X Black Holes Workshop – List of talks and abstracts

Aveiro 18-19 December 2017

Session 1

1. **Observational evidence for black holes**

   Vitor Cardoso, CENTRA - IST

   The 2017 Nobel prize in physics was awarded to the direct detection of gravitational waves. Gravitational waves offer a unique glimpse into the unseen universe in different ways, and allow us to test the basic tenets of General Relativity, some of which have been taken for granted without observations: are gravitons massless? Are black holes the simplest possible macroscopic objects? do event horizons and black holes really exist, or is their formation halted by some as-yet unknown mechanism? Do singularities arise in our universe as the outcome of violent collisions? In this talk, I will describe how one might quantify the evidence for black holes using gravitational-wave observations.

2. **Long-Lived Inverse Chirp Signals from Core-Collapse in Massive Scalar-Tensor Gravity**

   Ulrich Sperhake, University of Cambridge

   We model stellar core collapse in massive scalar-tensor theories of gravity. The presence of a mass term for the scalar field allows for dramatic increases in the radiated gravitational wave signal and may stretch out the signal to last for years or even centuries. There are several potential smoking gun signatures of a departure from general relativity associated with this process. These signatures could show up within existing LIGO-Virgo searches.

3. **Post-Kerr black hole spectroscopy**

   Kostas Glampedakis, University of Murcia

   In this talk we present a "post-Kerr" formalism for carrying out quasi-normal mode spectroscopy of black holes. The formalism does not assume any particular gravitational field equations but instead it relies on the connection between the geodesic photon ring and the fundamental quasi-normal mode to calculate the mode's frequency and damping time. These parameters are expected to dominate the final ringdown of merging black holes and the formalism presented here could be a useful tool for future LIGO/Virgo searches.

4. **Cassini states for black hole binaries**

   Alexandre Correia, University of Aveiro

   Cassini states correspond to the equilibria of the spin axis of a body when its orbit is perturbed. They were initially described for planetary satellites, but the spin axes of black hole binaries also present this kind of equilibria. In previous works, Cassini states were reported as spin-orbit resonances, but actually the spin of black hole binaries is in circulation and there is no resonant motion. Here we provide a general description of the spin dynamics of black hole binary systems based on a Hamiltonian formalism. In absence of dissipation, the problem is integrable and it is easy to identify all possible trajectories for the spin for a given value of the total angular momentum. As the system collapses due to radiation reaction, the Cassini states are shifted to different positions, which modifies the dynamics around them. This is why the final spin distribution may differ from the initial one. Our method provides a simple way of predicting the distribution of the spin of black hole binaries at the end of the inspiral phase.

5. **Gravitational wave searches for ultralight bosons with LIGO and LISA**

   Richard Brito, Max Planck Institute for Gravitational Physics, Potsdam

   Ultralight bosons can induce superradiant instabilities in spinning black holes, tapping their rotational energy to trigger the growth of a bosonic condensate. Possible observational imprints of these boson clouds include (i) direct detection of the nearly monochromatic (resolvable or stochastic) gravitational waves emitted by the condensate, and (ii) statistically significant evidence for the formation of "holes" at large spins in the spin versus mass plane of astrophysical black holes. In this work, I will give an overview on the prospects of LIGO and LISA detecting or constraining the presence of ultralight bosons in our Universe.

6. **Gravitational wave signatures of black hole mimickers**

   Andrea Maselli, Instituto Superior Tecnico

   Exotic compact objects (ECO), with microscopic corrections at the horizon scale, may form in Nature as binary sources, and mimic the coalescence of ordinary black holes. In this talk we discuss the signatures which may be used, together with gravitational wave observations, to distinguish between such exotic states of matter. We investigate two possible smoking gun effects, namely the ECO's tidal deformation, and the absence of absorption at the horizon. We assess the ability of present and future interferometers to detect the ECO's Love numbers and tidal heating, and their constraints. For space observatories, like LISA, we demonstrate how these effects can be used to bound the compactness of the exotic object down to the Planck scale.

7. **From Compact Objects to Quasi-Normal Modes and Back**

   Sebastian Völkel, University of Tübingen

   With the detection of gravitational waves by LIGO and Virgo, new frontiers in astrophysics and gravitational physics are waiting to be explored. This talk is dedicated to the theoretical description of ultra compact objects, including alternative models for black holes. These have drawn much attention recently, due to the possible detection of so-called "echoes" in LIGO data. Analytic and semi-analytic techniques can be used to study gravitational perturbations, where the associated quasi-normal mode spectrum contains important information of the source and is therefore a promising object for further research. During this talk it is shown how the techniques can be used to calculate the quasi-normal mode spectrum of the source. In the next step, the more complicated inverse problem is solved. Here one reconstructs the perturbation potential of the source from the knowledge of the quasi-normal mode spectrum.

8. **Light ring stability in ultra-compact objects**

   Pedro Cunha, Aveiro & IST-Lisbon

   The following theorem is proven: axisymmetric, stationary solutions of the Einstein field equations formed from classical gravitational collapse of matter obeying the null energy condition, that are everywhere smooth and ultracompact (i.e., they have a light ring) must have at least two light rings, and one of them is stable. It has been argued that stable light rings generally lead to nonlinear spacetime instabilities. Thus this result implies that smooth, physically and dynamically reasonable ultracompact objects are not viable as observational alternatives to black holes whenever these instabilities occur on astrophysically short time scales. The proof of the theorem has two parts: (i) We show that light rings always come in pairs, one being a saddle point and the other a local extremum of an effective potential. This result follows from a topological argument based on the Brouwer degree of a continuous map, with no assumptions on the spacetime dynamics, and hence it is applicable to any metric gravity theory where photons follow null geodesics. (ii) Assuming Einstein's equations, we show that the extremum is a local minimum of the potential (i.e., a stable light ring) if the energy-momentum tensor satisfies the null energy condition.

