VIII Black Holes Workshop

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Instituto Superior Técnico, Lisbon, Portugal

List of Abstracts

I

1. **Superradiant instability of AdS black holes**
   Akihiro Ishibashi (Kinki University, Japan)

   We show the occurrence of a superradiant instability for a wide class of asymptotically AdS black holes which possess an ergoregion with respect to horizon Killing field, employing the so-called canonical energy method of gravitational perturbations.

2. **Gravitational shockwave collisions in Anti-de Sitter spaces**
   Miguel Zilhão (Universitat de Barcelona, Spain)

   TBA

3. **Superfluid flow with external localized repulsive potential**
   Kengo Maeda (Shibaura Institute Of Technology, Japan)

   We analytically construct a gravity dual of a steady flow solution of superfluid with external localized repulsive potential using five-dimensional AdS black hole. We find a critical value of the strength of the potential above which there is no stationary solution. Below the critical value, there are two stationary solutions, and they coalesce at the critical value, agreeing with the picture of nonlinear Schrodinger fluid solution found by Hakim in 1997. We also investigate the superfluid density fluctuation of the solution.

II

4. **Gravitomagnetism and the significance of the curvature scalar invariants**
   Filipe Costa (CAMGSD/IST, University of Lisbon, Portugal)

   The curvature invariants have been subject of interest in recent years due to the ongoing debate concerning the notions of for intrinsic/extrinsic frame-dragging, and the question of whether there is a fundamental difference between the gravitomagnetic field arising from translational motion of the sources, detected with Lunar Laser Raging and in the observations of binary pulsars, and the gravitomagnetic field produced by the rotation of the Earth, detected in the LAGEOS Satellites data and with the Gravity Probe-B mission. In this talk I shall discuss the structure of the curvature invariants of the astrophysical setups of interest, including Kerr and Schwarzschild black holes. Both the algebraic implications and the physical meaning of the invariants are clarified, and their relationship with the gravitomagnetic effects is dissected. Finally, a new classification for intrinsic/extrinsic gravitomagnetism is put forth.

5. **A stellar model with diffusion in general relativity**
   Artur Alho (Instituto Superior Técnico, Portugal)

   We consider a stellar model in general relativity whose interior consists of a pressureless fluid undergoing microscopic velocity diffusion in a cosmological scalar field. We study the problem of matching an exterior Bondi type metric to the surface of the star and find that the exterior can be chosen to be a modified Vaidya metric with variable cosmological constant. Finally we study in detail the causal structure of an explicit, self-similar solution, and discuss the gravitational collapse.

6. **Binary pulsars as dark-matter probes**
   Paolo Pani (Sapienza U. of Rome, Italy & CENTRA-IST, Lisbon, Portugal)

   TBA

7. **Probing fundamental fields using compact stars**
   Richard Brito (Instituto Superior Técnico, Portugal)

   I will discuss how bosonic dark matter "condensates" interact with compact stars. Self-gravitating bosonic fields generically form "breathing" configurations, where both the spacetime geometry and the field oscillate, and can interact and cluster at the center of stars. I will show how to construct stellar configurations formed by a perfect fluid and a bosonic condensate, which may describe the late stages of dark-matter accretion onto stars, in dark matter-rich environments. Using perturbative analysis and Numerical Relativity techniques, we show that these stars are generically stable, and we provide criteria for instability. These results also indicate that the growth of the dark matter core is halted close to the Chandrasekhar limit, thus dispelling a myth concerning dark matter accretion by stars: dark mater accretion does not necessarily lead to the destruction of the star, nor to collapse to a black hole.

8. **Spontaneous scalarization in anisotropic configurations**
   Caio Macedo (Instituto Superior Técnico, Portugal)

   Some models (such as the Skyrme model, a low-energy effective field theory for quantum chromodynamics) suggest that the high-density matter prevailing in neutron star (NS) interiors may be significantly anisotropic. Anisotropy is known to affect the bulk properties of nonrotating NSs in general relativity (GR). We study the effects of anisotropy on slowly rotating stars in GR. We also consider one of the most popular extensions of Einsteins theory, namely scalartensor theories allowing for spontaneous scalarization (a phase transition similar to spontaneous magnetization in ferromagnetic materials). Anisotropy affects the moment of inertia of NSs (a quantity that could potentially be measured in binary pulsar systems) in both theories. We find that the effects of scalarization increase (decrease) when the tangential pressure is bigger (smaller) than the radial pressure, and we present a simple criterion to determine the onset of scalarization by linearizing the scalar-field equation.

