Black Holes, Neutron Stars, and Gravitational Waves @ Black Sea

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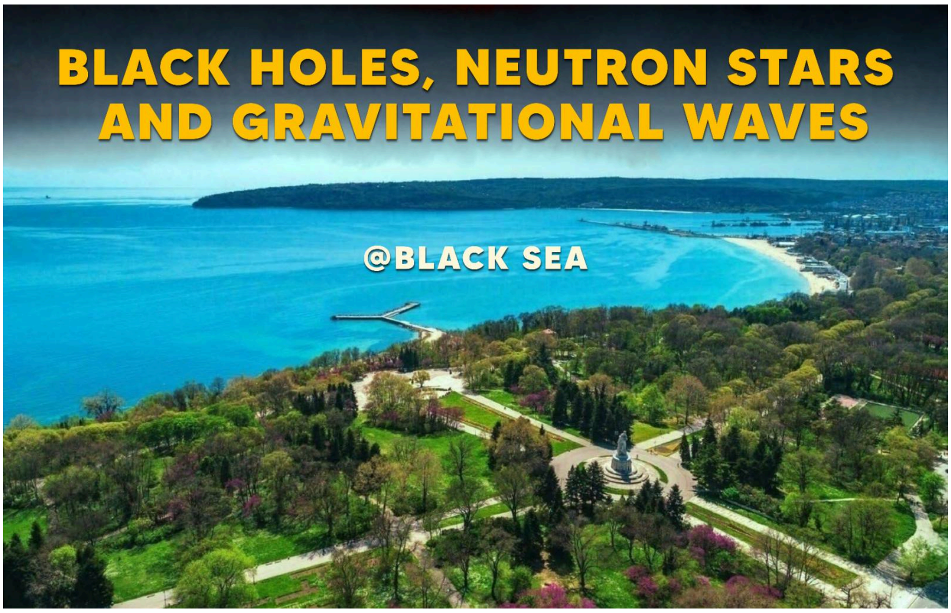

Book of Abstracts

Contents

2

Testing general relativity using binary black hole orbital frequency evolution on time-frequency plane

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The orbital evolution of binary black hole (BBH) systems is determined by the component masses and spins of the black holes and the governing gravity theory. General relativity (GR) is the simplest theory of gravity that lays the foundation for successfully explaining the current gravitational wave (GW) observations. We present a method of stacking up the time-frequency pixel energies through the orbital frequency (OF) evolution with the flexibility of gradually shifting the OF curve along the frequency axis. The time-frequency spectrogram is obtained using a high-resolution Synchroextraction method. We observe a distinct energy peak corresponding to the GW signal's quadrupole mode. If an alternative theory of gravity is considered and the analysis of the BBH orbital evolution is executed following GR, the energy distribution on the time-frequency plane will be significantly different. We propose a new consistency test to check whether GR explains the BBH orbital evolution. Finally, through the numerical simulation of beyond-GR theory of gravity and utilizing the framework of second-generation interferometers, we demonstrate the efficiency of this new method in detecting any possible departure from GR.

3

Well-posedness and gravitational collapse of self-interacting vector fields

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I will discuss the Cauchy problem for self-interacting massive vector fields, often facing instabilities and apparent pathologies when performing numerical simulations. After showing that these issues are due to the breakdown of the well-posedness of the initial-value problem, I will show how the pathologies can be classified, building on previous work done for ⊠-essence, and how these issues can be avoided by "fixing the equations", enabling stable numerical evolutions in spherical symmetry. Finally, I will display initial configurations for the massive vector field which lead to gravitational collapse and the formation of black holes in theories with cubic self-interactions.

4

Evolution of an exotic proto-neutron star into black hole

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A proto-neutron star forms after a successful supernova when the stellar remnant decouples from the ejecta. we explore a relativistic framework for the finite-temperature β-equilibrium limit of equation of state, constrained via a Bayesian inference methodology, subject to minimal constraints on a few nuclear saturation properties, low-density pure neutron matter constraints from chiral effective field theory, and a neutron star maximum mass greater than 2.0 $M_{\odot}$. We analyze a set of parameters for this study derived from the relativistic mean field model at the zero temperature limit. We compare results with the Γ-law approximation for thermal effects. Our finding in the present study is that the presence of hyperonic matter in the neutron star makes more likely collapse into black hole as compare to the presence of nuclear matter.

5

Torsional four-fermion interaction and the Raychaudhuri equation

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The intrinsic spin of fermions can generate torsion in spacetime. This gives rise to an effective four-fermion interaction that fermions experience within a fermionic distribution. This interaction is expected to become significant when densities become large, such as in early universe cosmology or in compact astrophysical objects like neutron stars. In this contribution, I will discuss the role of this interaction in a gravitationally collapsing fermionic distribution. Our specific aim is to explore if this interaction can provide a repulsive contribution and prevent the formation of the final singularity. We consider a collapsing distribution of fermions which incorporates both chiralities. We use the Raychaudhuri equation and the focusing condition for congruences to carry out our investigation. Using reasonable assumptions, we establish that a repulsive contribution arises depending on how torsion couples with different chiralities. Also, the interaction term will behave analogous to an exotic matter (dark matter) component, having an effective negative equation of state, and the effect of the interaction starts to dominate as the collapse proceeds, accelerating or decelerating the collapse depending on the relative signs of the geometrical interaction between different species of fermions.

This work contributes to the understanding of how torsion-driven effects in dense fermionic systems might resolve the final singularity formation, and may have implications for the end-states of stars, such as neutron stars or other dense astrophysical objects.

6

The effect of extra dimensions on astrophysical observables

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Kaluza and Klein proposed a theory with a compactified extra dimension, which may appear in high-energy phenomena, such as nuclear reactions, strong gravitational effects, or in the presence of superdense matter. In this work, I show how astrophysical observables will be modified in the presence of extra compactified dimensions.