Session 2

9. **Black holes and the universe: One hundred years of cosmological constant**

   Jose P. S. Lemos, CENTRA - IST

   We look back on the introduction of the cosmological constant by Einstein that allowed him in 1917 to find the first cosmological model, of a static, finite, and boundaryless universe. We then reassess the importance of the cosmological constant in black hole physics which, for instance, permits the possibility of having cylindrical black holes in general relativity. Possible future work involving the cosmological constant is also evaluated.

10. **Kerr black holes with synchronised hair and the endpoint of the superradiant instability**

    Eugen Radu, Aveiro University

    A 50 year-old lingering question in black hole (BH) physics is the endpoint of the Kerr BH superradiant instability, triggered by massive, bosonic fields. In a recent breakthrough, East and Pretorius reported long term numerical evolutions of this instability, using a Proca field to trigger it. Evolutions terminate in stationary states of the vector field condensate synchronised with a rotating BH horizon. We show these end points are fundamental states of Kerr BHs with synchronised Proca hair. We also propose a universal (i.e. field-spin independent), analytic model for the subset of BHs that possess a quasi-Kerr horizon, and show the model is accurate for hairy BHs that may emerge dynamically from superradiance.

11. **Symmetry inheritance of scalar and gauge fields**

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

    Matter and gauge fields do not necessarily inherit the symmetries of the spacetime they live in. The assumption about the symmetry inheritance stands among the pillars of various no-hair theorems (its breaking offers a way to find novel hairy black hole solutions), as well as in the proofs of fundamental relations for black holes, such is the Smarr formula. In this talk I shall present a brief overview of recent results on the general properties of symmetry inheritance for the real and complex scalar fields [1,3,5], and the (Maxwell's and nonlinear) electromagnetic fields [2,4]. Also, I shall discuss the current list of open questions related to this problem. References: [1] I. Smolić: "Symmetry inheritance of scalar fields", Class. Quantum Grav. 32 (2015) 145010 [arXiv: 1501.04967] [2] M. Cvitan, P. Dominis Prester and I. Smolić: "Does three dimensional electromagnetic field inherit the spacetime symmetries?", Class. Quantum Grav. 33 (2016) 077001 [arXiv: 1508.03343] [3] I. Smolić: "Constraints on the symmetry noninheriting scalar black hole hair", Phys. Rev. D 95, 024016 (2017) [arXiv: 1609.04013] [4] I. Barjašić, L. Gulin and I. Smolić: "Nonlinear electromagnetic fields and symmetries", Phys. Rev. D 95, 124037 (2017) [arXiv: 1705.00628] [5] I. Barjašić and I. Smolić: "On symmetry inheritance of nonminimally coupled scalar fields", [arXiv: 1709.07456]

12. **Accretion disks around Kerr black holes with scalar hair**

    Sergio Gimeno-Soler, University of Valencia

    Kerr black holes with scalar hair (KBHsSH) are solutions of the Einstein-Klein-Gordon field equations. The metric for these solutions is stationary and axisymmetric. Furthermore, if we consider a scalar field that only interacts gravitationally (as some dark matter models), then we can solve the equations of motion of a magnetized, stationary, perfect fluid on a KBHSH background, as the scalar field does not interact with the ordinary matter. In this talk, we will present sequences of magnetized, equilibrium tori around Kerr black holes with scalar hair in the test-fluid approximation, mainly focusing on their morphological and physical features.

13. **Numerical evolutions of spherical Proca stars**

    Nicolas Sanchis-Gual, University of Valencia

    Vector boson stars, or Proca stars, have been recently obtained as fully nonlinear numerical solutions of the Einstein-(complex)-Proca system. These are self-gravitating, everywhere nonsingular, horizonless Bose-Einstein condensates of a massive vector field, which resemble in many ways, but not all, their scalar cousins, the well-known (scalar) boson stars. We report fully nonlinear numerical evolutions of Proca stars, focusing on the spherically symmetric case, with the goal of assessing their stability and the end point of the evolution of the unstable stars. Previous results from linear perturbation theory indicate that the separation between stable and unstable configurations occurs at the solution with maximal ADM mass. Our simulations confirm this result. Evolving numerically unstable solutions, we find, depending on the sign of the binding energy of the solution and on the perturbation, three different outcomes. A long-lived Proca field remnant—a Proca wig—composed by quasibound states, may be seen outside the horizon after black hole formation, with a lifetime that scales inversely with the Proca mass.

14. **On the motion of stars driven by scalar fields**

    Miguel Ferreira, CENTRA - IST

    Ultra light scalar fields have been predicted in a variety of scenarios and advocated as a possible component of dark matter. Its phenomenology includes the formation of compact regular structures - boson stars - and, in the presence of a black hole, of scalar hair. In the latter case, the scalar field modifies the geometry of the spacetime surrounding the black hole, which gives rise to non-trivial effects on the motion of bodies orbiting it. We address this question by analysing an Extreme Mass Ratio Inspiral composed of a super massive black hole supporting an ultra light scalar field, which is orbited by a compact object (a stellar mass black hole, a neutron star or a white dwarf). Given the fact that the mass of the scalar field is very small, we use a perturbative approach to investigate its contribution to the motion of the compact object. We find that the presence of the scalar field leaves imprints on the orbital motion of the compact object, particularly it is responsible for the appearance of resonant orbits whose location depend on its mass. The existence of these resonances may enable angular momentum exchange between the scalar field and the orbiting object, giving rise to mechanisms similar to planet migration in proto-planetary discs. These effects have a direct consequence on the orbital evolution of binary systems and may be used as probes for the existence of scalar fields.