III

9. **Self-gravitating anisotropic fluids with rotation**
   Jorge Rocha (Universitat de Barcelona, Spain)

   I will present an analytic construction of rotating solutions of the Einstein field equations in five dimensions with matter corresponding to an anisotropic fluid. These novel solutions are stationary, regular and asymptotically (anti-)de Sitter. The use of such spacetimes as regular sources for rotating (Myers-Perry) black hole geometries will also be discussed.

10. **Thermodynamics of rotating thin shells in the BTZ spacetime**
    Masato Minamitsuji (Instituto Superior Técnico, Portugal)

    We investigate the thermodynamic equilibrium states of rotating thin shells in a (2+1)-dimensional spacetime. The inner and outer regions with respect to the shell are given by the vacuum AdS and the rotating BTZ spacetimes, respectively. The first law of thermodynamics on the thin shell, together with three equations of state for the pressure, the local inverse temperature and the thermodynamic angular velocity of the shell, yields the entropy of the shell depending on the gravitational radius. When the shell is pushed to its own gravitational radius and its temperature is taken to be the Hawking temperature of the corresponding black hole, the entropy of the shell coincides with the Bekenstein-Hawking entropy. We also discuss thermodynamics of extremal rotating thin shells and show that they have distinct properties compared to the nonextremal ones.

11. **Static Electrically Charged Shells: Normal and Tension Shells**
    Paulo Luz (Instituto Superior Técnico, Portugal)

The junction of an interior Minkowski with an exterior Reissner-Nordström spacetime is studied. Using the Israel junction formalism a perfect fluid static thin shell separating an interior Minkowski outside Reissner-Nordstrm spacetime is considered. Defining the Kruskal-Szekeres coordinates for the maximally extended Reissner-Nordstrm spacetime, the presence of a thin shell at any allowable sub-region is analyzed and the properties of the shell, the energy density and the pressure, are studied. The cases of pressure and tension static shells of matter appear naturally depending on the sub-region where the shell is considered. The energy conditions verified by a thin shell, for all the possible cases, are analyzed.

12. **Entropy of extremal black holes**
José Sande Lemos (Instituto Superior Técnico, Portugal)

Black hole entropy, S, is one of the most fascinating issues in contemporary physics, as one does not yet strictly know what are the degrees of freedom at the fundamental microlevel, nor where are they located precisely. In addition, extremal black holes, in contrast to non-extremal ones, present a conundrum, as there are two mutually inconsistent results for the entropy of extremal black holes. There is the usual Bekenstein-Hawking $S = A/4$ value, where A is the horizon area, obtained from string theory and other methods, and there is the prescription $S = 0$ obtained from the fact that for extremal black holes the period of the Euclidean time is not fixed in a classical calculation of the action. In order to better understand black hole entropy in its generality, and in particular in the extremal limit, we exploit a matter based framework and use a thermodynamic approach for an electrically charged thin shell. We find the entropy function for such a system. We then take the shell radius into its gravitational radius (or horizon) limit. This limit is the quasiblack hole limit. We show that: (i) For a non-extremal shell the gravitational radius limit yields $S = A/4$. The contribution to the entropy comes from the pressure. (ii) For an extremal shell the calculations are very subtle and interesting. The horizon limit gives an entropy which is a function of the horizon radius alone, but the precise functional form depends on how we set the initial shell. The values 0 and $A/4$ are certainly possible values for the extremal black hole entropy. This formalism clearly shows that non-extremal and extremal black holes are different objects. In addition, the formalism suggests that for non-extremal black holes all possible degrees of freedom are excited, whereas in extremal black holes, in general, only a fraction of those degrees of freedom manifest themselves. We conjecture that for extremal black holes the entropy S is restricted to the interval between 0 and $A/4$. Since an extremal shell has zero pressure, the contribution to the entropy comes from the shell's electricity. (iii) There is yet another possibility: to take the extremal limit concomitantly with the gravitational radius limit. In this case, and contrary to the two previous cases, remarkably, both the pressure and the electricity on the shell contribute to the entropy to give $S = A/4$.

IV

13. **Parametrization of arbitrary axially symmetric black hole space-times in metric theories of gravity**
Roman Konoplya (University of Frankfurt, Germany)

We propose a new parametric framework to describe the spacetime of axisymmetric black holes in generic metric theories of gravity. In this case the metric coefficients are functions of both the radial and the polar angular coordinates. The parametrization proposed here is applied, but not limited, to construction of parametrized representations of Kerr, rotating dilatonic and Einstein-dilaton-Gauss-Bonnet black holes.