The interior of a compact star is modelled as a multidimensional interacting degenerate Fermi gas, embedded in a static, spherically symmetric spacetime with extra compactified spatial dimensions. The equation of state of this extreme medium is given and compared to the standard models of superdense matter. The modification of the mass-radius relation of compact stars is calculated and compared to realistic star models and astrophysical observation data. The interaction strength has been determined for this extraordinary matter. Constraints on the size of the extra dimension have been estimated based on pulsar measurements [1,2].

[1] A. Horváth, E. Forgács-Dajka, G.G. Barnaföldi: "Application of Kaluza-Klein Theory in Modeling Compact Stars: Exploring Extra Dimensions", MNRAS, https://doi.org/10.1093/mnras/stae2637
[2] A. Horváth, E. Forgács-Dajka, G.G. Barnaföldi: "The effect of multiple extra dimensions on the maximal mass of compact stars in Kaluza-Klein space-time", Accepted to International Journal of Modern Physics A, https://doi.org/10.1142/S0217751X25420047

10

Towards a more realistic asteroseismology of core-collapse supernovae

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One of the most promising and challenging future gravitational wave (GW) sources are core-collapse supernovae. The oscillation modes of the newly born proto-neutron star (PNS) and the stalled accretion shock will be excited triggering the GW emission. Due to the stochastic nature of these signals, it is not possible to use template matching techniques. An alternative way to analyse the signal is to perform asteroseismology in order to infer properties of the PNS. The oscillations can be described by a system of partial differential equations (PDEs), which can be solved as an eigenvalue problem. In that frame, the eigenvalues are the characteristic frequencies of the oscillation modes. In this work, we relax the approximation of the hydrostatic equilibrium and allow for accretion of the PNS. By doing so, we can investigate the Standing Accretion Shock Instability and its effect on the modes.

11

binary black hole grmhd with einstein toolkit

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This paper presents a comprehensive study of binary black hole systems using general relativistic magnetohydrodynamics (GRMHD) simulations within the Einstein Toolkit framework. We investigate the complex interactions and accretion dynamics of merging black holes, highlighting the role of magnetic fields in shaping the gravitational wave signals and electromagnetic counterparts associated with these events. Our analysis focuses on the evolution of binary black holes from inspiral to merger, employing advanced numerical techniques to capture the intricate physics involved.

Key Contributions:

GRMHD Framework: We utilize the Einstein Toolkit to implement GRMHD simulations, allowing for a detailed examination of the magnetized plasma surrounding the black holes and its influence on the dynamics of the system.

Magnetic Field Effects: The study emphasizes how magnetic fields can alter the accretion processes and the resulting gravitational waveforms, providing a deeper understanding of the electromagnetic signals that accompany black hole mergers.

Comparative Analysis: We compare our simulation results with observational data from gravitational wave detectors, aiming to identify signatures that could indicate the presence of magnetic fields in binary black hole systems.

Implications for Astrophysics: The findings have significant implications for the understanding of black hole formation, the role of magnetic fields in astrophysical processes, and the interpretation of multi-messenger astronomy.

Future Work: We outline potential avenues for future research, including the exploration of different initial conditions and the impact of varying magnetic field strengths on the merger dynamics and associated emissions.

12

Probing Magnetic Fields in Neutron Star Binaries Through Gravitational Waves

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We investigate the imprint of magnetic fields on gravitational waves from the inspiral phase of eccentric binary neutron star binaries (BNS). While neutron stars are typically observed to exhibit strong magnetic fields ranging from 10^{14} to 10^{15} G, theoretical models predict strengths up to 10^{18} G. BNS systems formed through dynamical capture may retain substantial eccentricity and extreme magnetic fields during their late inspiral, potentially affecting the gravitational waveform. These fields can influence the orbital dynamics through magnetic interactions and electromagnetic emission. Using a perturbative approach, we derive solutions for the equations of motion, total energy loss rate, and gravitational wave (GW) phase evolution. Our findings indicate that dephasing effects caused by magnetic fields of 10ˆ15 G can produce sizable contributions to the gravitational wave signal detectable by third-generation gravitational wave detectors. In the deci-hertz band, our analysis suggests that even weaker fields of 10ˆ14 G could leave a detectable imprint. Thus, future GW observations could offer a novel way to probe neutron star magnetic fields, providing insight into magnetar binaries and their formation channels.

15

Hadrons vs. Quarks: A Bayesian Comparison of Neutron Star Equations of State Using Nuclear and Astrophysical Data

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The neutron star observables, such as mass, radius, and tidal deformability, non-radial oscillations are directly related to the equation of state (EOS). The exact nature of dense matter in neutron stars(NS) remains unknown. Several efforts have been made to constrain the EOS through theoretical modelling, incorporating inputs from nuclear physics experiments and astrophysical observations.

We study quasinormal f–mode oscillations in NS interiors within the linearized General Relativistic formalism. We utilize approximately a set of nuclear EOS constructed in relativistic mean field (RMF) formalism using spectral representation techniques, incorporating constraints on nuclear saturation properties, chiral Effective Field Theory (χEFT) for pure neutron matter, and perturbative Quantum Chromodynamics (pQCD) for densities pertinent to NS cores. Our study reveals a weak correlation between f–mode frequencies and individual nuclear saturation properties, but a robust linear relationship between the radii and f–mode frequencies with extreme masses ($1.34M_{\odot}$ and $2.0M_{\odot}$). However, for different masses on the NICER data, it has minimal overlap in the radius domain and differs in the frequency domain with our nucleonic EOS set.
The hybrid EOS models incorporating hadron-quark phase transition combines two theoretical frameworks: the RMF model for the nucleonic regime and a mean-field theory of quantum chromodynamics (MFTQCD) for the quark regime. Interestingly, our similar analysis corresponding the hybrid EoS lie very well within our NICER-derived constraints in the radius as well as the f–mode frequency domain, indicating a preference of hybrid EOS over the purely nucleonic ones for the first time. Observational data from pulsars PSR J0030+0451 and PSR J0740+6620 suggest a slight preference for EOSs with smooth phase transitions. In contrast, GW data remain largely inconclusive.