15. **Self-similar accretion in thin disks around near-extremal black holes**

    Roberto Oliveri, Universite Libre de Bruxelles (ULB)

    Near-extremal black holes display conformal symmetry in their near-horizon region, where critical phenoma might take place. We first show how conformal symmetry constrains physical observables in the near-horizon region of near-extremal black holes. Then, we introduce the Novikov-Thorne model of accretion thin disk and discuss its main features. Finally, we investigate the physics of accretion thin disks in the extremely high spin regime, where (a) a novel phase transition occurs and (b) the critical (self-similar) behavior of accretion is manifest. The talk is mainly based on arXiv:1703.00022 [astro-ph.HE] with G. Compère.

16. **Multipole moments of exotic ultracompact objects**

    Guilherme Raposo, Sapienza University of Rome

    The newborn gravitational-wave astronomy provides a new way to probe gravity in the strong-field regime and to test the geometry of dark ultracompact objects. Recently, it was shown that tidal Love numbers (directly related to the tidally induced multipole moments) may be used as a discriminator for exotic compact objects and as a smoking gun for new physics at the horizon scale. In this talk I will focus on the spin-induced multipole moments of compact rotating objects and analyze the behavior of these quantities in the black-hole limit.

Session 3

17. **Recent developments on the absorption of fields by black holes**

    Luís Carlos Bassalo Crispino, Universidade Federal do Pará

    I will present some recent results on the absorption and scattering of fields by different kinds of black holes, with emphasis on the absorption of electromagnetic waves by Kerr black holes.

18. **Self gravitating scalar field configurations around black holes**

    Juan Carlos Degollado, Physical Sciences Institute, UNAM

    We present new approximate solutions of the spherically symmetric Einstein-Klein-Gordon system which represent self-gravitating scalar configurations surrounding black holes. These configurations interpolate between boson stars and Schwarzschild black holes dressed with the long-lived scalar test field distributions. Nonlinear numerical evolutions of initial data sets extracted from our approximate solutions support the validity of our approach. Arbitrarily large lifetimes are possible, although for the parameter space that we analyze in this work they seem to decay faster than the linear quasi-bound states. Finally, we speculate about the possibility that these configurations could describe the innermost regions of dark matter halos.

19. **Black hole lasers powered by axion superradiant instabilities**

    João Rosa, University of Aveiro

    The superradiant instability can lead to the generation of extremely dense axion clouds around rotating black holes. We show that, despite the long lifetime of the QCD axion with respect to spontaneous decay into photon pairs, stimulated decay becomes significant above a minimum axion density and leads to extremely bright lasers. The lasing threshold can be attained for axion masses $\mu \gtrsim 10^{-8}$ eV, which implies superradiant instabilities around spinning primordial BHs with mass $\lesssim 0.01 M_\odot$. We further show that lasing can be quenched by Schwinger pair production, which produces a critical electron-positron plasma within the axion cloud. Lasing can nevertheless restart once annihilation lowers the plasma density sufficiently, resulting in multiple laser bursts that repeat until the black hole spins down sufficiently to quench the superradiant instability. In particular, axions with a mass $\sim 10^{-5}$ eV and primordial black holes with mass $\sim 10^{24}$ kg, which may account for all the dark matter in the Universe, lead to millisecond-bursts in the GHz radio-frequency range, with peak luminosities $\sim 10^{42}$ erg/s, suggesting a possible link to the observed fast radio bursts.

20. **Instabilities of charged black holes and small hairy black holes**

    Ramon Masachs, University of Southampton

    Reissner-Nordstrom black holes (RN BH) in AdS suffer from two linear instabilities, superradiance and the near horizon instability. The endpoint of these instabilities is a hairy black hole. I will present an analytic perturbative construction of these hairy black holes and analyse the phase space of solutions. In asymptotically flat spacetime, inspired by the black hole bomb of Press and Teukolsky, one can surround a RN BH by a reflecting box. It is known that this system suffers from superradiant instability. We show that the near horizon instability is also present there. As in the AdS case, the endpoint is a hairy black hole that we construct analytically in a perturbative expansion. We comment on the matter content of the box.

21. **Computing geodesics with SageMath**

    Karim Van Aelst, Laboratoire Univers et Théories, Observatoire de Paris

    SageMath is a free open-source software with capabilities regarding differential geometry and tensor calculus on manifolds. The last releases of SageMath include new features allowing to compute and study geodesics on any pseudo-Riemannian manifold. The talk will present the working principles of these functionalities (numerical integration, interpolation, plots) and provide examples based on familiar black hole spacetimes.

22. **Kerr-Newman-(anti-)de Sitter and charged test particles**

    Jiri Vesely, Charles University

    The Kerr-Newman-(anti-)de Sitter space-time is the most general stationary black hole solution within the framework of classical 4D general relativity, describing a charged rotating black hole with (anti-)de Sitter asymptotics due to a non-zero cosmological constant. After briefly reviewing some of the space-time's general properties and summarising the possible extremal configurations, we discuss selected trajectories of charged test particles in the space-time using Lagrangian formalism and focusing on the equatorial plane and the axis.