14. **Analytical solutions for black holes in cosmological background**
Alan Maciel da Silva (Universidade Federal do ABC, Brazil)

We consider the causal structure of generalized uncharged McVittie spacetimes with increasing central mass $m(t)$ and positive Hubble factor $H(t)$. Under physically reasonable conditions, namely, a big bang singularity in the past, a positive cosmological constant, and an upper limit to the central mass, we prove that the patch of the spacetime described by the cosmological time and areal radius coordinates is always geodesically incomplete, which implies the presence of event horizons in the spacetime. We also show that, depending on the asymptotic behavior of the m and H functions, the generalized McVittie spacetime can have a single black hole, a black-hole/white-hole pair or, differently from classic fixed-mass McVittie, a single white hole. A simple criterion is given to distinguish the different causal structures.

15. **Geometry behind the horizon in superposition of Schwarzschild black hole and Bach-Weyl ring.**
    Marek Basovník (Institute of Theoretical Physics, Faculty of Mathematics and Physics, Charles University, Czech Republic)

    Interaction of black holes with other gravitating sources is interesting for purely theoretical reasons (non-linear superposition in strong-field regime) as well as an within models of certain astrophysical sources. Here we try to learn and visualize Schwarzschild black hole subject to a presence of a (symmetrically placed) static and axially symmetric thin ring described by the Bach-Weyl solution. The external source may change the geometry inside the black hole considerably, even in the vicinity of singularity, although the singularities itself remains point-like in solutions studied here. We use various coordinate systems for clear describe of region below horizon where the spacetime follow axial symmetry and turns into dynamical system.

16. **Causality and black holes in spacetimes with a preferred foliation**
    Jishnu Bhattacharyya (University of Nottingham, United Kingdom)

    In this talk, I will elaborate on a recently developed framework to study of the causal structure of spacetimes with a causally preferred foliation. Such spacetimes may arise as solutions of Lorentz-violating theories, e.g. Horava gravity. The framework allows one to rigorously define concepts such as black/white holes and to formalize the notion of a " universal horizon", that has been previously introduced in the simpler setting of static and spherically symmetric geometries. I will further explain how to locally characterize universal horizons in stationary configurations. I will also discuss about the conditions under which universal horizons are cloaked by Killing horizons (which can act like usual event horizons for low-energy excitations) in static and axisymmetric spacetimes. Finally, time permitting, I will briefly touch upon the issue of development in spacetimes with a causally preferred foliations outline the proof that universal horizons are Cauchy horizons when evolution depends on boundary data or asymptotic conditions.

17. **Near-horizon geometry and integral quantities for strongly "magnetised" black holes**
    Filip Hejda (Instituto Superior Técnico, Portugal)

    TBA

18. **Local curvature invariants on stationary horizons**
    Andrey A. Shoom (Memorial University, Canada)

    We calculate scalar space-time curvature invariants on a stationary horizon and find relations between them and the horizon surface invariants. In addition, we find a procedure for a construction of algebraic curvature invariants vanishing on such horizons, which gives us a diagnostics for locating a black object.

19. **Magnetic catalysis in curved spacetimes**
    Vincenzo Vitagliano (Instituto Superior Técnico, Portugal)

    I will shortly discuss the combined effect of magnetic fields and geometry on systems of interacting fermions. At leading order in the heat-kernel expansion, the infrared singularity (that in flat space leads to the magnetic catalysis) is regulated by the so called 'chiral gap effect' and the catalysis is deactivated by effect of the curvature. I will show that an infrared singularity may reappear from higher-order terms in the heat kernel expansion leading to a novel form of geometrically induced magnetic catalysis (absent in flat space).