Our analysis also highlights tensions between earlier NICER measurements and recent observations of PSR J0437-4715. We find a clear distinction between the 90% credible intervals of neutron star observables—including mass, radius, tidal deformability, f-mode oscillation frequency, and GW damping time—when comparing purely hadronic and hybrid EOSs. The hybrid model allows for stiffer EOSs that better align with NICER data but predict higher tidal deformabilities, which conflict with GW observations. Our results indicate the need for more flexible EOS models to reconcile the discrepancies between different astrophysical observations.
Ref:
1. Bayesian evaluation of hadron-quark phase transition models through neutron star observables in light of nuclear and astrophysics data, D. Guha Roy, A. Venneti, T. Malik, S. Bhattacharya, S. Banik Physics Letters B Volume 859, 139128 (2024)
2. Analysis of Neutron Star f–mode Oscillations in General Relativity with Spectral Representation of Nuclear Equations of State, D. Guha Roy, T. Malik, S. Bhattacharya, S. Banik, ApJ 968 124 (2024)

17

Bianchi Type-V Universe in Fractal Gravity with Observational Constraints

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The aim of the current investigation is to determine the evolution characteristics of anisotropic and homogeneous universe within the context of fractal theory of gravitation. The Bianchi type-V spacetime has been employed to derive the field equations of fractal theory. Based on the signature flip property of the deceleration parameter, we have derived the scale factor and the Hubble parameter We have obtained the approximate best-fit values of the model parameters using the least squares method, incorporating observational constraints from available datasets such as Hubble H(z) and Pantheon, by applying the root mean square error (RMSE) formula. In addition, we discuss various physical parameters, including pressure, energy density, and energy conditions. Also we discuss some cosmographic parameters jerk, snap and lerk.

18

Fastest spinning millisecond pulsars: indicators for quark matter in neutron stars?

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We study rotating hybrid stars, with a particular emphasis on the effect of a deconfinement phase transition on their properties at high spin. Our analysis is based on a hybrid equation of state with a phase transition from hypernuclear matter to color-superconducting quark matter, where both phases are described within a relativistic density functional approach. By varying the vector meson and diquark couplings in the quark matter phase, we obtain different hybrid star sequences with varying extensions of the quark matter core, ensuring consistency with astrophysical constraints from mass, radius, and tidal deformability measurements. We test whether the early deconfinement phase transition is consistent with the present observational data. We show how the fastest spinning pulsars and the appearance of the quasi-radial oscillations and non-axisymmetric instabilities constrain the strongly interacting matter equation of state at zero temperature. Our findings reveal that incorporating the hybrid equation of state into the analysis of pulsars has significant implications for the constraints on the properties of strongly interacting matter and neutron stars which is of the high interest for the future SKA observations.

19

Perfect fluid dynamics with observational constraints in the framework of \(f(T)\) gravity

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In this study, we explore cosmological models within the framework of \(f(T) \) gravity by utilizing the energy-momentum tensor for a perfect fluid to solve the corresponding field equations. We derive key cosmological parameters, including the Hubble parameter \(H \). Parameter constraints were applied using the \(R^2 \) test, resulting in best-fit values of \(\beta = 108.51^{+0.41}{-0.40} \) and \(\xi_1 = -0.14717^{+0.00094}{-0.00096} \), with a strong alignment with the \(\Lambda\)CDM model (\(R^2 = 0.9280 \); RMSE = 11.4068). The deceleration parameter, calculated in terms of cosmic time and redshift, indicates a transition from deceleration to acceleration, consistent with current observations of an accelerating universe. Additionally, we examined the pressure \(p \), energy density \(\rho \), and equation of state parameter \(\omega \) for two specific models: Model-I for \(f(T) = \lambda T \) and Model-II for \(f(T) = T + \beta T^2 \). The Om diagnostic plotted against redshift for \(\xi_1 \) shows that \(\Omega(z) \) stabilizes around \(0.3 \) after a slight deviation at \(z \approx 0 \), with a narrow uncertainty band. The model closely aligns with \(\Lambda\)CDM at higher redshifts. The pair of statefinder diagnostics \(r \) vs. \(s \) is also discussed, and our model for \((r,s)=(1,0) \) represents the \(\Lambda\)CDM model.

23

Impact of magnetic field gradients on the development of the MRI in binary neutron star mergers

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The magneto-rotational instability (MRI) is a cornerstone of accretion disk theory, and it is often invoked to explain the generation of large-scale, poloidal magnetic fields in binary neutron star mergers. However, simulations that begin with weak seed fields and follow their amplification to saturation lack convincing evidence of MRI activity, casting doubts on its role in this setting. In this talk, I will discuss how the classical MRI extends under more realistic post-merger conditions, where magnetic fields present complex topologies and field gradients are significant. In particular, I will present modified expressions for the timescale and wavelength of the fastest growing mode, along with a generalised instability criterion that captures the influence of magnetic field inhomogeneities. Finally, I will show the results of applying the extended MRI to a high-resolution simulation of a long-lived merger remnant. Our results indicate that the MRI is significantly hindered in the early post-merger phase, with favourable conditions—where the instability condition is met and the growth rate is sufficiently fast—emerging only at later stages, of the order of 100 milliseconds after merger.

