One Hundred Years of Strong Gravity

10-12 June 2015
Instituto Superior Técnico, Lisbon, Portugal

List of Abstracts

Invited talks (45 minutes):

1. **Black holes in massive gravity**
   Eugeny Babichev (LPT, Orsay, France)

   I will review the black hole solutions of massive and bi-gravity gravity theories and outline the main results on the stability of these solutions against small perturbations. I will show that massive and bi-gravity accommodate exact black hole solutions, analogous to those of General Relativity. Apart from GR-like solutions, hairy black holes also exist in massive gravity. Due to the presence of extra degrees of freedom, the stability properties of black holes in massive and bi-gravity differ from those in GR. In particular, the bi-Schwarzschild black hole exhibits an unstable spherically symmetric mode, while the bi-Kerr geometry is also generically unstable, both against the spherical mode and against superradiant instabilities.

2. **Neutron stars as probes of strong gravity**
   Emanuele Berti (University of Mississippi, USA)

   Neutron stars are excellent astrophysical laboratories for high-energy physics and strong-field gravity. I will discuss several ideas revolving around strong gravity tests with neutron stars, including:

   1) the degeneracy between strong gravity tests and our ignorance of the high-density equation of state of matter,

   2) the possibility to parametrize deviations from general relativity in a large class of modified gravity theories, and

   3) recent work on the "spontaneous scalarization" phenomenon first proposed by Damour and Esposito-Farese.

3. **Hairy black holes in scalar tensor theories**
   Christos Charmousis (LPT Orsay, France)

   We will review scalar tensor theories of gravity, where we have an additional scalar field coupling non minimally to the metric tensor. By means of a theorem given by Horndeski back in 1974 we will briefly discuss the most general of these theories acquiring second order field equations. We will examine a particular sub-class of Horndeski theory which has interesting properties with respect to the cosmological constant problem. We will then find black hole solutions of this subclass which in some cases will be identical to GR solutions. The novel ingredient will be the presence of a time and space dependent scalar field. As we will see time dependence and higher order Galileon terms will bifurcate no hair theorems and provide scalar tensor black holes with a non trivial scalar field.

4. **Exploring black hole spacetimes with SageManifolds**
   Eric Gourgoulhon (LUTH Observatoire de Paris, France)

   I shall first present SageManifolds, which is an extension of the modern open-source computer algebra system SageMath towards differential geometry and tensor calculus. Then I will illustrate the use of SageManifolds on various computations regarding black hole spacetimes in general relativity and alternative theories of gravitation.

5. **Accreting black holes as probes of strong-field gravity**
   Leonardo Gualtieri (Sapienza University of Rome, Italy)

   Quasi-periodic oscillations observed in the X-ray flux emitted by accreting black holes carry the imprint of the strong-field regime of gravity. We study how this signal is affected by high-curvature corrections of GR, such as those predicted by Einstein-Dilaton-Gauss-Bonnet gravity. To this aim, we extend current black hole solutions in this theory, to the case of large values of the coupling constant and of the rotation rate. We find that a detection of quasi-periodic oscillations with the expected sensitivity of the proposed ESA mission LOFT would set stringent constraints on the parameter space of this theory.

6. **High energy particle collision and collisional Penrose process near a Kerr black hole**
Tomohiro Harada (Rikkyo University, Japan)

The centre-of-mass energy of two colliding test particles near a rapidly rotating Kerr black holes can be arbitrarily if the angular momentum of the particle is fine-tuned to some critical value. This phenomenon is robust as it is founded on the basic properties of geodesic orbits around a near-extremal Kerr black hole. On the other hand, the maximum energy of the acceleration is subjected to several physical effects. The ejecta of such a high-energy collision can convey more energy than that of the incident colliding particles to infinity. The extraction efficiency can be considerably high in some cases.

7. **Stationary, asymptotically flat black holes with harmonic scalar fields.**
Carlos A.R. Herdeiro (Universidade de Aveiro, Portugal)

Over the last year, new families of asymptotically flat, regular on and outside a horizon, stationary black holes with scalar hair have been found, exploring the possibility that scalar fields and the geometry may not share the same symmetries. In particular stationary BH geometries are compatible with a complex scalar field with harmonic time dependence. In four dimensions, such solutions interpolate between Kerr black holes and gravitating solitons called boson stars and have a close connection to the superradiant instability of Kerr black holes. I shall describe various physical properties of these solutions and potential phenomenological applications. I will also briefly discuss higher dimensional generalizations, wherein a more subtle picture emerges since hairy black holes still exist but they do not reduce globally to Myers-Perry black holes.

