

# **Gravity: Challenges beyond General Relativity**



**GRAVITY: CHALLENGES  
BEYOND GENERAL RELATIVITY**

## **Report of Contributions**

Contribution ID: 1

Type: **not specified**

## Black hole thermodynamics and boundary terms

*Wednesday 22 May 2024 17:20 (5 minutes)*

I discuss sensitivity of black hole thermodynamics to certain boundary terms in the gravitational action. In some cases, boundary terms can alter not only the black hole entropy but even its thermodynamic temperature. Remarkably, this behaviour is confirmed by both covariant phase space (Iyer-Wald) and Euclidean (Brown-York) methods. I demonstrate our results on the example of 4D scalar-tensor Einstein-Gauss-Bonnet gravity. I also discuss the implications of our findings for thermodynamics of regular black holes

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**Presenter:** LIŠKA, Marek (Charles University, Prague)

**Session Classification:** Gongshow

Contribution ID: 3

Type: **not specified**

## Fantastic higher-curvature gravities and where to find them

*Thursday 23 May 2024 17:30 (15 minutes)*

In this talk I will present some classification results of higher-curvature gravities (in generic space-time dimensions) satisfying a quite remarkable property: the differential order of their equations of motion gets reduced when considered on certain specific backgrounds. First, I will consider those higher-order gravities whose equations of motion become second-order (or less) on top of static and spherically symmetric backgrounds. This class of theories has been previously studied in the literature and were shown to form a perturbative basis of the space of effective gravitational theories. Secondly, I will focus on those theories whose equations of motion are second-order in derivatives for FLRW configurations. Finally, I will consider the intersection of the previous two classes and discuss some interesting properties of the corresponding four-dimensional theories. The talk would be mainly based on Phys.Rev.D 108 (2023) 4, 044016 and arXiv:2311.12104 [gr-qc].

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Contribution ID: 6

Type: **not specified**

## Logarithmic Corrections in AdS/CFT

*Thursday 23 May 2024 12:05 (15 minutes)*

It is well known that in the semi-classical limit, the entropy of black holes is universally given by the Bekenstein-Hawking formula. There are in fact corrections to this formula arising from higher derivative terms in the gravitational path integral or quantum effects to due matter fields propagating on a fixed gravitational background. Evaluating such corrections is a challenging endeavor, but there is one term, of logarithmic form, that is more accessible. In this talk, I will discuss how logarithmic corrections in four-dimensional AdS gravity theories can be extracted via the heat kernel and the differences between the logarithmic term in asymptotically flat and AdS spacetimes. I will show that our results match the one-loop computations from holographic field theories when it is known, and explain how the logarithmic correction produces constraints on effective field theories coupled to gravity.

**Author:** DAVID, Marina (KU Leuven)**Presenter:** DAVID, Marina (KU Leuven)

Contribution ID: 10

Type: **not specified**

# Properties of Dynamical Black Hole Entropy

Thursday 23 May 2024 11:50 (15 minutes)

We study the first law for non-stationary perturbations of a stationary black hole whose event horizon is a Killing horizon, that relates the first-order change in the mass and angular momentum to the change in the entropy of an arbitrary horizon cross-section. Recently, Hollands, Wald and Zhang [1] have shown that the dynamical black hole entropy that satisfies this first law, for general relativity, is  $S_{\text{dyn}} = (1 - v\partial v)S_{\text{BH}}$ , where  $v$  is the affine parameter of the null horizon generators and  $S_{\text{BH}}$  is the Bekenstein-Hawking entropy, and for general diffeomorphism covariant theories of gravity  $S_{\text{dyn}} = (1 - v\partial v)S_{\text{Wall}}$ , where  $S_{\text{Wall}}$  is the Wall entropy. They obtained the first law by applying the Noether charge method to non-stationary perturbations and arbitrary cross-sections. In this formalism, the dynamical black hole entropy is defined as an “improved” Noether charge, which is unambiguous to first order in the perturbation. In the present article we provide a pedagogical derivation of the physical process version of the non-stationary first law for general relativity by integrating the linearised Raychaudhuri equation between two arbitrary horizon cross-sections. Moreover, we generalise the derivation of the first law in [1] to non-minimally coupled matter fields, using boost weight arguments rather than Killing field arguments, and we relax some of the gauge conditions on the perturbations by allowing for non-zero variations of the horizon Killing field and surface gravity. Finally, for  $f(\text{Riemann})$  theories of gravity we show explicitly using Gaussian null coordinates that the improved Noether charge is  $S_{\text{dyn}} = (1 - v\partial v)S_{\text{Wall}}$ , which is a non-trivial check of [1]. explicitly using Gaussian null coordinates that the improved Noether charge is  $S_{\text{dyn}} = (1 - v\partial v)S_{\text{Wall}}$ , which is a non-trivial check of [1].

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Contribution ID: 12

Type: **not specified**

# Implications of Palatini gravity for inflation and beyond

*Thursday 23 May 2024 17:15 (15 minutes)*

We present an introduction to cosmic inflation in the framework of Palatini gravity, which provides an intriguing alternative to the conventional metric formulation of gravity. In the latter, only the metric specifies the spacetime geometry, whereas in the former, the metric and the spacetime connection are independent variables—an option that can result in a gravity theory distinct from the metric one. In scenarios where the field(s) responsible for cosmic inflation are non-minimally coupled to gravity or the gravitational sector is extended, assumptions about the underlying gravitational degrees of freedom can have substantial implications for the observational effects of inflation. We examine this explicitly by discussing various compelling scenarios, such as Higgs inflation with non-minimal coupling to gravity, Higgs inflation with non-minimal derivative coupling,  $R^2$  inflation, and beyond. We also comment on reheating in these models. Finally, as an application of the general results of Palatini  $R^2$  inflation, we review a model of successful quintessential inflation, where a single scalar field acts initially as the inflaton and then becomes dynamical dark energy, in agreement with all experimental constraints.