23. **Progress in generalising the BSW effect to extremal rotating electrovacuum black holes**

    Filip Hejda, CENTRA - IST & Charles University

    In the last decade, a lot of literature emerged about the Bañados-Silk-West-type high-energy particle collisions near extremal black holes. Despite this, the effect still has not been studied under the most general circumstances. In our previous work [Phys. Rev. D 95, 084055 (2017)], we generalised it to the situation where both dragging and electromagnetic field is present. Unifying these two cases that have been previously studied separately, we concluded that four types of the effect are theoretically possible, resulting from different combinations of kinematic restrictions. In the work in progress, we want to achieve a further generalisation by relaxing the restriction to the equatorial motion. However, this leads to severe complications, as test particles motion is chaotic in a general ("dirty") black hole spacetime. To avoid this obstacle, whilst preserving some model independence, we turn to Carter's spacetime with separable Hamilton-Jacobi equation. Techniques used for the equatorial motion can be applied to this case, but the generalisation is not unique. Thus, this talk will focus on comparison of the available methods, using preliminary results for Kerr-Newman spacetime, and on their respective advantages and drawbacks.

24. **From relativistic geodesy to black holes**

Dennis Philipp, ZARM, University of Bremen

Methods, notions, and concepts developed in the field of relativistic geodesy also have direct application to astrophysics of compact objects such as black holes. This connection will be outlined and, in particular, I will review the definition(s) of the relativistic geoid and the corresponding spacetime foliation into isochronometric surfaces in general. Furthermore, the deviation of timelike geodesics will be discussed as well as the exact timing of clocks in space and redshift formulae for various situations in both fields, geodesy and black hole physics.

Session 4

25. **Massive gravitons in arbitrary spacetimes**

Mikhail Volkov, University of Tours

A consistent theory of massive gravitons in arbitrary spacetimes is presented.

26. **Quasinormal modes of static black holes in dilatonic Einstein-Gauss-Bonnet theory**

Jose Luis Blazquez Salcedo, Oldenburg University

We present a study of the quasinormal mode spectrum of static Einstein-Gauss-Bonnet-dilaton black holes. Both axial and polar perturbations are analysed for arbitrary values of the coupling constants of the theory. We compare the spectrum of the Schwarzschild black hole with the spectrum of the dilatonic black holes, which present a new component related with the scalar field. Some black holes become unstable in the large dilaton coupling regime. We study the implications of this quasinormal mode spectrum on the emission of gravitational waves during the ringdown phase of astrophysical black holes.

27. **Generalized collapsing matter shells with rotation**

Jorge Rocha, U. Barcelona

I will present a method to analytically construct spacetimes describing collapses (or bounces) of thin shells with rotation, in arbitrary higher odd dimensions. Based on this, an extensive analysis of the various possible shell trajectories has been conducted, by varying spacetime dimensionality, shell velocity at infinity and equation-of-state parameter, in addition to the shell's mass and spin. I will discuss results of the scan of this large parameter space, testing the weak and dominant energy conditions along the way. In the end I establish a connection with the celebrated cosmic censorship conjecture.

28. **Wormhole solutions in generalized hybrid metric-Palatini gravity**

João Luis Rosa, CENTRA - IST

In this work, we consider wormhole solutions in the recently proposed generalized hybrid metric-Palatini theory, given by the gravitational action $f(R, \mathcal{R})$, where R is the metric Ricci scalar, and $\mathcal{R} \equiv \mathcal{R}^{ab} g_{ab}$ is the Palatini curvature which is defined in terms of an independent connection. The gravitational action in the scalar-tensor representation is presented in terms of two scalar fields and the equations of motion are obtained. It is shown that the higher-order curvature terms, which may be interpreted as a gravitational fluid, support these nonstandard wormhole geometries, and the stress-energy tensor of matter satisfies the weak energy condition at the throat. More specifically, numerical solutions are obtained, by considering choices for the redshift and shape functions, and for the potential, which describe asymptotically flat wormhole geometries.

29. **A simple test for stability of black hole**

    Masashi Kimura, CENTRA - IST

    We study a sufficient condition to prove the stability of a black hole when the master equation for linear perturbation takes the form of the Schrödinger equation. If the potential contains a small negative region, usually, the S-deformation method was used to show the non-existence of unstable mode. However, in some cases, it is hard to find an appropriate deformation function analytically because the only way known so far to find it is a try-and-error approach. In this talk, we show that it is easy to find a regular deformation function by numerically solving the differential equation such that the deformed potential vanishes everywhere, when the spacetime is stable. Even if the spacetime is almost marginally stable, our method still works. We also discuss a simple toy model which can be solved analytically, and show the condition for the non-existence of a bound state is the same as that for the existence of a regular solution for the differential equation in our method. From these results, we conjecture that our criteria is also a necessary condition.

30. **Electromagnetic perturbations of black holes in general relativity coupled to nonlinear electrodynamics**

    Bobir Toshmatov, Silesian University in Opava

    The electromagnetic perturbation of an exact black hole solutions of the general relativity coupled to nonlinear electrodynamics will be presented. It will be shown that unlike the case in linear electrodynamic field, in the nonlinear electrodynamic field, effective potentials of electrically and magnetically charged black holes are different, consequently, their quasinormal frequencies as well. As a special case, quasinormal modes and stability of new black hole solution in nonlinear electrodynamics will be presented.