24

Revisiting Buchdahl transformations: new static and rotating black holes in vacuum and hairy extensions

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This work investigates Buchdahl transformations within the framework of Einstein and Einstein-Scalar theories. Specifically, we establish that the recently proposed Schwarzschild–Levi-Civita spacetime can be obtained by means of a Buchdahl transformation of the Schwarschild metric along the spacelike Killing vector. The study combines Buchdahl's original theorem with the Kerr–Schild representation. In doing so, we construct new vacuum-rotating black holes in higher dimensions which can be viewed as the Levi-Civita extensions of the Myers–Perry geometries. In the context of the Einstein-Scalar system, the paper extends the corresponding Buchdahl theorem to scenarios where a static vacuum seed configuration, transformed with respect to a spacelike Killing vector, generates a hairy black hole spacetime. We analyze the geometrical features of these spacetimes and investigate how a change of frame, via conformal transformations, leads to a new family of black hole spacetimes within the Einstein-Conformal-Scalar system.

25

Doubly regular black holes

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Black holes in general relativity possess curvature singularities. These are not the only type of singularities that a spacetime can possess though. The Kerr solution, for example, also exhibits a *thermodynamic singularity* at a specific, non-extremal value of the spin parameter where the heat capacity diverges ("Davies' point"). Given the deep connections between black holes and thermodynamics, it seems desirable to consider objects which are not only physical-space regular but phase-space regular also. I will discuss some results regarding such "doubly-regular" holes, including context with respect to physical interpretations of the heat capacity.

26

How Gravitational Wave Data From binary Black Hole mergers constrains black hole entropy

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Gravitational wave data from BBH coalescence have recebtly been analyzed to validate Hawking's Area Theorem. We discuss how this validation constrains theoretical calculations of black hole entropy, including corrections to quantal or classical modifications of classical general relativity. We show how observational data discriminates between quantum gravity corrections to the Bekenstein-Hawking area formula, by unequivocally ascertaining the algebraic sign of these corrections. The origin and implications of these algebraic signs will be discussed for two approaches to black hole entropy corrections, namely Loop Quantum gravity and Euclidean Quantum Gravity. We shall also discuss a perturbative approach to classical modifications of general relativity, and discuss what that implies for the Wald formula for black hole entropy. The talk is based on the ArXiv'd papers 2305.09391v3 (published in PLB 2024) and 2408.13820v3 (published in PRD 2025).

27

Numerical Relativity Simulations of Dark Matter Admixed Binary Neutron Stars

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Binary neutron star mergers provide insights into strong-field gravity and the properties of ultra-dense nuclear matter. These events offer the potential to search for signatures of physics beyond the standard model, including dark matter. We present the first numerical-relativity simulations of binary neutron star mergers admixed with dark matter, based on constraint-solved initial data. Modeling dark matter as a non-interacting fermionic gas, we investigate the impact of varying dark matter fractions and particle masses on the merger dynamics, ejecta mass, post-merger remnant properties, and the emitted gravitational waves. Our simulations suggest that the dark matter morphology - a dense core or a diluted halo - may alter the merger outcome. Scenarios with a dark matter core tend to exhibit a higher probability of prompt collapse, while those with a dark matter halo develop a common envelope, embedding the whole binary. Furthermore, gravitational wave signals from mergers with dark matter halo configurations exhibit significant deviations from standard models when the tidal deformability is calculated in a two-fluid framework, neglecting the dilute and extended nature of the halo. This highlights the need for refined models in calculating the tidal deformability when considering mergers with extended dark matter structures. These initial results provide a basis for further exploration of dark matter's role in binary neutron star mergers and their associated gravitational wave emission and can serve as a benchmark for future observations from advanced detectors and multi-messenger astrophysics.

28

Stationary and axisymmetric solutions in modified gravity

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This talk will address the study of stationary and axisymmetric exact solutions in scalar-tensor theories. We will review de Weyl problem in GR and its stationary extension, to present then a generalisation valid in the presence of scalar fields. We will show new rotating spacetimes in four and five dimensions and a systematic procedure to construct them. Extensions to generalised scalar-tensor theories are discussed as well.

29

Time evolution characterization as a sieve for gravity theories

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Having well posed time evolution is an important property we seek to have in our theories of nature. In this talk, I will present how some simple classical field theories can be ruled out due to a breakdown of time evolution in their dynamics. I will also speculate on using similar analyses to constrain the alternative theory landscape of gravity, helping the observational and experimental tests.

30

Exact rotating wormholes via Ehlers transformations

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In this paper, we construct exact rotating wormholes using the Ehlers solution-generating technique. This is based on the Ernst description of four-dimensional, stationary, and axially symmetric solutions of the Einstein-Maxwell theory. We adopt the static Barceló-Visser wormhole derived from the Einstein-Maxwell-conformal-scalar theory as a seed and demonstrate, through the Ernst approach, how to construct two novel geometries of rotating wormholes. These geometries correspond to the Barceló-Visser wormhole embedded within a rotating and a magnetic background. In the first case, the rotation is a result of a dragging force (due to the rotating background) acting on the initial static wormhole, while in the second case, it is caused by the electromagnetic interaction between the electric charge of the static wormhole and the external magnetic field. We conduct a comprehensive analysis of the geometric properties of these configurations and examine the new features introduced by rotation, such as the emergence of ergoregions. Recent evidence suggests that incorporating slow rotation can stabilize wormholes, rendering these exact, fully rotating solutions particularly appealing.

31

XMM-Newton Insights into the Reflection and Variability of Mrk 841

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Mrk 841 is known for its high variability, complex iron line component and strong soft excess. We use the most recent and longest XMM-Newton observations, with durations exceeding 100 ks. We explore several theoretical models to explain the puzzling behaviors of the reflecting component, considering parameters such as disk ionisation and relativistic effects. This offers a rare glimpse into the dynamic processes shaping AGN emission, advancing our understanding of black hole accretion physics.