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Contribution ID: 15

Type: **not specified**

## Superradiant Instability of Magnetic Black Holes

*Friday 24 May 2024 16:30 (15 minutes)*

Black hole superradiance has proven being very valuable in several realms of gravitational physics, and holds a promising discovery potential. In this talk I will show how it can shed light on a long standing problem in physics, the quest for magnetic monopoles in the Universe. Placing them in the interior of primordial rotating black holes, which act as natural amplifiers, I will show that massive

charged bosonic fields in their vicinity exhibit a superradiant instability which surpasses significantly that of neutral Kerr black holes. Strikingly, this is true for black holes containing an order-one

number of magnetic monopoles, or merely a single one, and possessing either low, moderate or large values of angular momentum. In particular, the instability is drastically faster than the radiative decay time of charged pions, thus making it physically relevant. Furthermore, the most unstable modes are a class of monopole spheroidal harmonics, that we dub north and south monopole modes, whose morphology is markedly different from the usual superradiantly unstable modes since they extend along the rotational axis. These results make primordial magnetic black holes promising multimessenger sources in the high-frequency range.

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Contribution ID: 16

Type: **not specified**

## Quantum backreactions in (A)dS3 massive gravity and logarithmic asymptotic behavior

*Friday 24 May 2024 15:45 (15 minutes)*

We study the interplay between higher curvature terms and the backreaction of quantum fluctuations in 3-dimensional massive gravity in asymptotically (Anti-)de Sitter space. We focus on the theory at the special point of the parameter space where the two maximally symmetric vacua coincide. In the case of positive cosmological constant, this corresponds to the partially massless point, at which the classical theory admits de Sitter black holes and exhibits an extra conformal symmetry at linear level. We explicitly find the quantum corrected black hole geometry in the semiclassical approximation and show that it induces a relaxation of the standard asymptotic conditions. Nonetheless, the new asymptotic behavior is still preserved by an infinite-dimensional algebra, which, in addition to Virasoro, contains logarithmic supertranslations. Finally, we show that all the results we obtain for the quadratic massive gravity theory can be extended to theories including cubic and quartic terms in the curvature.

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Contribution ID: 17

Type: **not specified**

## Fundamental Physics at the Galactic Center

The Galactic Center of the Milky Way can serve as a test bench to investigate physical phenomena at the edge of astrophysics and fundamental physics. As such, it offers a unique laboratory to probe General Relativity, modified theories of gravity, different paradigms of dark matter, and black hole mimickers. I will provide a general overview of the results achieved in recent years emphasizing their importance in opening a new avenue to improve our understanding of the underlying theory of gravity in the surroundings of a supermassive compact object.

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Contribution ID: 18

Type: **not specified**

## High accuracy binary modelling in scalar-tensor theories of gravity using the self-force approach

*Thursday 23 May 2024 17:00 (15 minutes)*

A key science target for LISA is testing General Relativity by measuring extreme-mass-ratio inspirals. Modelling such binaries with numerical relativity is not viable due to the disparate length scales. Perturbation theory comes to the rescue: leveraging the disparate length scales, we can model the binary using the self-force approach. Great effort is being expounded in pursuing high-accuracy self-force models in General Relativity. A chief obstacle in producing these models is obtaining the necessary second-perturbative-order contributions. However, testing our fundamental theory of gravity also requires models in alternative theories. We can then measure which models best agree with LISA data. In this talk, I formulate the self-force method in general shift-symmetric scalar-tensor theories of gravity to second-perturbative-order. I then comment on how difficult it will be to produce the high-accuracy waveform templates in these theories in time for LISA's launch in circa 2035.

**Authors:** Dr MASELLI, Andrea (Gran Sasso Science Institute); SPIERS, Andrew (University of Nottingham); Prof. SOTIRIOU, Thomas (University of Nottingham)

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Contribution ID: 19

Type: **not specified**

## Black-hole solutions with primary scalar hair

*Wednesday 22 May 2024 12:30 (15 minutes)*

We present explicit black holes endowed with primary scalar hair within the shift-symmetric subclass of Beyond Horndeski theories. These solutions depend, in addition to the conventional mass parameter, on a second free parameter encoding primary scalar hair. The properties and characteristics of the solutions at hand are analyzed with varying scalar charge. We observe that when the scalar hair parameter is close to zero or relatively small in comparison to the black hole mass, the solutions closely resemble the Schwarzschild spacetime. As the scalar hair increases, the metric solutions gradually depart from General Relativity. Notably, for a particular relation between mass and scalar hair, the central singularity completely disappears, resulting in the formation of regular black holes or solitons. The scalar field accompanying the solutions is always found to be regular at future or past horizon(s), defining a distinct time direction for each. As a final byproduct of our analysis, we demonstrate the existence of a stealth Schwarzschild black hole in Horndeski theory with a non-trivial kinetic term.

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Contribution ID: 20

Type: **not specified**

## Ringdowns for black holes with scalar hair: the large mass case

*Wednesday 22 May 2024 16:45 (5 minutes)*

Deviations from General Relativity can be probed with black hole spectroscopy, as the quasi-normal mode (QNM) frequency spectrum of a black hole with additional ‘hair’ is expected to differ from that of a Kerr black hole. We construct an effective field theory scheme for QNMs to capture deviations from Kerr for black holes in theories with a coupling between a shift-symmetric scalar and the Gauss-Bonnet invariant. I will explain how our analysis, which is particularly suited for black holes in the LISA range, places limits on the prospects of detecting evidence of scalar hair in ringdown signals.