31. **Quasinormal Modes and Strong Cosmic Censorship**

    Kyriakos Destounis, Instituto Superior Tecnico - CENTRA

    The fate of Cauchy horizons, such as those found inside charged black holes, is intrinsically connected to the decay of perturbations exterior to the event horizon. As such, the validity of the strong cosmic censorship (SCC) conjecture is tied to how effectively the exterior damps fluctuations. Here, we study massless scalar fields in the exterior of Reissner-Nordstrom-de-Sitter black holes. Their decay rates are governed by quasinormal modes of the black hole. We identify three families of modes in these spacetimes: one directly linked to the photon sphere, well described by standard WKB-type tools; another family whose existence and timescale is closely related to the de-Sitter horizon. Finally, a third family which dominates for near-extremally-charged black holes and which is also present in asymptotically flat spacetimes. The last two families of modes seem to have gone unnoticed in the literature. We give a detailed description of linear scalar perturbations of such black holes, and conjecture that SCC is violated in the near extremal regime.

32. **Extended bodies in general relativity**

    Vítek Veselý, Charles University, Prague

    In a curved spacetime, free test point masses follow geodesics. Extended bodies can be approximated by a system of point masses which act on one another. The simplest example of an extended body is a "dumbbell" consisting of two point masses, whose distance can be modified as a function of time and other variables.

The trajectory of the geometric centre of the dumbbell can deviate from a geodesic. We discuss various possible approaches to such a problem and review a purely relativistic effect of slowing down the pace of radial fall of an oscillating dumbbell in Schwarzschild spacetime. We examine effects not reported previously in the literature such as the limits of the model for high frequencies of oscillations and the impact of multiple oscillations on both position and velocity of the dumbbell.

Session 5

33. **Symmetries, Holography and phase transition for 2D black holes**

Mariano Cadoni, Department of Physics, University of Cagliari

We discuss the pattern of conformal symmetry breaking for a class of two-dimensional AdS black holes and its realisation in the holographically dual conformal field theory. The effect of this breaking is the generation of both a mass gap in the infrared and of Goldostone modes, which accounts for the microscopic entropy of the 2D black hole. The symmetry breaking is also related to a zero-temperature phase transition, which from the point of view of higher-dimensional black holes can be thought as a (quantum gravity) spontaneous dimensional reduction to two dimensions.

34. **Holographic Collisions, Phase Transitions and Inhomogeneous Horizons**

Miguel Zilhão, Instituto Superior Tecnico

Understanding the dynamics of out-of-equilibrium matter in strongly coupled systems is an important and challenging problem in theoretical physics. A particularly interesting example is the Quark-Gluon Plasma formed in relativistic colliders such as RHIC or the LHC, which motivates the study of the relaxation process in strongly coupled non-abelian field theories. In this talk it will be shown how we use holography to map the dynamics of a non-conformal gauge theory to a gravitational system, and the strategy we use to numerically evolve Einstein's equations. With these tools, we can perform holographic Heavy Ion collisions at different energies in gauge theories with different degrees of non-conformality, and analyse corresponding relaxation times. We will also see how we can study the spinodal instability of a four-dimensional, strongly-coupled gauge theory with a first-order thermal phase transition by evolving the dual gravitational description, which is afflicted by a Gregory-Laflamme instability. We numerically evolve Einstein's equations to follow the instability until the system settles down to some stationary, inhomogeneous black brane, and show that the time evolution of the instability and the final states are accurately described by second-order hydrodynamics.

35. **Quasinormal modes of Kerr-AdS_5 via Isomonodromic Deformations**

José Julián Barragán Amado, Universidade Federal de Pernambuco & University of Groningen

We compute the quasinormal modes of a massive scalar field scattered by a Kerr-AdS_5 black hole. On one had, these frequencies are obtained by solving the radial differential equation numerically and on the other hand, in therms of an asymptotic expansions of the Painlevé VI tau-function.

36. **Chaos & bound-states in anti-de Sitter spacetime**

Jorge Lopes, CENTRA - IST

Chaos is an emergent phenomenon in a wide variety of nonlinear scenarios. Here, we provide numerical evidence for the presence of, and characterize, chaos in the Einstein-Klein-Gordon system in asymptotic anti-de Sitter spacetime. Our results indicate that chaos signals either delayed collapse or formation of regular, bound scalar eld states.

37. **Exact gravitational field of a tachyon moving in the (anti-)de Sitter universe**

Ondřej Hruška, Institute of Theoretical Physics, Faculty of Mathematics and Physics, Charles University

The Schwarzschild metric, describing a static source, belongs to the class of so-called AI-metrics (in the classification of Ehlers and Kundt). The class of B-metrics can be formally obtained from the A-metrics via transformation using a complex unit. In 1974, J. R. Gott demonstrated that the BI-metric can be interpreted as describing a tachyonic source moving at superluminal velocity along a spacelike trajectory in flat space. We now generalize this interpretation to any value of a cosmological constant. Specifically, we interpret the BI-metric with the cosmological constant as an exact gravitational field of a tachyon moving in the (anti-)de Sitter universe. This is a natural counterpart of the static Schwarzschild–(anti-)de Sitter AI-metric.

38. **Generalized Skyrmions and hairy black holes in asymptotically AdS_4 spacetime**

Ilya Perapechka, Belarusian State University

We investigate the properties of spherically symmetric black hole solutions in the generalized Einstein-Skyrme model theory in four-dimensional asymptotically anti-de Sitter space-time. The dependencies of the Skyrmion fields on the cosmological constant and on the strength of the effective gravitational coupling are examined. We show that the increase of the absolute value of the cosmological constant qualitatively yields the same effect as increasing of the effective gravitational coupling. We confirm that, similar to the model in the asymptotically flat space-time, a necessary condition for the existence of black holes with Skyrmionic hair is the inclusion of the Skyrme term.