33

Quasinormal modes of charged and static wormholes

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In this talk we discuss the quasinormal mode (QNM) spectrum of charged and static wormholes, which is interesting for understanding gravitational-wave phenomena in this kind of objects. We compute the QNMs employing a spectral method, which allows us to study in a systematic way the properties of the modes as we vary the charges of the wormholes. We discuss several properties of the QNM spectrum, such as the different families of modes we find (gravitational, scalar and electromagnetic -led modes), isospectrality, excitations, comparison with the spectrum of the Ellis-Bronnikov wormhole, and stability under linear perturbations.

34

Quantum Properties and Gravitational Field of an Oscillator in Proper Time

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By restoring the symmetry between time and space in a matter field, we reconciled the properties of a zero-spin quantum field from a system that has vibrations of matter in time. This quantized real scalar field obeys the Klein-Gordon equation and Schrodinger equation. The particles observed are oscillators in proper time. In motion, the proper time oscillation translates to the oscillations of a particle in both time and space. By neglecting all the quantum effects and assuming the particle as a classical object that can remain stationary in space, we show that the proper time oscillator can mimic a point mass at rest in general relativity. The spacetime outside this proper time oscillator is static and satisfies the Schwarzschild solution.

References
[1] Yau, H. Y.: Time and space symmetry in a quantum field. J. Phys.: Conf. Ser. 1194, 012116 (2019)
[2] Yau, H. Y.: Thin shell with fictitious oscillations", in Spacetime Physics1907 –2017, Chapter 6 (Minkowski Institute Press, Montreal, 2019)
[3] Yau, H. Y.: Self-adjoint time operator in a quantum field. J. Quant. Info. 1941016 (2020)
[4] Yau, H. Y.: Schwarzschild field of a proper time oscillator. Symmetry 12(2), 312 (2020)
[5] Yau, H. Y.: Proper time operator and its uncertainty relation. J. Phys, Commun. 105001 (2021)

35

What if black hole spacetimes are singularity-free?

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Although the Penrose-Hawking singularity theorems leave little room for the fate of collapsing matter, since the 1960s there has been great interest in the possibility of deriving black hole solutions with a regular center. In this talk, after a brief historical review, I will discuss the main features of regular black holes and their implications for fundamental physics. Finally, I will comment on the emerging new phenomenology in astrophysics and particle physics and what can be learned from such spacetimes for the future.

36

Black Holes in massive scalar Gauss-Bonnet using GRFolres

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Testing the strong-field regime of gravity has become of great interest in the scientific community following the first gravitational wave detections and the growing theoretical and experimental indications that General Relativity (GR) may require modifications in extreme conditions.
In this context **Scalar-Gauss-Bonnet** (sGB) not only provides a natural framework for such deviations but is also well motivated as it directly arises from fundamental high-energy physics such as string theory.
While massless versions of this theory have dominated past studies, introducing a **scalar mass** is crucial for a more realistic treatment and may reveal new dynamical features.

Starting from the necessity of solving Einstein's equations beyond highly idealized, symmetric cases, **Numerical Relativity** (NR) has proven to be a fundamental tool, central to research in gravitational physics. This has recently led to the development of specialized NR codes capable of handling alternative theories of gravity, such as **GRFolres**.

With this work, I focus on simulating **black holes in sGB gravity**, aiming to improve our current understanding of the role of scalar fields in black hole dynamics and provide benchmarks for future studies.
Furthermore, these simulation serve as a stepping stone towards our final goal of modeling **binary black hole mergers** in modified gravity frameworks.

The presentation will discuss the methodology, the numerical challenges encountered and preliminary results from single black hole experiments, along with an outlook on future binary merger simulations.

37

Numerical Relativity Insights into Tidal Resonance Phenomena

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Gravitational wave observations of neutron star collisions offer a unique avenue into a regime where gravity and matter entangle strongly and evolve dynamically. As these waves travel essentially undistorted through the cosmos to reach the detectors, they constitute the most promising messenger to probe into nuclear physics at extreme densities and low temperatures. In this talk, we will focus on the imprint on the waveforms left by the tidal resonance phenomenon that could happen in the last 100 milliseconds of inspiral. After introducing the analytic model for such effects, we will present recent results of numerical simulations where we confirm in part our theoretical understanding while revealing further issues that require the next level of modeling.

38

Binary neutron star mergers in massive scalar-tensor theory

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We study binary neutron stars in the framework of Damour-Esposito-Farese-type (DEF) scalar-tensor theory of gravity with a massive scalar field. In this talk, I will start from the quasiequilibrium sequences of binary neutron stars, paying particular attention to the case where neutron stars are already spontaneously scalarized at distant orbits, i.e., in the high-coupling constant case. In particular, we are able to constrain the scalar mass from gravitational wave observations of binary neutron star mergers by inspecting the dephasing. Then, I will discuss the properties of post-merger remnants of binary neutron star mergers resulted by numerical relativity simulation and provide a distinctive signature in gravitational waves signal.

39

Strong-gravity tidal interactions in hierarchical triple systems

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Tidal interactions play a fundamental role in shaping binary systems and affect their gravitational wave (GW) signals, which is crucial for future detectors such as LISA and ET. While tidal effects on binaries are often studied in a weak-field approximation, their role in the strong-gravity regime remains largely uncharted.

We present two frameworks to analyze strong-gravity tidal effects from a supermassive black hole on an inspiraling binary within a hierarchical triple system. Using the small-tide approximation, we introduce relativistic corrections at the quadrupolar level that are captured by electric and magnetic tidal moments.
First, we examine the recently discovered precession resonances between the inner binary's periastron precession and its orbital motion around a supermassive black hole. By modeling the latter as a Schwarzschild metric, we discover a significantly richer resonance spectrum than predicted by Newtonian mechanics, with distinct implications for orbital evolution.
Second, we derive the first explicit metric expression for a tidally perturbed Kerr black hole by using reconstruction techniques based on the Teukolsky Master Equation. This solution, valid for general quadrupolar tidal deformations, captures spin-tidal couplings and enables us to compute shifts in the trajectories of a particle in the spacetime of the perturbed black hole.