V

20. **Hairy black holes and the end point of superradiant instabilities**
    Carlos A.R. Herdeiro (Universidade de Aveiro, Portugal)

    TBA

21. **Lensing by boson stars and shadows of Kerr black holes with scalar hair**
Pedro V. P. da Cunha (Universidade de Aveiro, Portugal)

Kerr BHs, which are black holes (BHs) with rotation, are presently the most standard BH solutions, and possibly also the most realistic ones. However, in order to provide alternative shadow templates for upcoming astronomical observations, namely for the observation of the supermassive BH candidate Sgr A* in the center of our galaxy by the Event Horizon Telescope, it is timely to also consider different types of solutions. Hence, a novel class of BHs in equilibrium with a massive scalar field, Kerr BHs with scalar hair, was considered. This class exhibits intriguing properties, some of which are shadows that differ significantly from the Kerr prediction. For an observer, a shadow is a BHs apparent shape in the sky due to gravitational lensing of nearby radiation, emitted by an external source. It was discovered that these hairy BHs possess smaller shadows than the corresponding Kerr BHs. Additionally, under some conditions novel exotic shadow shapes can arise. Thus, hairy BHs could potentially provide new shadow templates for the afore mentioned experiments. These hairy BH solutions are also continuously connected to Boson Stars, described by the massive Klein-Gordon equation in curved space-time. Thus, the gravitational lensing of the later is of especial interest to understand the new shadow shapes of the hairy BHs.

22. **Absorption and superradiance of the massive and charged scalar field by Reissner-Nordstrom black holes**
Authors: Carolina Loureiro Benone and Luis Carlos Bassalo Crispino
Carolina Loureiro Benone (Universidade Federal do Pará, Brazil)

We consider a charged and massive scalar field around a charged black hole, and compute its absorption cross section numerically. We also investigate analytically the high- and low-frequency regimes, which we compare with our numerical results.

VI

23. **Superradiant scattering in astrophysical binary systems**
João Rosa (Universidade de Aveiro, Portugal)

I will discuss the generic properties of plane wave scattering in the Kerr spacetime, in both the electromagnetic and gravitational cases. I will then show how these results can be applied to realistic astrophysical systems involving a rotating black hole and a companion that emits radiation, and examine the conditions under which an overall amplification of the companion's luminosity due to superradiant scattering may occur. I will then discuss examples of systems where observational signatures of black hole superradiance may potentially be found.

24. **Superradiance in stars**
João Luís Rosa (Instituto Superior Técnico, Portugal)

Superradiance is a radiation enhancement process that involves rotating dissipative systems. In black hole (BH) spacetimes, superradiance is due to dissipation at the event horizon, with interesting associated phenomena, namely oating orbits and BH-bombs. BH superradiance is a very interdisciplinary topic, and its study allows us to obtain important results in the area of particle physics. The scattering of a scalar eld by a rotating BH leads to the formation of quasi-boundstates. In rotational systems, these states can give rise to superradiant instabilities. These results were recently used to impose constraints to the mass of fundamental particles and darkmatter candidates. In this work, it is shown that, when dissipation is properly included, similar results are achievable in self-gravitating systems other than black-holes, such as perfect uid stars. It is also demonstrated that the relativistic effects related to the phenomenon of frame-dragging are neglectable in this calculation.

25. **High energy collisions near black holes and super-Penrose process**
O. B. Zaslavskii (Department of Physics and Technology, Kharkov V. N. Karazin National University, Kharkov, Ukraine)

If two particles collide near a rotating black hole, their energy in the centre of mass frame $E_{\text{c.m.}}$ can become unbound under certain conditions. In doing so, the Killing energy E of debris at infinity is, in general, restricted. However, there are scenarios in which E can significantly increase or become unbound along with $E_{\text{c.m.}}$ (so-called the super-Penrose process). We discuss the conditions necessary for such a process for collisions (i) near the horizon, (ii) inside the ergoregion but not in the proximity to the horizon.

26. **On the angular momenta of two classical black holes**
Samuel Rocha de Oliveira (Unicamp, Brazil)

Using exact two Kerr-NUT black holes exact axisymmetric solutions we make some remarks on possible interaction of two classical black holes with respect to their angular momenta.

27. **A local non-negative initial data scalar characterisation of the Kerr solution**
Alfonso García-Parrado (Universidad del País Vasco, Spain)

For any vacuum initial data set, we define a local, non-negative scalar quantity which vanishes at every point of the data hypersurface if and only if the data are "Kerr initial data". Our scalar quantity only depends on the quantities used to construct the vacuum initial data set which are the Riemannian metric defined on the initial data hypersurface and a symmetric tensor which plays the role of the second fundamental form of the embedded initial data hypersurface. The dependency is algorithmic in the sense that given the initial data one can compute the scalar quantity by algebraic and differential manipulations, being thus suitable for an implementation in a numerical code. The scalar could also be useful in studies of the non-linear stability of the Kerr solution because it serves to measure the deviation of a vacuum initial data set from the Kerr initial data in a local and algorithmic way.