References

(1) Carlos A. R. Herdeiro and Eugen Radu, "Kerr black holes with scalar hair", Phys.Rev.Lett. 112 (2014) 221101

(2) Yves Brihaye, Carlos Herdeiro and Eugen Radu, "Myers-Perry black holes with scalar hair and a mass gap", Phys.Lett. B739 (2014) 1-7

(3) Carlos Herdeiro and Eugen Radu, "Construction and physical properties of Kerr black holes with scalar hair", To appear in CQG, e-Print: arXiv:1501.04319 [gr-qc]

(4) Carlos A. R. Herdeiro and Eugen Radu, "Asymptotically flat black holes with scalar hair: a review", To appear in IJMPD, e-Print: arXiv:1504.08209

8. **Probing the non-linear dynamics of the black hole-axion system by gravitational waves**
Hideo Kodama (KEK,Japan)

The superradiant instability of tiny-mass scalar fields around a rotating black hole provokes rich phenomena such as periodic occurrence of bose nova and complicated interactions of different unstable modes, if non-linear self-interactions of the scalar fields are taken into account. The very fascinating point of these phenomena is that they may actually occur in astrophysical black holes in the Axiverse. In that case, we can observe them through the detection of continuous and bust-type gravitational waves emitted from astrophysical black hole-axion/scalar field systems, and obtain information on the axion mass and decay constant. In the present talk, after overviewing the basic idea of this approach and the main results obtained so far, I report the results of our recent work on this problem in collaboration with Hirotaka Yoshino. In particular, we point out that the instability growth rate does not necessary decrease with the radial quantum number of modes, and show some results of our numerical simulations for the non-linear evolution of an axion cloud with multi-mode excited initially. We further show that the energy emission rates of gravitational waves from axion clouds are much larger than nave estimates by the quadrupole formula both for continuous and burst types in some cases. On the basis of this new estimation, we argue that we can obtain rather strong constraints on the axion decay constant by a targeted search of continuous wave signals in the LIGO data and by simple search of repeated signals of burst-type gravitational waves by KAGRA that will start operation in three years.

References

(1) Hirotaka Yoshino and Hideo Kodama: Class. Qaunt. Grav., Focus Issue on "Black holes and fundamental fields", in preparation (2015). "Bose nova and Axiverse"

(2) Hirotaka Yoshino and Hideo Kodama: PTEP 2015, to be published. [arXiv:1407.2030] "Probing the string axiverse by gravitational waves from Cygnus X-1"
(3) Hirotaka Yoshino and Hideo Kodama: PTEP 2014, 043E02 (2014). [arXiv:1312.2326] "Gravitational radiation from an axion cloud around a black hole: Superradiant phase"

9. **Entropy of matter systems in strong gravitational fields and the black hole limit**
   Jose P. S. 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 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 and there is the usual Bekenstein-Hawking S=A/4 value, where A is the horizon area, obtained from string theory and other methods. In order to better understand black hole entropy in its generality, and in particular in the extremal limit, we exploit a matter based framework in a strong gravitational field 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, and (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. 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.

10. **On the gravitational collapse in confined geometries**
    Hirotada Okawa (Waseda University, Japan)

    It was recently pointed out that anti-de Sitter(AdS) spacetime is unstable against gravitational collapse. The pertubation in AdS does not simply decay away and can be reflected by AdS boundary. Such waves nonlinearly interact with one another and the energy is transferred to higher modes, resulting in the black hole formation. It is also pointed out, however, that a particular initial data makes considerably long-lived bound-states and there would exist "stability islands". In this talk, I would like to show our results and discuss open problems(role of confinement, initial data, and so on) after making a brief review.

11. **Tidal deformations of a spinning compact object**
    Paolo Pani (Sapienza University of Rome, Italy)

    The deformability of a compact object induced by a perturbing tidal field is encoded in the tidal Love numbers, which depend sensibly on the object's internal structure. Tidal Love numbers are known only for static, spherically-symmetric objects. As a first step to compute the tidal Love numbers of a spinning compact star, here we extend powerful perturbative techniques to compute the geometry of a tidally-distorted spinning object to second order in the angular momentum. The spin of the object introduces couplings between electric and magnetic deformations and new classes of induced Love numbers emerge. For example, a spinning object immersed in a quadrupolar, electric tidal field can acquire some induced mass, spin, quadrupole, octupole and hexadecapole moments to second order in the spin. The deformations are encoded in a set of inhomogeneous differential equations which, remarkably, can be solved analytically in vacuum. We prove that the tidal Love numbers of a Kerr black hole are zero to second order in the spin and provide the explicit solution for a slowly-rotating, tidally-deformed Kerr black hole.

12. **Bigravity and graviton oscillation**
    Takahiro Tanaka (Kyoto University, Japan)

    We discuss the viability of recently found ghost-free bigravity model as a cosmological model. We also discuss the possible signature which may appear in the gravitational waveform.