These findings open new observational pathways for detecting strong-gravity effects in hierarchical triple systems. Specifically, these effects can produce distinctive GW waveform modulations and phase shifts that could serve as smoking-gun signatures of strong-field tidal effects.

40

3D collapse of rapidly rotating neutron stars into black holes in massive scalar-tensor theory

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We present a full 3D numerical evolution code to study rotating neutron stars in massive-scalar-tensor (MST) theories.
The implementation consists in a modified version of the Baumgarte-Shapiro-Shibata-Nakamura (BSSN) formalism such that the simulations are performed in the physical Jordan frame, where the scalar field is directly coupled with the spacetime evolution. This approach allows to preserve the standard hydrodynamic evolution for matter fields,
allowing eventually for the inclusion of more microphysics. As an example of a use case of this implementation, we study the problem of gravitational collapse of rapidly rotating neutron stars in MST theories by exploring the parameter space (couplings and mass of the scalar field) and its impact on the dynamical properties of the process and on the emitted scalar and gravitational radiation.

41

Black Hole Dynamics in Extensions of General Relativity

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Extensions of General Relativity can give rise to black holes with nontrivial scalar structure, commonly called "hairy" black holes. This work investigates the dynamics of spherically symmetric black holes in scalar–Gauss–Bonnet gravity through fully nonlinear simulations incorporating excision techniques. These theories often suffer from an ill-posed initial value formulation, which limits their predictive power. We show that, within the framework of effective field theory, including appropriately chosen interactions, resolves this issue. Our results offer a path toward restoring predictivity in extended gravitational theories and provide new insights into their consistent formulation.

42

Observing horizonless compact objects by the Event Horizon Telescope

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Horizonless compact objects may produce phenomenological features which distinguish them observationally from black holes. In particular, the images of the accretion disks around them may possess a characteristic morphology including a series of central bright rings instead of a shadow. We demonstrate how the central ring structure arises relating it to the behavior of the deflection angle on the scattering geodesics and the light ring structure of the spacetime. Focusing on reflective naked singularities and wormholes we further discuss whether the central rings can be observed by the present and near-future Event Horizon Telescope (EHT) arrays. While they may be hard to be

distinguished by the current capacities, the next-generation EHT will be able to detect them as qualitative deviations in the image morphology. The effect can be further confirmed by measurements of the linear polarization of the emission from the accretion disk. In these cases it forms a characteristic pattern which can serve as an independent channel for detection of horizonless compact objects.

44

Simulating and Interpreting the Multimessenger Picture of Neutron Star Mergers

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The correct interpretation of multimessenger data obtained from binary neutron star mergers, including gravitational waves and electromagnetic signals, requires accurate theoretical predictions that can be cross-correlated with observations. These models can be constructed by combining ab initio numerical-relativity simulations with derived analytical knowledge. In addition, an efficient Bayesian framework for multimessenger analysis is indispensable for extracting meaningful information from observational data. We will discuss how numerical-relativity simulations and multimessenger data analysis go hand in hand to provide valuable insights into neutron star mergers and fundamental physics principles.

46

Black hole scalarization at all scales

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The most well-studied class of theories of gravity beyond General Relativity is represented by scalar-tensor gravity, in which at least one fundamental scalar degree of freedom is included in the gravitational sector. This family is theoretically appealing due to its simplicity and due to its capability to describe cosmic dynamics at large scales.
Within this class, a particularly relevant theory is the one in which the scalar field is coupled to the Gauss-Bonnet invariant. In fact, in this theory BHs can exist in different branches of solutions, including the GR solution and different "scalarized" ones.
The transition of black holes from the GR branch to a scalarized one is a process known as scalarization.
I will discuss this phenomenon in BH binary systems, as well as its possible implications in gravitational wave observations.

47

Cubic parametrization of the deceleration parameter within f(T) gravity

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In this study, we used the \(f(T) \) gravity framework with the energy-momentum tensor for a perfect fluid to derive key cosmological parameters, including the Hubble parameter \(H \), deceleration parameter \(q \) and Statefinder diagnostics. Model parameters were optimized using an \(Rˆ2 \) test, resulting in \(\beta = 1.312ˆ{+0.013}{-0.014} \), \(\xi = 1.273ˆ{+0.0065}{-0.0071} \), and \(H_0 = 72.60ˆ{+0.50}_{-0.49} \), with an \(Rˆ2 \) of 0.9527. Our model aligns closely with the \(\Lambda\)CDM model and shows good performance based on AIC and BIC criteria. Analyzing the \(q(z) \) curve revealed the transition from deceleration to acceleration in the universe's expansion. Additionally, we examined pressure, energy density, and equation of state parameter for two models, \(f(T) = \lambda T \) and \(f(T) = T + \beta Tˆ2 \), both aligning well with observational data. The \(r \)-\(s \) and \(r \)-\(q \) diagnostics further confirm our model's consistency with \(\Lambda\)CDM, making it a strong alternative for explaining cosmic expansion. The evolution of \(\Omega(z)\) shows strong consistency with the \(\Lambda\)CDM model, with the Om parameter approaching 0.3 at lower redshifts and parameter uncertainties highlighting the model's reliability.

48

A new model of spontaneous scalarization induced by curvature and matter

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We present a model of black hole scalarization where a scalar field couples simultaneously to the Gauss–Bonnet invariant and the electromagnetic Maxwell field. This combined interaction broadens the conditions for spontaneous scalarization. We track how the electric charge and the two coupling constants control the onset of the scalar field and uncover new solution branches with non-trivial scalar profiles. Scalarization occurs across a wide range of parameters and even with negative Gauss–Bonnet coupling at sub-extremal charge (q).