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**Session Classification:** Gongshow

Contribution ID: 21

Type: **not specified**

# Thermodynamics of black holes featuring primary scalar hair

*Wednesday 22 May 2024 16:35 (5 minutes)*

In this work, we embark on the thermodynamic investigation concerning a family of primary charged black holes within the context of shift and parity symmetric Beyond Horndeski gravity. Employing the Euclidean approach, we derive the functional expression for the free energy and derive the first thermodynamic law, offering a methodology to address the challenge of extracting the thermal quantities in shift-symmetric scalar tensor theories characterized by linear time dependence in the scalar field. Following the formal analysis, we provide some illustrative examples focusing on the thermal evaporation of these fascinating objects.

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**Session Classification:** Gongshow

Contribution ID: 22

Type: **not specified**

## Compact objects in beyond Horndeski theories

*Wednesday 22 May 2024 12:15 (15 minutes)*

We analyse in all generality beyond Horndeski theories of shift symmetry in a static and spherically symmetric spacetime. By introducing four auxiliary functions, we write the field equations in a particularly compact form. We show that assuming additionally parity symmetry renders the system directly integrable giving multiple families of black-hole solutions. These have typically an asymptotically-flat Reissner-Nordstrom behaviour, and emerge in the presence of a canonical kinetic term for the scalar field. In the absence of parity symmetry, we present a general method which allows us to integrate the field equations by choosing the form of only one coupling function and an auxiliary quantity. This method leads to asymptotically flat and AdS black hole solutions with differing properties. We finally discuss disformal transformations within this context as a means of obtaining wormhole and black hole solutions in different theories.

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Contribution ID: 24

Type: **not specified**

## Regular black holes from pure gravity

*Friday 24 May 2024 17:15 (15 minutes)*

I will show via an explicit construction how an infinite tower of higher-curvature corrections generically leads to the resolution of the Schwarzschild singularity in any spacetime dimension  $D \geq 5$ . The theories we consider have two key properties that ensure the results are general and robust: (1) they provide a basis for (vacuum) gravitational effective field theory in five and higher-dimensions, (2) for each value of the mass, they have a unique static spherically symmetric solution. I will present several exact solutions of the theories that include the Hayward black hole and others similar to the Bardeen and Dymnikova ones. Unlike previous constructions, these regular black holes arise as vacuum solutions, as we include no matter fields whatsoever in our analysis. Additionally, their thermodynamics properties can be studied in a completely universal and unambiguous way.

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**Presenter:** BUENO, Pablo (ICCUB)

Contribution ID: 28

Type: **not specified**

## The Fate of Matter Fields in Metric-Affine Gravity

*Wednesday 22 May 2024 17:35 (5 minutes)*

General relativity (GR) exists in different formulations. They are equivalent in pure gravity but generically lead to distinct predictions once matter is included. After a brief overview of various versions of GR, I will focus on metric-affine gravity, which avoids any assumption about the vanishing of curvature, torsion, or nonmetricity. With a view toward the Standard Model, we can construct a generic model of (complex) scalar, fermionic, and gauge fields coupled to GR and derive an equivalent metric theory, which features numerous new interaction terms. There are multiple phenomenological consequences, which I will detail: an improved setting for Higgs inflation, a new (purely gravitational) production channel for fermionic dark matter, and an outlook on axion inflation.

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**Session Classification:** Gongshow



Contribution ID: 29

Type: **not specified**

## Exact black holes in string-inspired Euler-Heisenberg theory

*Wednesday 22 May 2024 17:05 (5 minutes)*

We consider higher-order derivative gauge field corrections that arise in the fundamental context of dimensional reduction of String Theory and Lovelock-inspired gravities and obtain an exact and asymptotically flat black-hole solution, in the presence of non-trivial dilaton configurations. Specifically, by considering the gravitational theory of Euler-Heisenberg non-linear electrodynamics coupled to a dilaton field with specific coupling functions, we perform an extensive analysis of the characteristics of the black hole, including its geodesics for massive particles, the energy conditions, thermodynamical and stability analysis. The inclusion of a dilaton scalar potential in the action can also give rise to asymptotically (A)dS spacetimes and an effective cosmological constant. Moreover, we find that the black hole can be thermodynamically favored when compared to the Gibbons-Maeda-Garfinkle-Horowitz-Strominger (GMGHS) black hole for those parameters of the model that lead to a larger black-hole horizon for the same mass. Finally, it is observed that the energy conditions of the obtained black hole are indeed satisfied, further validating the robustness of the solution within the theoretical framework, but also implying that this self-gravitating dilaton-non-linear-electrodynamics system constitutes another explicit example of bypassing modern versions of the no-hair theorem without any violation of the energy conditions.

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**Session Classification:** Gongshow

Contribution ID: 30

Type: **not specified**

## Signatures of ultralight bosons in the orbital eccentricity of binary black holes

*Wednesday 22 May 2024 12:00 (15 minutes)*

We show that the existence of clouds of ultralight particles surrounding black holes during their cosmological history as members of a binary system can leave a measurable imprint on the distribution of masses and orbital eccentricities observable with future gravitational-wave detectors. Notably, we find that for nonprecessing binaries with chirp masses  $< 10$  solar masses, formed exclusively in isolation, larger-than-expected values of the eccentricity, i.e.  $> 0.01$  at gravitational-wave frequencies  $\sim 10^{-2}$  Hz, would provide tantalizing evidence for a new particle of mass between  $[0.5, 2.5] \times 10^{-12}$  eV in nature. The predicted evolution of the eccentricity can also drastically affect the in-band phase evolution and peak frequency. These results constitute unique signatures of boson clouds of ultralight particles in the dynamics of binary black holes, which will be readily accessible with the Laser Interferometer Space Antenna, as well as future mid-band and Deci-hertz detectors.

