizons and without singularities). One of the main results of this work is the full classification of the several types of horizons of regular space-times created by a nonminimal magnetic monopole. We also discuss the interior structure of these objects. We distinguish models in which the space-time contains four specific elements arising from the nonminimal character of the solutions: a repulsion barrier hedging off the center, a trap between the center and the barrier peak, a standard zone of a Newtonian-type attraction and a distant equilibrium point, in which the metric function has a minimum. These solutions enlarge the spectrum of regular black holes. It is always tempting to make a connection of these solutions with elementary particles at the Planck scale.
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12. **Caio Macedo:** *Astrophysical signatures of boson stars*

    Compact bosonic field configurations, or boson stars, are promising dark matter candidates which have been invoked as an alternative description for the supermassive compact objects in active galactic nuclei. Boson stars can be comparable in size and mass to supermassive black holes and they are hard to distinguish by electromagnetic observations. However, boson stars do not possess an event horizon and their global spacetime structure is different from that of a black hole. This leaves a characteristic imprint in the gravitational-wave emission, which can be used as a discriminant between black holes and other horizonless compact objects. Here we perform a detailed study of boson stars and their gravitational-wave signatures in fully relativistic setting, a study which was lacking in the existing literature in many respects. We construct several boson star configurations, including for the first time nontopological solitonic solutions, and we analyze their geodesic structure and their free oscillation spectra, or quasinormal modes. We explore the gravitational and scalar response of boson star spacetimes to an inspiralling stellar-mass object. We find that a generic signature of compact boson stars is the resonant-mode excitation by a small compact object on stable quasi-circular geodesic motion. Finally, we compare gravitational energy fluxes emitted in extreme mass-ratio inspirals around boson stars to their black hole counterpart, and analyze the ability of current and future gravitational-wave detectors to discriminate between these objects.

13. **Filipe Moura:** *Tensorial perturbations and stability of spherically symmetric d-dimensional black holes in string theory*

    We compute the tensorial perturbations to a general spherically symmetric metric in d dimensions with string-theoretical corrections quadratic in the Riemann tensor. We then study the stability of corresponding black holes under such perturbations, focusing mainly on a double-charged solution.

14. **Francesco Pannarale:** *The Black Hole Remnant of Black Hole-Neutron Star Coalescing Binaries*

    I present a model for determining the dimensionless spin parameter and mass of the black hole remnant of black hole-neutron star mergers with parallel orbital angular momentum and initial black hole spin. This approach is based on the Buonanno, Kidder, and Lehner method for binary black holes and it is successfully tested against the results of numerical-relativity simulations: the dimensionless spin

parameter is predicted with absolute error ~ 0.02, whereas the relative error on the final mass is $<$ 2%, its distribution being pronouncedly peaked at 1%. This approach and the recent fits to the torus remnant mass of black hole-neutron star mergers thus constitute an easy- to-use analytical model that accurately describes the remnant of these mergers. We investigate the space of parameters consisting of the binary mass ratio, the initial black hole spin, and the neutron star mass and equation of state. We provide indirect support to the cosmic censorship conjecture for black hole remnants of black hole-neutron star mergers. We show that the presence of a neutron star affects the quasi-normal mode frequency of the black hole remnant, thus suggesting that the ringdown epoch of the gravitational wave signal may virtually be used to (1) distinguish binary black hole from black hole-neutron star mergers and to (2) constrain the neutron star equation of state.

15. **João Rosa:** *Boosted black string bombs*

    We study the formation of superradiant bound states for massive scalar fields in five-dimensional rotating black string geometries with a non-vanishing Kaluza-Klein momentum along the compact direction. Even though all Kaluza-Klein modes may form bound states in this geometry, in realistic extra-dimensional models and astrophysical black holes only the zero-mode is sufficiently light for superradiant instabilities to develop, provided the field has a small but non-vanishing mass, as for example for axion-like particles. We use analytical and numerical methods to show that, although the Kaluza-Klein momentum decreases the upper bound on the field mass for an instability to develop, it may enhance its maximum growth rate by more than 50%, thus boosting the black hole bomb mechanism. We discuss the possible observational consequences of this result and its potential as an astrophysical probe of non-trivial extra-dimensional compactifications.

16. **Diego Rubiera:** *Energy-density effects on the formation of Schwarzschild black holes in extended Palatini gravity*

    Palatini modified theories of gravity are those based on the assumption that metric and connection are independent physical entities. These theories have several interesting features, such as second-order field equations in all cases and absence of ghost and other dynamical instabilities. In these theories in vacuum (or when $R = const$) the solutions are exactly the same as those of General Relativity with a cosmological constant term. But when the invariant $Q = R_{\mu\nu}R^{\mu\nu}$ comes into play, even solutions with $R = Q = 0$ may have nontrivial solutions due to the energy density of the matter. We illustrate this peculiarity of Palatini approach by considering the formation of Schwarzschild black holes from an ingoing flux of pressureless null neutral matter (null fluid). We show that during the time that the black hole is absorbing matter the (Vaidya-type) metric becomes formally that of a Reissner-Nordström black hole but with a charge term with an opposite sign in front of it.