39. **Hysteresis in QFTs Dual to Spherical Black Holes**

Matteo Tuveri, University of Cagliari and INFN Cagliari

Usually, one uses holographic dualities to learn about transport coefficients in the hydrodynamic limit of strongly coupled QFTs by investigating bulk gravity configurations. However, it is still possible to change the paradigm, i.e. to use transport properties of the dual quantum field theory to infer about the behaviour of bulk gravity solutions. Following this perspective, in this talk I will show, using the AdS/CFT framework, that transport coefficients computed in a quantum field theory can lead to a better understanding of black hole physics. In particular, I will focus on the shear viscosity and its relationship with thermodynamics of charged black holes. Interestingly enough, I will show that the shear viscosity to entropy density ratio in the hydrodynamic limit of the QFT dual to charged black holes exhibits a temperature-dependent hysteresis, reflecting the rich phase structure, in particular metastabilities and Wan der Walls-like behaviour, of charged black holes.

40. **Geometric polarization of plasmas and Love numbers of AdS black branes**

Raimon Luna, Universitat de Barcelona

We use AdS/CFT holography to study how a strongly-coupled plasma polarizes when the geometry where it resides is not flat. We compute the linear-response polarization coefficients, which are directly related to the static two-point correlation function of the stress-energy tensor. In the gravitational dual description, these parameters correspond to the tidal deformation coefficients—the Love numbers—of a black brane. We also compute the coefficients of static electric polarization of the plasma.

Session 6

41. **Neutron stars in vector-tensor theories**

    Masato Minamitsuji, CENTRA, IST, U-Lisboa

    We investigate neutron star (NS) solutions in the most general vector-tensor theories with second-order equations of motion. We consider the polytropic as well as Damour and Esposito-Farèse (DEF) equations of state (EOSs) to study how the vector field A_μ affects the structure of NSs. In the presence of cubic and quartic vector Galileons with negative coupling constants, there is a tendency that the mass of NSs increases compared to that in GR. This effect is more significant for the larger temporal vector component A_0 at the center of NSs. For the polytropic EOS it is difficult to realize the the largest observed mass $\simeq 2M_\odot$ of NSs , but for the DEF EOS the presence of cubic and quartic Galleons can easily reach the mass $2M_\odot$ even if the mass of the GR counterpart is smaller than $2M_\odot$. On the other hand, in the presence of sixth order and intrinsic vector-field couplings, we show that the NS solution in GR with a trivial vector field is the unique solution.

42. **Superradiance in the BTZ black hole**

    Hugo Ferreira, Pavia University/INFN Pavia

    We show the existence of superradiant modes of massive scalar fields propagating in BTZ black holes when certain Robin boundary conditions are imposed at spatial infinity. These never include the commonly considered Dirichlet boundary conditions. Given the anti-de Sitter asymptotics of these spacetimes and the inherent ambiguity in choosing a natural notion of time for a distant observer, we classify as superradiant those mode solutions whose energy flux across the horizon is towards the exterior region. Differently from rotating, asymptotically flat black holes, not all modes which grow up exponentially in time are superradiant; for some of these modes, the instability is caused by the AdS asymptotics.

43. **A cosmic no-hair theorem for spherically symmetric spacetimes**

    Pedro F. C. Oliveira, Instituto Superior Técnico

    A cosmic no-hair statement describes an isotropization of a spacetime with a positive cosmological constant. In this talk, we shall look at what happens beyond the cosmological horizon in the case involving the presence of a massless scalar field, the novelty here being the treatment of a cosmological black hole scenario. In this setting, an observer who heads into the cosmological region and towards infinity will see the metric asymptotically approaching that of the de Sitter spacetime. To this effect, we start by establishing the unboundedness of the radius function and then estimate the decay rates of the fields. Finally, we prove the cosmic no-hair theorem concerning this family of spacetimes.

44. **Thermal Stability of Quantum Black Holes**

    Partha Sarathi Majumdar, Physics Department, RKM Vivekananda University, India

    Starting with generic properties of a canonical quantum theory of gravity, we discuss a set of criteria for thermal stability of black holes under Hawking radiation. The actual derivation of these criteria do not require any aspect of classical geometry (e.g., metric), even though the criteria themselves can be applied to predict the thermal stability of large classes of black holes, once their metric is known. As fiducial checks, some known examples of black holes will be discussed for their thermal stability. For rotating, charged black holes, some unexpected features in their thermal behavior will be brought out.

45. **Quasinormal modes and greybody factors in Einstein-Born-Infeld dilaton black holes in 1+3 dimensions**

Grigorios Panotopoulos, CENTRA, Técnico Lisboa

We have analysed in detail the propagation of a minimally coupled massless scalar field in the gravitational background of the Einstein-Born-Infeld dilaton charged black hole in four dimensions. We have obtained exact analytical expressions for the absorption cross section as well for the quasinormal spectrum of the black holes. The frequencies turn out to be purely imaginary, and we have confirmed our analytical expression employing a recently developed numerical scheme.

46. **Scalar field coupling with matter inside scalarized neutron stars**

Nicola Franchini, University of Nottingham

In scalar-tensor theories, spontaneous scalarization is a phase transition that can occur in ultra-dense environments such as neutron stars. The scalar field develops a non-trivial configuration once the stars exceeds a compactness threshold. If the scalar exhibits some additional coupling to matter, it could give rise to significantly different microphysics in these environments. In this presentation I will show a toy model in which the photon is given a large mass when spontaneous scalarization occurs. The results demonstrate clearly the effectiveness of spontaneous scalarization as a Higgs-like mechanism in neutron stars.

47. **Shaping the horizon of black holes influenced by external static sources**

Marek Basovnik, Institute of Theoretical Physics, Charles University

We present the shape and other geometric properties of the static black hole horizon in the proper distance description and their influence in the presence of external static sources. Examples of sources are the superposition of static ring solutions and the presence of other black holes allowing static configuration. For these examples, we show a direct shape and their relationship to curvature invariants.