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Contribution ID: 31

Type: **not specified**

## Scalar-Induced Gravitational Waves probing cosmological models

*Wednesday 22 May 2024 17:15 (5 minutes)*

There are a few unanswered questions about standard cosmological model. An open question to answer is if we can use gravitational waves (GWs) to probe beyond General Relativity? Due to their weak interaction with matter, we hope to observe Primordial GWs which can give us a better understanding of the physics of the early Universe. Primordial GWs come in the form of a stochastic background (SGWB) due to the quantum nature of the fluctuations that generate them. One contribution to the latter arise from second-order effects and coupling of scalar fluctuations, known as “scalar-induced”GWs (SIGWs). In this talk, I present my computations of the source term of SIGW both in standard cosmology and beyond General Relativity, specifically considering  $f(R)$  modified gravity model. I will concentrate on the understanding the effect of the first-order correction to the source term and power spectrum w.r.t. General Relativity. I will compare the results of standard cosmology to its modification, to see the order to the effect and how observations of this signature can help in improving our understanding.

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**Session Classification:** Gongshow

Contribution ID: 36

Type: **not specified**

## Dynamics, hyperbolicity and singularities in spherically symmetric massive gravity

*Wednesday 22 May 2024 17:10 (5 minutes)*

In modified theories of gravity, the question of well-posedness of their equations underlies any attempts at numerical simulations. These in turn are crucial for comparison with experimental data and possible confirmation of the theory's predictions. In this talk, we will concentrate on ghost-free massive gravity, notable for being a genuine IR modification of general relativity. Through a clever choice of variables, its equations in spherical symmetry can be rendered strongly hyperbolic, and hence well-posed. This enables us to perform numerical situations of spherical collapse. For small initial data, we find that the matter simply disperses. However, as we increase the amplitude of the initial data, the evolution eventually becomes singular in a way distinct from black hole formation in standard GR.

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**Session Classification:** Gongshow

Contribution ID: 37

Type: **not specified**

## Entanglement generation in the Hawking effect for realistic Black Holes

*Thursday 23 May 2024 15:45 (15 minutes)*

In this talk we will explain how to quantify the entanglement generated in the Hawking process for rotating black holes illuminated by CMB radiation. We will show how ergoregions leave a specific signature in the entanglement structure of Hawking radiation, absent for Schwarzschild black holes. The formalism we develop applies for gravitational as well as analogue black holes. We will finish by discussing laboratory analogues where these novel signals can be detected in the near future.

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Contribution ID: 38

Type: **not specified**

## Propagators in AdS for higher-derivative and nonlocal gravity

*Friday 24 May 2024 11:50 (15 minutes)*

The covariant position-space propagators for GR in the Euclidean AdS background have been known for more than 25 years (partially even before the AdS/CFT). However, due to the complicated bi-tensorial structure of these quantities, no such explicit formulas have been presented in the literature for gravitational theories beyond GR. In this talk, I will describe a new method of construction of the propagators in the  $N$ -dimensional AdS space that can be applied to any gravitational theory with the Lagrangian that is an analytic expression in the metric, curvature, and covariant derivative, i.e., to all higher- or infinite-derivative theories of gravity. It employs the Landau gauge and is based on the heat kernels for scalars and symmetric rank-2 tensors on the hyperbolic  $N$ -space. I will also comment on the correction of the derivation of the equivalent action and extension of the quadratic action to arbitrary  $N \geq 3$  dimensions. The talk is based on 2307.13056.

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**Presenter:** KOLAR, Ivan (Charles University)

Contribution ID: 44

Type: **not specified**

## Anomaly-induced Inflation in the Minimal Quartic Extension of Einstein's Gravity

Wednesday 22 May 2024 16:50 (5 minutes)

The exploration of modified gravity theories using cosmology has gained considerable attention in recent years. In this context, we investigate anomaly-induced inflation within the framework of a Born-Infeld type modified gravity theory, which represents a minimal extension of Einstein's gravity. This theory, elaborated in recent works [1][2][3], exhibits intriguing properties, including a unique vacuum and the presence of a single massless spin-2 particle in its particle spectrum. Our analysis focuses on trace-anomaly driven inflation, where inflationary dynamics are triggered by a quantum anomaly leading to a non-vanishing trace of the energy-momentum tensor contingent upon curvature terms.

Central to our investigation is the comparison between the Minimum Standard Model (MSM) and the Minimal Supersymmetric Standard Model (MSSM) scenarios, representing initial unstable and stable de Sitter phases, respectively. We demonstrate that the modified gravity framework imposes constraints crucial for viable inflationary dynamics. Notably, the presence of modified gravity facilitates a graceful exit from inflation, even near to the stable de Sitter solution in the case of MSSM.

Furthermore, we provide insights into observational constraints by deriving key inflationary parameters such as the spectral index and tensor-to-scalar ratio within the slow-roll regime. Our findings shed light on the interplay between modified gravity theories and inflationary cosmology, offering valuable implications for both theoretical and observational cosmology.

[1] I. Gullu, T. C. Sisman and B. Tekin, "Born-Infeld Gravity with a Massless Graviton in Four Dimensions," *Phys. Rev. D* 91, 044007 (2015).

[2] I. Gullu, T. C. Sisman and B. Tekin, "Born-Infeld Gravity with a Unique Vacuum and a Massless Graviton," *Phys. Rev. D* 92, 104014 (2015).

[3] A. Karasu, E. Kenar and B. Tekin, "Minimal Extension of Einstein's Theory: The Quartic Gravity," *arXiv:1602.02567 [hep-th]*.