17. **Marco Sampaio:** *Scattering & stability around charged black holes*

    I will present recent attempts to study the stability issue of the Reissner-Nordström Black hole in 4D and higher dimensional generalisations, by using numerical techniques common to the problem of studying scattering for the Proca Field.

18. **Matteo Serra:** *Hyperscaling violation and phase transition for scalar black branes in arbitrary dimensions*

    We discuss an exact integrable Einstein-scalar gravity model in arbitrary dimensions. The extremal, zero temperature solution is a scalar soliton interpolating between a conformal invariant AdS vacuum in the infrared and a scale covariant metric, generating hyperscaling violation, in the ultraviolet. Considering the black brane solution as a thermodynamical system, we show the presence of a phase transition between the Schwarzschild-AdS black brane and our scalar-dressed solution.

19. **Sanjar Shaymatov:** *Penrose process in Kerr-Taub-NUT spacetime*

    Penrose process on rotational energy extraction of the black hole in the Kerr-Taub-NUT spacetime is studied. It has been shown that for the radial motion of particles NUT parameter slightly shifts the shape of the effective potential down. The dependence of the extracted energy from compact object on NUT parameter has been found.

20. **Thomas Sotiriou:** *Black holes in scalar-tensor gravity*

    Black holes in scalar-tensor gravity will be considered. I will present a proof that stationary, asymptotically flat black holes in this class of theories are no different that black holes in general relativity, and I will discuss the physical implication of this fact.

21. **Kentaro Tanabe:** *Black hole with two large angular momenta in blackfold approach*

    In my talk, we investigate the possible horizon topology of black holes with two large angular momenta using the blackfold approach. We find solutions with various horizon topology and their connections in phase space.

22. **Ian Vega:** *Horizon geometry of a tidally deformed Schwarzschild black hole*

    We provide a description of the event horizon of a perturbed Schwarzschild black hole is provided in terms of the intrinsic and extrinsic geometries of the null hypersurface. We apply the formalism to solutions to the vacuum field equations that describe a tidally deformed black hole. In a first instance we consider a slowly-varying, quadrupolar tidal field imposed on the black hole, and in a second instance we examine the tide raised during a close parabolic encounter between the black hole and a small orbiting body.

23. **Mengjie Wang:** *Hawking radiation for charged Proca field*

    In this talk I will report our recent work on Hawking radiation of charged Proca field in the charged background. Since the mass term introduces a coupling between two physical degrees of freedom of the Proca field, we have to solve equation of motion of the field numerically. First I will briefly introduce our framework to deal with Proca field in the spherical background. Then I will focus on charged Proca field. I will show some results of transmission factor as well as Hawking spectrum for charged Proca field. Due to the the charged field can extract the coulomb energy of the black hole, we observed superradiance. Finally I will mention some further work for charged Proca field.

24. **Helvi Witek:** *Superradiant instabilities in astrophysical systems*

    Black holes are key players in a wide range of fundamental physics including astrophysics as well as high energy physics. Crucial questions concern the stability properties of these fascinating objects with potentially important implications for the phase-space of solutions or the understanding of condensates in the vicinity of black holes. Of particular interest is the superradiant or "BH-bomb" like instability of Kerr BHs which arises naturally in aymptotically anti-de Sitter spacetimes or in the presence of massive fields surrounding the BH. Here, we focus on the latter scenario and present our investigations of massive scalar and vector fields in generic BH backgrounds. Specifically, we have explored the time evolution of these fields with generic initial configurations in highly spinning BH environments. We

have found interesting, non-trivial evolution patterns and have been able to deduce the growth rate of the superradiant instability.

25. **Xiaoning Wu:** *Gravity/fluid correspondence for general black holes*

    Based on the idea of AdS/CFT and holographic principle, there exist a correspondence between the gravity theory in bulk and field theory on boundary. Under low energy and non-relativistic limit, such correspondence should appear as correspondence between the gravitational perturbation in bulk and fluid on boundary. Such correspondence has been realized for some special space-time by many authors. Here we want to prove such correspondence holds for general non-rotation black hole. Besides that, we also prove the entropy produced by the boundary fluid is just equal to the variation of entropy of black hole at the center of the bulk. This gives an independent check for the gravity/fluid correspondence conjecture.

26. **Naqing Xie:** *On local minimum of quasilocal energy*

    Recently, Wang and Yau proposed a new concept of quasilocal energy. This talk concerns joint work with Pengzi Miao and Luen-Fai Tam on the issue that Brown-York quasilocal energy minimizes Wang-Yau quasilocal energy for time symmetric initial data set under certain geometric conditions.

27. **Oleg Zaslavskii:** *Black holes as particle accelerators*

    We suggest brief review of the effect of acceleration of particles by event horizons of rotating and charged black holes to unbound energies in the centre of mass frame. Emphasis is made on recent developments. The similar effect near the inner black hole horizon is also discussed and the role of the bifurcation point is revealed. We also discuss which energies can be detected by an observer at infinity.