Scalar clouds and fully scalarized black holes form above several mass thresholds; varying the Maxwell coupling or the charge makes the highest threshold mass almost three times the lowest. Multiple branches of scalarized solutions converge to the same final state, indicating non-unique growth of scalar hair. The model also produces overcharged black holes ($q > 1$) while the Gauss–Bonnet coupling remains positive. Several examples show horizon areas larger than those of the Reissner–Nordström solutions with the same mass and charge.

The Maxwell term shifts the scalarization onset and tends to stabilize the solutions, as seen from the evolution of the scalar charge and horizon quantities. These results provide an alternative route to scalarization, may avoid the instabilities of curvature-only or matter-only models, and open new possibilities for testing strong-gravity effects in upcoming observations.

49

Nonlinearities in black hole ringdown

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Nonlinear effects in black hole perturbation theory may be important for describing a black hole ringdown, as suggested by recent works. I will describe a new class of "quadratic" quasi-normal modes at second order in perturbation theory. Remarkably, not only their frequency but also their amplitude is completely determined by the linear modes themselves. I will present how one can compute them using Leaver's algorithm. Quadratic modes could be used to improve ringdown models by adding nonlinear features without introducing any supplementary free parameter for data analysis purposes, or to test GR in the nonlinear regime.

50

Hybrid Nuclear Matter EOS with Color Superconducting Quark Phase: Bayesian Constraints from Observations

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We perform a Bayesian analysis of the equation of state (EOS) constraints using recent observational data, including pulsar masses, radii, and tidal deformabilities. Our focus is on a class of hybrid neutron star EOS that incorporates color superconducting quark matter, based on a recently developed nonlocal chiral quark model. The nuclear matter phase is described using a relativistic density functional approach within the DD2 class, while the phase transition between nuclear and quark matter is described using a Maxwell construction.
Our analysis identifies a region within the two-dimensional parameter space, defined by the vector meson coupling and scalar diquark coupling, where the observational constraints are met with the highest probability (90% of the maximum). We present the overlap of this region with those where other properties are fulfilled:
1. A strong phase transition that produces a third family of compact stars.
2. A maximum mass of the hybrid neutron star that exceeds that of the purely nucleonic star.
3. An onset mass for quark deconfinement below one solar mass.

51

Black holes with electroweak hair

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We construct static and axially symmetric magnetically charged hairy black holes in the gravity-coupled Weinberg-Salam theory. Large black holes merge with the Reissner-Nordstr\"om (RN) family, while the small ones are extremal and support a hair in the form of a ring-shaped electroweak condensate carrying superconducting W-currents and up to 22% of the total magnetic charge. The extremal solutions are asymptotically RN
with a mass {\it below} the total charge, $M < |Q|$, due to the negative Zeeman energy of the condensate interacting with the black hole magnetic field. Therefore, they cannot decay into RN black holes. As their charge increases, they show a phase transition when the horizon symmetry changes from spherical to oblate. At this point they have the mass typical for planetary size black holes of which $\approx 11\%$ are stored in the hair. Being obtained within a well-tested theory, our solutions are expected to be physically relevant.

52

Neutron star crust elasticity and elastic oscillations

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The oscillation signals are important information for extracting the interior properties of the oscillating source. This technique for stars is known as asteroseismology, which is similar to seismology on Earth and helioseismology on the Sun. Since the oscillation frequencies are excited due to the corresponding physics, one could extract the properties associated with such physics once one identifies the frequencies with a specific mode. In particular, the neutron star crust has an elasticity with which the elastic modes can be excited. The neutron star crust properties relatively weakly affect the neutron star mass and radius, but their density region is around the nuclear saturation density, i.e, we can approach physics in the neutron star crust from astronomical observations and terrestrial experiments. In this presentation, we identify the magnetar QPOs with the torsional modes to extract the physical properties, and also discuss the other oscillation modes, i.e., the shear and interface modes, which may be associated with the resonance shattering in the binary neutron star evolution.

53

Stability of Neutron Stars for Causal Relativistic Viscous Fluids

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First order relativistic viscous theories had, until recently, been believed to not be well-behaved (i.e. causal, stable and strongly hyperbolic). Because of this, relativistic viscosity in astrophysical contexts has remained understudied. Recently, the Bemfica-Disconzi-Noronha-Kovtun (BDNK) theory has been shown to be causal, stable and strongly hyperbolic, which makes it a well-suited model for extending viscosity in the relativistic regime. In this presentation, I study the stability of neutron stars to viscous effects through perturbation theory and find necessary conditions for radial stability for the BDNK theory.

54

Free hyperboloidal evolution and strong field initial data

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Gravitational wave radiation is only unambiguously defined at future null infinity – the "location" where light rays arrive and where global properties of spacetimes can be measured. Reaching future null infinity is thus crucial for extracting correct waveforms from numerical relativity simulations of compact binaries. Hyperboloidal slices extend to null infinity while being spacelike and smooth everywhere. Among the current efforts to the hyperboloidal method, I will focus on free evolution of the conformally compactified BSSN / Z4 equations. After illustrating relevant aspects of the approach, I will focus on hyperboloidal initial data including black holes and neutron stars in spherical symmetry. I will finish with an update on the ongoing efforts towards hyperboloidal simulations in full 3D.

55

Spectrum and dynamics of bosonic stars and their hairy black holes

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I will discuss the current understanding of the landscape of bosonic stars in simple GR models, the hairy black holes that are associated with them, and the corresponding dynamics. Some applications to both phenomenological and conceptual questions will be addressed.

56

Why is CFL quark matter in neutron stars non-conformal?