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**Session Classification:** Gongshow

Contribution ID: 45

Type: **not specified**

## The non-spherical ground state of Proca stars

*Wednesday 22 May 2024 16:40 (5 minutes)*

Spherical Proca Stars (PSs) are regarded as the ground state amongst the family of PSs. In accordance, spherical PSs are thought to have a fundamental branch of stable solutions. In this Letter, we provide energetic, morphological and dynamical evidence that spherical PSs are actually excited states. The ground state is shown to be a family of static, non-spherical, in fact prolate, PSs. The spherical stars in the fundamental branch, albeit stable against spherical perturbations, turn out to succumb to non-spherical dynamics, undergoing an isometry breaking into prolate PSs. We also provide evidence for the dynamical formation of prolate PSs, starting from spherical dilute initial data, via gravitational cooling. Consequently, PSs provide a remarkable example of (possibly compact) relativistic stars, in General Relativity minimally coupled to a simple, physical, field theory model, where staticity plus stability implies non-sphericity.

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**Session Classification:** Gongshow



Contribution ID: 46

Type: **not specified**

## Quasinormal modes of hairy black holes in scalar-tensor theories

*Thursday 23 May 2024 16:45 (15 minutes)*

Various recent works have explored the emergence and properties of compact object solutions including black holes, in models with a metric tensor and a scalar field within the Horndeski framework of theories. Studying the quasinormal mode (QNM) spectrum of hairy black holes is particularly useful when considering the potential of observing hairy solutions in nature. In this talk we discuss how the QNMs of such solutions may actually deviate significantly from their General Relativity (GR) counterparts, allowing us therefore to potentially probe the validity of GR in the strong gravitational regime.

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Contribution ID: 48

Type: **not specified**

## Non-uniqueness of spherical black holes in five dimensions

*Friday 24 May 2024 16:45 (15 minutes)*

Black holes are not unique in higher dimensions. It is well known that, in five dimensions, stationary, biaxisymmetric black holes with the horizon of  $S^3$ -topology and  $S^2 \times S^1$ -topology can exist for the same asymptotic charges, in contrast to the black holes in four dimensions where the horizon must have  $S^2$ -topology.

In this talk, we aim to demonstrate that even if the horizon topology is fixed to be  $S^3$ , the black hole in five dimensions is still not unique in terms of asymptotic charges. For this, we present a new type of spherical black hole endowed with a nontrivial spacetime structure called “bubble” attached on the horizon [1]. The new spherical black hole, which we call a “capped black hole”, is the non-BPS solution of five-dimensional minimal supergravity, constructed by the combination of two different solution generating techniques: the inverse scattering method and electric Harrison transformation [2]. We briefly introduce the basic feature of the new solution and then compare it with the known spherical black hole (Cvetič-Youm black hole). As a result, we show that the two solutions can have the same asymptotic charges, i.e. the uniqueness is violated for the  $S^3$ -horizon. Moreover, we find that the new solution can have the larger entropy than the Cvetič-Youm black hole in a certain parameter range.

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[arXiv:2311.11653 [hep-th]].
- [2] R. Suzuki and S. Tomizawa,  
“Solution Generation of a Capped Black Hole,”  
[arXiv:2403.17796 [hep-th]].

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Contribution ID: 51

Type: **not specified**

## Higher-curvature gravity in AdS3, c-theorems and hairy black holes

*Friday 24 May 2024 17:00 (15 minutes)*

We show that, in general three-dimensional higher-curvature gravity, imposing a simple holographic c-theorem as well as a single vacuum allows for the existence of a family of hairy black hole solutions. These solutions, which exist in a special point in the theory space, correspond to a generalization of the usual the Bañados-Teitelboim-Zanelli black hole. We compute the thermodynamic quantities of these solutions and verify the Cardy formula.

**Author:** MORENO, Javier

**Co-authors:** GIRIBET, Gastón (Department of Physics, New York University); OLIVA, Julio (Departamento de Física, Universidad de Concepción); CHERNICOFF, Mariano (Facultad de Ciencias, UNAM); ROJAS, Raúl (Departamento de Física, Universidad de Concepción)

**Presenter:** MORENO, Javier

Contribution ID: 52

Type: **not specified**

## The entropy of non-smooth black holes

*Wednesday 22 May 2024 16:55 (5 minutes)*

In general relativity, dynamical black holes generically have non-smooth horizons. One can study the properties of the non-smooth structures that are stable under perturbations of the horizon. This analysis does not make use of the Einstein equations, and hence is potentially relevant to higher-derivative theories of gravity. We describe the possible non-smooth structures and discuss some implications for the entropy of a black hole. In particular, we speculate whether creases (structures where two generators enter the horizon) could contribute to the entropy, and argue that the Gauss-Bonnet term is non-topological for non-smooth horizons. This talk is based on work done with Harvey Reall.

**Authors:** Prof. REALL, Harvey (University of Cambridge); GADIOUX, Maxime (University of Cambridge)

**Presenter:** GADIOUX, Maxime (University of Cambridge)

**Session Classification:** Gongshow

Contribution ID: 53

Type: **not specified**

## Ringdown of rotating black holes in higher-derivative gravity

*Wednesday 22 May 2024 17:25 (5 minutes)*

We computed the spectrum of linearized gravitational excitations of black holes with substantial angular momentum in the presence of higher-derivative corrections to general relativity. We do so perturbatively to leading order in the higher-derivative couplings and to more than sixteen orders in the black hole angular momentum. This allows us to accurately predict quasi-normal mode frequencies of black holes with spins up to about 0.8 of the extremal value. We find that sizeable rotation can enhance the frequency shifts relative to the static case. By implementing the leading effect of these higher-derivative corrections on the quasi-normal spectrum in the ringdown analysis package pyRing we constrain the coupling strength of these corrections based on GW observations. (Presentation based on 2304.02663, 2307.07431 and work in preparation.)