VII

28. **Resolution of black hole singularities in Palatini gravity**
Diego Rubiera-Garcia (Instituto de Astrofísica e Ciências do Espaço, Universidade de Lisboa, Portugal)

We discuss the robustness of singularity avoidance in electrovacuum black hole space-times within the framework of Palatini gravity, where GR is replaced by generalized functions depending on geometrical objects. Such singularity avoidance, as defined by geodesic completeness (despite the generic divergence of curvature scalars), is generated by the existence of a wormhole structure replacing the GR point-like singularity, without violation of the energy conditions. Complementary criteria for non-singular space-times are discussed.

29. **Higher-dimensional extremal Reissner-Nordstroem black holes are fragile**
Masashi Kimura (DAMTP, University of Cambridge, United Kingdom)

We study stationary perturbation around higher-dimensional extremal Reissner-Nordstroem black holes. We find that the non-trivial solutions of the perturbative equations always have singular behavior at the horizon which break the smoothness of the horizon in contrast to the case of four dimensions. This property comes from the boundary condition on the event horizon which is extremal. Especially, the $\ell = 2$ modes cause curvature singularities at the horizon if the dimension is higher than five. Our results suggest that the only regular static extremal black hole in the Einstein-Maxwell system is the extremal Reissner-Nordstroem black hole if $D \geq 6$. The case of AdS background is also discussed.

30. **Gravitational Wave Extraction in Higher Dimensional Numerical Relativity**
William Cook (DAMTP, University of Cambridge, United Kingdom)

In numerical relativity, in order to study the simplest gravitational two body problem, the collision and merger of two black holes, we need to understand the gravitational radiation that the black holes emit during this process. In four dimensions, a widely used method to extract gravitational radiation is based upon the Weyl scalars calculated in the Newman-Penrose formalism. Here we present an implementation of a higher dimensional analogue to the Weyl scalars and Newman-Penrose formalism as developed by M. Godazgar and

H. Reall in [arXiv:1201.4373], and show that the energy lost in gravitational wave radiation in black hole-black hole collisions from rest in 5D matches previous calculations using the Kodama-Ishibashi formalism by H. Witek et al. in [arXiv:1006.3081].

31. **Gravity's Rainbow and the Tolman-Oppenheimer-Volkoff equation**
    Remo Garattini (Universit degli Studi di Bergamo, Italy)

    We consider the application of Gravity's Rainbow to the TOV equations for compact stars. The distorted TOV equations are discussed in this context.

VIII

32. **Vacuum polarization on the brane**
    Elizabeth Winstanley (The University of Sheffield, United Kingdom)

    We compute the renormalized vacuum polarization (VP) of a massless, conformally coupled, quantum scalar field on the brane of a higher-dimensional black hole. The quantum scalar field is in a thermal state at the Hawking temperature. An exact, closed-form expression is derived for the VP on the event horizon of the black hole. Outside the event horizon, the VP is computed numerically. The magnitude of the VP increases rapidly as the number of bulk space-time dimensions increases.

33. **Black Hole to White hole trasition amplitudes in the framework of Loop Quantum Gravity**
    Marios Christodoulou (Center of Theoretical Physics, Aix Marseille University, France)

    Loop Quantum Gravity provides a canonical quantization of GR. The dynamics can be implemented via the EPRL model in the spinfoam formalism. Using coherent spin network states describing the classical geometry of Black and White hole slices, EPRL transition amplitudes between these geometries can be calculated and the time of transition as a function of the mass deduced. This can provide an avenue for experimental testing of LQG.

34. **Dark energy fingerprints in the nonminimal Wu-Yang wormhole structure**
    Alexei Zayats (Kazan Federal University, Russia)

    We discuss new exact solutions to nonminimally extended EinsteinYangMills equations describing spherically symmetric static wormholes supported by the gauge field of the Wu-Yang type in a dark energy environment. For the solutions we consider the problem of horizons and find constraints for the parameters of nonminimal coupling and for the constitutive parameters of the dark energy equation of state, which guarantee that the nonminimal wormholes are traversable.

35. **Stability and the effective metric**
    Santiago Bergliaffa (Universidade Estadual do Rio de Janeiro, Brazil)

    The effective metric governs the propagation of perturbations in non- linear theories. I will present the relation between the effective metric and linear stability, as well as an application of this relation to a non-gravitating "ghost condensate" in stationary and spherically symmetric accretion onto a Schwarzschild black hole. I will also show that the determination of linear stability using the effective metric is simpler than the traditional method of the effective potential.