48. **Holographic complexity of the BTZ black hole**

Ignacio Reyes, Wuerzburg University

In recent years, gauge/gravity duality has led to many new insights into quantum gravity by unfolding its connection to quantum information. In particular, the study of black holes remains at the center of attention. In this context, we consider subregion complexity for the BTZ black hole: we show that it is temperature independent up to topological terms, and interpret it as a problem of information compression.

Session 7

49. **Rigidly-rotating thermal states on black hole space-times**

Victor E. Ambrus, West University of Timisoara

Using the relativistic Boltzmann equation, we study equilibrium states undergoing rigid rotation on black hole space-times. We highlight the formation of speed-of-light surfaces (i.e. where co-rotating observers travel at the speed of light) and discuss their topology.

50. **Thermodynamics in a Rotating Background**

Remo Garattini, University of Bergamo

We consider the effects of rotations on the calculation of some thermodynamical quantities like the free energy, internal energy and entropy. In ordinary gravity, when we evaluate the density of states of a scalar field close to a black hole horizon, we obtain a divergent result which can be kept under control with the help of some standard regularization and renormalization processes. We show that when we use the Gravity's Rainbow approach such regularization/renormalization processes can be avoided. A comparison between the calculation done in an inertial frame and in a comoving frame is presented.

51. **Semiclassical corrections to a regularized Schwarzschild metric**

Hristu Culetu, Ovidius University

A version of the Schwarzschild metric to be valid in microphysics is proposed. The source fluid is anisotropic with $p_r = -\rho$ and fluctuating tangential pressures. At large distances with respect to the Compton wavelength associated to the source particle, they do not depend on the mass m of the source and everywhere depend on $\hbar$ and the velocity of light c but not on the Newton constant G. The particle may be a black hole for $m \geq m_P$ only and when $m = m_P$ becomes an extremal black hole. The Komar energy W of the gravitational fluid is mc^2 for $\hbar = 0$ and at large distances and vanishes at $r_0 = 2\hbar/emc$. The WEC is violated when $r < r_0/2$ due to the negative tangential pressures. The horizon entropy for the extremal black hole is finite though W and the temperature T are vanishing there.

52. **Butterfly Effect in 3D Gravity**

Mohammad M. Qaemmaqami, Institute for Research in Fundamental Sciences (IPM)

We study the butterfly effect by considering shock wave solutions near the horizon of the anti–de Sitter black hole in some three-dimensional gravity models including 3D Einstein gravity, minimal massive 3D gravity, new massive gravity, generalized massive gravity, Born-Infeld 3D gravity, and new bigravity. We calculate the butterfly velocities of these models and also we consider the critical points and different limits in some of these models. By studying the butterfly effect in the generalized massive gravity, we observe a correspondence between the butterfly velocities and right-left moving degrees of freedom or the central charges of the dual 2D conformal field theories.

53. **Static spherically symmetric Seth elastic bodies in Newtonian gravity**

Artur Alho, CAMGSD

We consider static spherically symmetric Seth elastic bodies (B. R. Seth Philosophical Transactions of the Royal Society of London. Series A, Mathematical and Physical Sciences Vol. 234, No. 738 (Apr. 27, 1935), pp. 231-264) in Newtonian gravity. We reduce the field equations to a two dimensional analytic dynamical system on compact state space. It is shown that the Seth's model does not possess solutions of compact support, and thus they do not provide a physical reasonable model for astrophysics. The proof is based on the desingularisation of a dicritical degenerate singular point of the system, which shows that all solutions are tangent to a center manifold.

54. **Evidence of cosmic strings by the observation of the alignment of quasar polarization axes on Mpc scale**

Reinoud Jan Slagter, ASFYON Astronomisch Fysisch Onderzoek Nederland

The recently found alignment of the polarization axes of quasars in large quasar groups on Mpc scales, can be explained by general relativistic cosmic string networks. By considering the cosmic string as a result of spontaneous symmetry breaking of the gauged U(1) abelian Higgs model with topological charge n, many stability features of the n-vortex solutions of superconductivity can be taken over. Decay of the high multiplicity (n) super-conducting vortex into a lattice of n vortices of unit magnetic flux is energetically favourable. The temporarily broken axial symmetry will leave an imprint of a preferred azimuthal-angle on the lattice. The stability of the lattice depends critically on the parameters of the model, especially when gravity comes into play. In order to handle the strong nonlinear behavior of the time-dependent coupled field equations of gravity and the scalar-gauge field, we will use a high-frequency approximation scheme to second order on a warped 5D axially symmetric spacetime with the scalar-gauge field residing on the brane. We consider different winding numbers for the subsequent orders of perturbations of the scalar field. A profound contribution to the energy momentum tensor comes from the bulk spacetime and can be understand as "dark"-energy. The cosmic string becomes super-massive by the contribution of the 5D Weyl tensor on the brane and the stored azimuthal preferences will not fade away. During the recovery to axial symmetry, gravitational and electro-magnetic radiation will be released. The perturbative appearance of a non-zero energy-momentum component $T_{t\varphi}$ can be compared with the phenomenon of bifurcation along the Maclaurin-Jacobi sequence of equilibrium ellipsoids of self-gravitating compact objects, signaling the onset of secular instabilities. There is a kind of similarity with the Goldstone-boson modes of spontaneously broken symmetries of continuous groups. The recovery of the SO(2) symmetry from the equatorial eccentricity takes place on a time-scale comparable with the emission of gravitational waves. The emergent azimuthal-angle dependency in our model can be used to explain the aligned polarization axes in large quasar groups on Mpc scales. Spin axis direction perpendicular to the major axes of large quasar groups when the richness decreases, can be explained as a second order effect in our approximation scheme by the higher multiplicity terms. The preferred directions are modulo $\frac{180^o}{i}$, with i an integer dependent on the i-th order of approximation. When more data of quasars of high redshift will become available, one could proof that the alignment emerged after the symmetry breaking scale and must have a cosmological origin. The effect of the warp factor on the second-order perturbations could also be an indication of the existence of large extra dimensions.