**Author:** MAENAUT, Simon (KU Leuven)**Presenter:** MAENAUT, Simon (KU Leuven)**Session Classification:** Gongshow

Contribution ID: 54

Type: **not specified**

## Perturbation of slowly evolving black holes: quasi-normal modes and tidal response

*Wednesday 22 May 2024 16:30 (5 minutes)*

The mass of a black hole can dynamically evolve due to various physical processes beyond vacuum General Relativity, such as accretion, Hawking radiation, superradiance or gravitational wave backreaction. This evolution can have a significant impact on astrophysical observables like the inspiral or ringdown signal. An effective description of a spherically symmetric evolving black hole is provided by the Vaidya metric. In our investigation, we explore the dynamics of perturbations on this background, assuming a slow evolution. This approach enables us to expand relevant physical quantities around their static values and compute corrections at leading order in the mass derivative. In particular, we quantify how this phenomenon affects the spectrum of the quasi-normal modes and the tidal response

**Authors:** BARAUSSE, Enrico; CAPUANO, Lodovico (SISSA); SANTONI, Luca

**Presenter:** CAPUANO, Lodovico (SISSA)

**Session Classification:** Gongshow

Contribution ID: 55

Type: **not specified**

## Cosmological Constrains on 4-dimensional Einstein-Gauss-Bonnet Gravity

*Wednesday 22 May 2024 17:00 (5 minutes)*

In the last few years the contribution of higher-curvature terms in modified gravity has received quite a lot of attention. This is due to the discovery of a 4-dimensional limit of Einstein-Gauss-Bonnet theory that has non-trivial contributions from the Gauss-Bonnet invariant. The theory is a very interesting phenomenological competitor to General Relativity insofar as it passes all solar-system tests, but has notably different strong field behaviour. Cosmological spacetimes have been investigated in this context but are less well studied. We consider the theoretical and observational implications of this theory in both the early and late universe, (re-)deriving background and perturbation equations and constraining its characteristic parameters with data from cosmological probes. We particularly focus on the sound and particle horizons and show how this theory can resolve the horizon problem for certain values of the coupling parameter  $\alpha$ . The theory also includes a geometric term in the equations of motion that resembles dark radiation for the background spacetime, but whose influence on the perturbed equations is qualitatively distinct from that of standard forms of dark radiation. In this limit, only one beyond- $\Lambda$ CDM degree of freedom persists, which we denote as  $\tilde{\alpha}_C$ . Our analysis yields the estimate  $\tilde{\alpha}_C = (-9 \pm 6) \times 10^{-6}$  thereby providing a new constraint of a previously untested sector of 4DEGB.

**Authors:** HULL, Brayden R. (University of Waterloo); ZANOLETTI, Carola; Dr LEONARD, Danielle; Prof. MANN, Robert B.

**Presenter:** HULL, Brayden R. (University of Waterloo)

**Session Classification:** Gongshow

Contribution ID: 56

Type: **not specified**

## Revisiting alpha prime corrections to heterotic two-charge black holes

*Wednesday 22 May 2024 17:40 (5 minutes)*

Based on: 2311.03308

Authors: Stefano Massai, Alejandro Ruiperez, Matteo Zatti

**Abstract:** We find solutions of the heterotic string effective action describing the first-order alpha prime corrections to two-charge black holes at finite temperature. Making explicit use of these solutions, we compute the corrections to the thermodynamic quantities: temperature, chemical potentials, mass, charges and entropy. We check that the first law of black hole mechanics is satisfied and that the thermodynamics agrees with the one extracted from the Euclidean on-shell action. Finally, we show that our results are in agreement with the corrections for the thermodynamics recently predicted by Chen, Maldacena and Witten.

**Authors:** Dr RUIPEREZ, Alejandro (University Roma Tor Vergata & INFN); ZATTI, Matteo (IFT UAM/CSIC); Dr MASSAI, Stefano (University of Padova & INFN)

**Presenter:** ZATTI, Matteo (IFT UAM/CSIC)

**Session Classification:** Gongshow



Contribution ID: 57

Type: **not specified**

## Quasi-normal modes of rotating black holes beyond general relativity

*Thursday 23 May 2024 16:30 (15 minutes)*

In this talk, I will summarize the recent advancements of quasi-normal modes in alternative theories of gravity. I will briefly explain the main issues in computing the characteristic frequencies of rotating black holes and what are the most prominent strategies to tackle this problem. The approaches covered include the slow-spin and small-coupling expansions. In particular, I will present a beyond-Teukolsky approach for the computation of quasi-normal modes using the continued fraction method, and its application in several modified theories of gravity.

**Author:** FRANCHINI, Nicola (APC)

**Co-authors:** CAPUANO, Lodovico (Sissa); CANO, Pablo (ICCUB); VOLKEL, Sebastian (AEI); MAE-NAUT, Simon (KU Leuven)

**Presenter:** FRANCHINI, Nicola (APC)

Contribution ID: 59

Type: **not specified**

## Light rings in stationary axisymmetric spacetimes: blind to the horizon's topology and able to coexist

*Wednesday 22 May 2024 17:30 (5 minutes)*

It is well established that black holes satisfying some quite general set of assumptions are always surrounded by a light ring. These are a special set of bound null orbits. Such orbits are of particular relevance when entering the new era of precision test of General Relativity, as they leave imprints on both gravitational wave observations, and on the black hole shadows, the two main new observation channels. The intimate relation between light rings and black holes, together with their observational relevance serve to highlight the need for a more profound understanding of light rings. Namely, the existence of light rings around black hole foils, be it horizonless compact objects or wormholes, or black hole spacetimes violating the assumptions of the original theorem. This work focus on the latter. The original result established that  $1 + 3$  dimensional asymptotically at, axisymmetric, stationary, and circular spacetimes containing a nonextremal topologically spherical event horizon admit, at least, one light ring outside the horizon, per rotation sense. In order to improve the strength of this theorem we dropped a few of these assumptions to check if the conclusions hold. Specically, the requirement that the event horizon is topologically spherical was dropped and toroidal black holes were considered, to verify if light rings could be used as a probe of the topology of the black hole. Furthermore, the robustness of the light rings was tested by considering spacetimes harbouring multiple black holes. The results indicate that toroidal black holes obey a similar theorem as the spherical ones, and that in a spacetime with an arbitrary number of (spherical and toroidal) black holes each black hole contributes with at least one light, per rotation sense. This indicates that light rings obey a kind of superposition principle.