Contributed talks (30 minutes):

1. **Binary black-hole spin precession: a tale of three timescales**
   Davide Gerosa (University of Cambridge, UK)

   The dynamics of precessing black-hole binaries in the post-Newtonian regime is deeply characterized by a timescale hierarchy: the orbital timescale is very short compared to the spin-precession timescale which, in turn, is much shorter than the radiation-reaction timescale on which the orbit is shrinking due to gravitational-wave emission. The binary dynamics is typically studied in an orbit-averaged fashion: one only cares about the orbit itself, not the instantaneous position of each black hole. Here we also average over the precessional time, thus considering the precessional cones "as a whole", without tracking the spin's secular motion. These solutions improve our understanding of spin precession in much the same way that the conical sections for Keplerian orbits provide additional insights beyond Newton's $1/r^2$ law. Double averaging leads to impressive computational speed-up: post-Newtonian inspirals can now be computed from arbitrarily large separations, thus bridging the gap between astrophysics and numerical relativity. More on PRL:114-081103 and arXiv:1411.0674.

2. **FRW Viscous Cosmology with Inhomogeneous Equation of State and Future Singularity**
   Goverdhan Khadekar (Nagpur University, India)

   A universe media is considered as a bulk viscosity described by inhomo- geneous equation of state of the form $p = (\gamma - 1)\rho + \Lambda(t)$, where $\Lambda(t)$ is a time dependent parameter. A generalized dynamical equation for the scale factor of the universe is proposed to describe the cosmological evolution, for which we assume the bulk viscosity and time dependent parameter Λ are lin- ear combination of two terms of the form: $\zeta = \zeta_0 + \zeta_1 H$ and $\Lambda(t) = \Lambda_0 + \Lambda_1 H$ i.e. one is constant and other is proportional to Hubble parameter $H = \dot{a}/a$. In this framework we demonstrate that this model can be used to explain the dark energy dominated universe, and the inhomogeneous term of specific form is introduced in equation of state, may lead to three kinds of fates of cosmological evolution: no future singularity, big rip or Type III singularity as presented by [S. Nojiri and S. D. Odintsov, Phys. Rev. D 72, 023003 (2005)].

3. **Charged black strings in Kasner universe**
   Masashi Kimura (University of Cambridge, UK)

   We construct time-dependent charged black string solutions in five-dimensional Einstein-Maxwell theory. In the far region, the spacetime approaches to a five-dimensional Kasner universe that describes a universe with the expanding three-dimensional space and the shrinking extra dimension. Near the event horizon, the spacetime is approximately static and has a smooth event horizon. We also study the motion of test particles around the black string and show the existence of quasi-circular orbits. Finally, we briefly discuss the stability of this spacetime. Although its geometry near the horizon is approximately that of a known unstable black string solution, these solutions might instead be stable because the extra dimension shrinks with time evolution.

4. **Quadrupole Moments of Rapidly Rotating Compact Objects in Dilatonic Einstein-Gauss- Bonnet Theory**
   Sindy Roco Mojica (Oldenburg University, Germany)

   Rapidly rotating compact objects are considered laboratories to test general relativity and theories beyond. We determined observables such as the mass, the angular momentum, the moment of inertia, or the quadrupole moment for neutron stars and black holes in dilatonic Einstein-Gauss-Bonnet theory, a theory motivated by string theory. We used several equations of state (EOS) for the neutron matter and considered the dependence of the observables on the EOS and on the Gauss-Bonnet coupling constant. While there is a considerable EOS dependence for the observables themselves, the relation between the scaled moments of inertia and the scaled quadrupole moments is almost independent of the EOS, when the scaled angular momentum is held fixed.

5. **Scalarisation of disformally coupled accretion disks**
   Hannu Nyrhinen (Helsinki Institute of Physics, Finland)

   In scalar-tensor theories, presence of matter in the vicinity of black holes can lead to the so called "spontaneous scalarisation" instability that can trigger the development of scalar hair. In the Brans-Dicke type theories, this effect can be understood as a result of tachyonic effective mass of the scalar field, induced by the purely conformal coupling to matter. I will discuss aspects of this instability in more general scalar-tensor theories featuring non-conformal, i.e. "disformal" couplings to matter. I'll present results for matter configurations around both Schwarzschild and rotating black holes. Our results show that on one hand the disformal coupling can add to scalarisation by making the configuration more unstable. On the other hand, especially large enough disformal part of the coupling tends quite generically to stabilise the system.

6. **Rotating black holes in Einstein-Maxwell-Chern-Simons theory with negative cosmological constant**

   Jose Luis Blazquez Salcedo (Oldenburg University, Germany)

   We study 5-dimensional black holes in Einstein-Maxwell-Chern-Simons theory with negative cosmological constant, and free Chern-Simons coupling parameter. We consider topologically spherical black holes, with both angular momenta of equal magnitude. In particular, we study extremal black holes, which can be used to determine the boundary of the domain of existence. We compare the results of asymptotically flat solutions with the asymptotically Anti-de Sitter case. Several branches of black holes are found depending on the coupling parameters. The near horizon formalism is used to obtain some analytical results.