55. **Recoling black holes in analytical and numerical galaxy potential**

Majda Smole, Astronomical Observatory, Belgrade

During a BH merger asymmetric emission of gravitational wave radiation can lead to BH kick. Gravitational wave recoil can completely eject black hole (BH) from it's host if the kick velocity is larger than the escape velocity from the galaxy,which could affect growth of supermassive black holes through mergers. We investigate trajectories of recoiling BHs in analytical and numerical host galaxy models whose components are dark matter halo, bulge and disc. In order to test how galaxy formation channel affects its capability to retain the central BH, we separately model major (1:1) and minor (1:10) merger galaxy remnants. In numerical models BHs are ejected from their host before the merger remnant becomes virialized, so escape velocities are lower in numerical models compared to analytical models where galaxy potential is unperturbed. This effect is especially pronounced after major mergers.

56. **An emergent Van der Waals-like description of a SAdS black hole**

Andrés Felipe Vargas Sánchez, Universidad de los Andes

An emergent semiclassical statistical mechanical approach to black hole entropy based on Van der Waals horizon thermodynamics for the Schwarzschild-Anti de Sitter solution is presented. In particular, an heuristic picture of the black hole as a Van der Waals gas of spacetime atoms obeying Maxwell-Boltzmann statistics will be discussed. Following this a canonical partition function is proposed from which the black hole equation of state is obtained and the Bekenstein-Hawking entropy is recovered.

Session 8

57. **Ultra-high energy particle collisions near black holes and singularities and super-Penrose process**

    Oleg Zaslavskii, V. N. Kharkov Karazin National University

    A brief review of the effect of acceleration of particles to unbounded energies in their centre of mass frame due to collision is suggested. The main emphasis is made on the properties of debris after collision that can be observed at infinity. When collission occurs near a black hole, the efficiency of the process is limited. However, near singularities an unbounded efficiency (the so-called super-Penrose process) becomes possible. Consideration applies to a wide class of axially symmetric stationary rotating spacetimes.

58. **On the influence of spin in the formation of singularities**

    Paulo Luz, CENTRA and CMAT

    The gravitational collapse of an inhomogeneous uncharged matter cloud with non-null average (intrinsic) spin in a general Szekeres space-time is studied. Using the Einstein-Cartan theory to include the effects of (intrinsic) matter spin in General Relativity, the gravitational collapse of a perfect fluid with non-null average spin density is analyzed and it is shown that if during the collapse the matter cloud is composed by effective dust and certain generic constraints on the initial data are verified, a shell-focusing or shell-crossing singularity will not form.

59. **On Black Holes and Quantum Information**

    Adil Belhaj, Sultan Moulay Slimane University

    In this talk, qubit information systems from black holes in string/ M-theory are discussed.

60. **Supersymmetry breaking and singularity in string theory**

    Kunihito Uzawa, Kwansei Gakuin University

    The supersymmetry arises in certain theories of fermions coupled to gauge fields and gravity in a spacetime of higher dimensions as well as 4 dimensions. Dynamical brane backgrounds in supergravity and string theory have mainly been studied for the class of purely bosonic solutions only, but recent developments involving time-dependent brane solution have made it clear that one can get more information by asking what happens on supersymmetric systems. In this talk, we present exact supersymmetric solutions of dynamical D-brane, M-brane backgrounds in the 10- and 11-dimensional supergravities. We also show supersymmetry breaking, and discuss geometric features near the singularity and the black hole horizon.

61. **Absorption of scalars by extremal black holes in string theory**

    Filipe Moura, LIP

We show that the low frequency absorption cross section* of minimally coupled test massless scalar fields by extremal spherically symmetric black holes in d dimensions is equal to the horizon area, even in the presence of string–theoretical α' corrections. Classically one has the relation $\sigma = 4GS$ between that absorption cross section* and the black hole entropy. By comparing in each case the values of the horizon area and Wald's entropy, we discuss the validity of such relation in the presence of higher derivative corrections for extremal black holes in many different contexts: in the presence of electric and magnetic charges; for nonsupersymmetric and supersymmetric black holes; in $d = 4$ and $d = 5$ dimensions. The examples we consider seem to indicate that this relation is not verified in the presence of α' corrections in general, although being valid in some specific cases (electrically charged maximally supersymmetric black holes in $d = 5$). We argue that the relation should be valid for the absorption cross section* of scalar fields which are part of the model (and not "test"), at least in string theory.

62. **Graph theory and quantum information**

Bensed Mohammed, Ibn Tofail University

We discuss the relationship between graph theory and quantum information systems via black holes. Using colored toric geometry, we give graphical representations of information theory.

63. **Defining energy in general relativity**

Diogo Bragança, Stanford University

We analyse the properties of Brown-York's and Lynden-Bell and Katz's quasilocal energy definitions in specific spacetimes and derive the laws of black hole mechanics that come from each definition. Comparing the results in the Newtonian limit, we find a suitable interpretation for the localization of gravitational energy for each definition. The quasilocal laws of black hole mechanics allow us to choose a more natural energy definition among the two.