**Authors:** HERDEIRO, Carlos (University of Aveiro); NOVO, João (Universidade de Aveiro); Dr CUNHA, Pedro (Universidade de Aveiro)

**Presenter:** NOVO, João (Universidade de Aveiro)

**Session Classification:** Gongshow

Contribution ID: 60

Type: **not specified**

## The three-dimensional C-metric

*Friday 24 May 2024 12:05 (15 minutes)*

In this talk, we will focus on describing features of the C-metric in 2+1 dimensions. Starting from a general ansatz we construct three classes of geometries which can be interpreted by studying their physical parameters. From these, we identify stationary, accelerating point particles; one-parameter extensions of the BTZ family resembling an accelerating black hole; and a novel “accelerating BTZ geometry” not continuously connected to the BTZ black hole as well as some black funnel solutions. We will comment on the current understanding of the thermodynamics and holographic properties of these solutions with particular emphasis on the accelerating BTZ black hole.

**Author:** Dr ARENAS-HENRIQUEZ, Gabriel (Tsinghua University)

**Co-authors:** Dr CISTERNA, Adolfo (Charles University); Dr SCOINS, Andrew (Durham University); Dr DIAZ, Felipe (Universidad Andres Bello); Prof. GREGORY, Ruth (KCL)

**Presenter:** Dr ARENAS-HENRIQUEZ, Gabriel (Tsinghua University)

Contribution ID: 65

Type: **not specified**

## The impact of modifications to gravity on black holes and inhomogeneous cosmologies

*Thursday 23 May 2024 15:00 (45 minutes)*

I will describe recent developments in numerical relativity that permit us to simulate non trivial scalar-tensor theories of gravity, which represent the next order corrections in an effective field theory approach. Whilst these techniques were developed mainly to aid the study of black holes spacetimes, they can also be applied to cosmology, in particular to the non linear dynamics of preheating and the initial condition problem for inflation (the question of whether inflation can start from strongly inhomogeneous initial conditions). I will give an overview of our work in this direction.

**Presenter:** CLOUGH, Katy

Contribution ID: 66

Type: **not specified**

## New methods in black hole perturbation theory

*Wednesday 22 May 2024 11:15 (45 minutes)*

I will introduce a new method to study perturbations around black holes, using the black hole's characteristic (quasinormal, quasibound or superradiant) modes. The new method hinges on a new relativistic product, under which modes are orthogonal. Using this product, one can derive the analog of time-dependent and independent perturbation theory in quantum mechanics. I will present a first application: the calculation of the self-gravitational frequency shift in a superradiant boson cloud, in closer agreement with numerical relativity than the non-relativistic “gravitational atom” approximation. The approach has many other practical applications, in gravitational-wave astronomy and beyond general relativity.

**Presenter:** SBERNA, Laura

Contribution ID: 67

Type: **not specified**

## Mergers of black holes and exotic compact objects in the extreme mass ratio regime

*Friday 24 May 2024 14:15 (45 minutes)*

The collision of compact objects, such as black holes and neutron stars, is a spectacular cosmic event of great interest to gravitational wave astronomy. Since 2015 we have been gathering information about such binary systems through the observation of the gravitational waves they generate. Most of these detections—and the determination of the parameters of the binary that sourced the gravitational waves—typically rely on a combination of advanced methods in General Relativity and Numerical Relativity.

Nonetheless, in recent years elementary ray-tracing techniques have been shown to capture the main characteristics of black hole mergers by considering the extreme mass ratio limit in an unorthodox way. In this regime, the evolution of the event horizon, when a large black hole merges with a small compact object, can be computed (semi-)analytically.

In this talk, I will exploit this idea in the context of compact object mergers in modified gravities respecting the equivalence principle. Two specific cases will be discussed: the fusion between a large black hole and a small traversable wormhole, and the collision between two black holes in cubic gravity. Differences with respect to black hole mergers in General Relativity will be highlighted.

**Presenter:** ROCHA, Jorge

Contribution ID: 68

Type: **not specified**

## New type I black holes in General Relativity and some hairy extensions

*Wednesday 22 May 2024 15:15 (45 minutes)*

This talk explores novel algebraically general black hole solutions by reevaluating Buchdahl transformations within Einstein and Einstein-Scalar theories. It investigates the relationship between Buchdahl transformations and Levi-Civita spacetimes when applied along a spacelike Killing vector of a given seed. By employing Kerr-Schild transformations, our study extends Buchdahl's theorem to construct new vacuum-rotating black holes in higher dimensions, specifically Levi-Civita extensions of the Myers-Perry geometry. In the context of the Einstein-Scalar system, we will extend the corresponding Buchdahl theorem to scenarios where a static vacuum seed, transformed with respect to a spacelike Killing vector, generates a hairy black hole spacetime. We will analyze the primary geometrical features of these spacetimes and explore how a change of frame, via conformal transformations, leads to a new family of black hole spacetimes within the Einstein-Scalar-Conformal system. The presentation concludes by suggesting several avenues for further exploration of these novel techniques.

**Presenter:** CISTERNA, Adolfo

Contribution ID: 69

Type: **not specified**

## Shine-through-the-horizon (and some thoughts on dynamics of massive fields)

*Wednesday 22 May 2024 09:45 (1 hour)*

Precision gravitational-wave astronomy is under way, able to probe strong-field gravity to unprecedented levels. Which is the correct description of gravity, and of the matter content of the universe? I will not answer these questions, but will discuss some of the smoking-guns for the simplest extensions of General Relativity and of the Standard Model, in the context of black hole physics: new massive degrees of freedom. I will discuss the status of superradiant constraints on massive fields, and show how energy extraction occurs naturally in the presence of multiple propagation speeds. Finally, I will argue that current constraints on massive gravitons must take into account new polarization states, and discuss how effectively massive fields affect black hole relaxation.

**Presenter:** CARDOSO, Vitor



Contribution ID: 70

Type: **not specified**

## Higher-derivative corrections to BPS black hole thermodynamics and holography

*Thursday 23 May 2024 11:05 (45 minutes)*

Holography allows us to address the microstate counting of AdS black holes from the dual CFT. Recently, a certain Cardy-like regime of the so-called superconformal index has been shown to single out the saddle which carries the Bekenstein-Hawking entropy of the dual supersymmetric AdS<sub>5</sub> black hole. In this talk I shall discuss how this match can be extended to account for corrections in the large- $N$  expansion, which are captured in the bulk by suitable higher-derivative terms. Time permitting, I shall also discuss the ungauged limit of our results, which allows us to study corrections to the thermodynamics of the BMPV black hole.

**Presenter:** RUIPÉREZ, Alejandro

Contribution ID: 71

Type: **not specified**

## **Black holes beyond general relativity: theory, phenomenology and open problems**

*Thursday 23 May 2024 14:15 (45 minutes)*

Black holes are the perfect probes to understand the nature of the gravitational interaction: they are the simplest gravitating objects in the universe, and can generate the strongest gravitational fields. We shall discuss how black hole solutions and their behaviour are affected by modifications of general relativity, and how gravitational and electromagnetic signals from black holes can be used to look for such modifications. Our analysis will focus on theories, like those with higher-derivative terms, which modify gravity in the large-curvature regime. Finally, we shall discuss the main theoretical and phenomenological challenges in exploiting black hole observations from present and near-future detectors to look for signature of physics beyond general relativity.

**Presenter:** GUALTIERI, Leonardo

Contribution ID: 72

Type: **not specified**

## A new formulation of conserved quantities in generic gravity theories

*Wednesday 22 May 2024 14:30 (45 minutes)*

For asymptotically constant curvature spaces, such as (A)dS, the conserved quantities depend not only on the geometry but also on the theory under consideration. I shall give a new construction of conserved charges both in cosmological Einstein's theory and generic  $f(R)$  theories. The final expressions are in terms of the linearized Riemann tensor at the boundary of spacetime and are explicitly gauge invariant.

**Presenter:** TEKIN, Bayram

Contribution ID: 73

Type: **not specified**

## Exotic black hole thermodynamics

*Thursday 23 May 2024 09:45 (1 hour)*

Using the framework of extended black hole thermodynamics, where the cosmological constant is one of the thermodynamic parameters and is allowed to vary in the first law, I will discuss some recent advances towards understanding the thermodynamic behavior of exotic black hole spacetimes, such as accelerated black holes or black holes equipped with the NUT parameter.

**Presenter:** KUBIZNAK, David

Contribution ID: 74

Type: **not specified**

## Quantum black holes at world's end

*Friday 24 May 2024 11:05 (45 minutes)*

Semi-classical gravity is a useful proxy to study quantum effects in gravity. Yet, generically, consistent solutions to the semi-classical Einstein equations accounting backreaction remain out of reach, limiting our understanding of quantum corrections to black hole physics. In this talk, I review the construction of three-dimensional ‘quantum’ black holes. Such spacetimes live on holographic end-of-the-world branes and are exact solutions to an induced higher-derivative theory of gravity consistently coupled to a large- $c$  conformal field theory with an ultraviolet cutoff, accounting for all orders of semi-classical backreaction. Notably, such quantum-corrected black holes are much larger than the Planck length and are thereby robust against quantum gravitational effects. I describe the geometry and thermodynamics of a host of (anti-) de Sitter quantum black holes, and survey applications of these constructions.

**Presenter:** SVESKO, Andrew

Contribution ID: 75

Type: **not specified**

## Developing a paradigm of non-singular black holes

*Friday 24 May 2024 15:00 (45 minutes)*

Black holes are arguably the most fascinating prediction of general relativity. These solutions of general relativity are singular and are therefore expected to be an approximation. One of the promises of quantum gravity is providing a complete and non-singular description of black holes. This complex task has been addressed by different groups using different bottom-up and top-down approaches and, while a definitive picture remains elusive, much has been learned thanks to these efforts. In this talk, I will summarize some of these results and discuss their implications for our understanding of the ultimate nature of black holes.

**Presenter:** CARBALLO-RUBIO, Raúl

Contribution ID: 76

Type: **not specified**

## Simulating Quantum Black Holes

*Friday 24 May 2024 09:45 (1 hour)*

A black hole is characterised by the event horizon, a boundary of information that can be accessed from that which cannot. Horizons can occur in a wide range of physical situations, many of which we can construct in the lab, leading to the field of Analog Gravity. Most gravity simulators observe features, like super-radiance, that are analysed as a continuum effect in gravity, whereas many interesting “beyond GR” features theorise about the impact of quantised aspects of the black hole. In this talk, I will discuss recent experimental work on a liquid helium giant vortex that naturally has quantisation, and how we hope to build a quantised analog black hole that can start to explore “black hole” phenomena in a much broader context.

**Presenter:** GREGORY, Ruth