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We propose a three-flavor nonlocal Nambu–Jona-Lasinio model of quark matter with attractive scalar and diquark, and repulsive vector interaction channels to study the question whether an approximately conformal behavior of the strongly interacting quark matter in neutron star interiors is possible. The model qualitatively agrees with the perturbative quantum chromodynamics (pQCD), which predicts asymptotically conformal behavior of quark matter. In particular, the color-flavor-locked (CFL) color superconducting state is shown to be the ground state at asymptotically high densities. The conformal limit for the speed of sound and the dimensionless interaction measure is also shown to be reached from below and above, respectively. The developed equation of state is constrained by the results of a physics-informed Bayesian analysis using modern multi-messenger neutron star observations. It is shown that in the phenomenologically relevant range of parameters the model exhibits a narrow interval of densities close to the central densities of the heaviest neutron stars, where the speed of sound and dimensionless interaction measure simultaneously attain almost conformal values. A microscopic quantity, which characterizes single particle excitations of quarks and quantifies deviation from the conformal behavior of quark matter, is constructed to test the hypothesis of approximately conformal behavior of quark matter in neutron stars. Analysis of this quantity does not support the assumption about the nearly conformal behavior of quark matter even in the mentioned density range. Therefore, the apparent behavior of speed of sound and dimensionless interaction measure is denoted as pseudoconformal behavior.

[1] O. Ivanytskyi, Asymptotically conformal color-flavor-locked quark matter within a nonlocal chiral quark model, Phys. Rev. D 111 (2025) 034004.
[2] A. Ayriyan et al., Bayesian analysis of neutron star EOS with asymptoticaly conformal color-flavor-locked quark cores, in preparation (2025).

57

Evolution of a black hole cluster in full general relativity

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The dynamical interactions of compact objects in N-body clusters are of great interest for understanding the formation of black holes (BHs) in the upper mass gap, as well as intermediate and supermassive BHs. These systems are potential sources of gravitational waves (GWs) detectable by both current and future observatories. We present, for the first time, a fully general relativistic evolution of a small, collisional N-body BH cluster with arbitrary total mass M. The bound cluster is initially compact, stable, and composed of 25 equal-mass, non-spinning BHs. Unlike previous Newtonian and post-Newtonian N-body simulations, no "subgrid physics" is required to handle collisions and mergers. In full general relativity, we confirm several predictions from these earlier simulations and analytic estimates: the runaway growth of a large BH through repeated mergers; spindown of the central BH with successive captures; ejection of a BH with high asymptotic velocity following a multi-body interaction; and a regime where mergers occur primarily via direct collisions on highly eccentric orbits rather than through quasicircular inspirals. We extract the GW signal and identify several distinct features characteristic of the compact cluster regime. Our results suggest that the signal is sufficiently strong for next-generation observatories to detect similar events across much of the observable universe.

58

Signatures from metastable oppositely-charged black hole binaries in scalar Gauss-Bonnet gravity

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Gravitational wave observations of compact objects have provided new opportunities to test our understanding of gravity in the strong-field, highly dynamical regime. To perform model-dependent tests of General Relativity with these observations, as well as to guide theory-agnostic tests, it is crucial to develop inspiral-merger-ringdown waveforms in alternative theories of gravity. In this talk, we present an example of a type of binary system in an alternative theory of gravity that undergoes a sudden state transition during the inspiral. This gives rise to telltale signatures such as a change in the multipolar character of the scalar radiation and the introduction of eccentricity in the orbit.

59

Ringdown tests of the black-hole paradigm

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Gravitational waves offer the promising prospect of testing one of the main predictions of general relativity, namely the presence of black holes beyond which nothing can escape.

The ringdown is the final stage of a compact binary coalescence when the remnant settles down to a stationary configuration. It is modelled as a superposition of exponentially damped sinusoids whose frequencies and damping times are related to the remnant's oscillation frequencies, the so-called quasinormal modes.
In this talk, I will describe how parametrised tests of general relativity can test the black-hole paradigm by constraining deviations in the frequency and damping time of the quasinormal modes. I will also describe how false violations of general relativity can arise in the data due to missing physics in the waveform models or poorly understood noise artefacts.

60

Exploring neutron-star mergers in numerical relativity

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Numerical relativity plays many important roles in astrophysics and general relativity, e.g., in understanding mergers of black holes and neutron stars, formation processes of black holes for a wide variety of stellar collapse, and launching mechanisms of jets. In this talk, I will summarize our current understanding of the merger and post-processes for neutron-star binaries introducing our latest results of numerical simulations. I will pay particular attention to nucleosynthesis of heavy elements and provide predictions for the future observations and also give a speculation for the merger process of GW170817 if I have time.

61

Gravitational wave tests of generic EFT-inspired theories of gravity

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Next generation of gravitational wave detectors will have the sensibility to detect potential deviations in gravitational waveforms with respect to general relativity. However, current agnostic tests of gravity with gravitational waves are plagued by a lack of realistic deviations, making it difficult to interpret such detections with respect to specific theories. In this talk, I present a dictionary that identifies the scaling of deviations with the objects'masses and the leading order post-Newtonian corrections in generic theories constructed through the Effective Field Theory approach based on curvature. In particular, I will demonstrate that a vast set of theories only deviates from General Relativity beginning at a relatively high order. The obtained results can be readily incorporated in all gravitational wave tests already under use by current detectors.

62

Non-linear dynamics beyond GR

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In this talk I will discuss our recent progress in performing numerical simulations in the Einstein-scalar-Gauss-Bonnet theory of gravity, both for equal and unequal mass binary black hole systems, which result in waveforms with dephasings from GR consistent with PN calculations.

63

Black Holes in Einstein-Scalar-Gauss-Bonnet Theories

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Black holes represent an ideal laboratory to test Einstein's theory of general relativity and alternative theories of gravity. Among the latter, Einstein-Scalar-Gauss-Bonnet Theories have received much attention in recent years. In this talk some properties of their black holes are recalled, which depend significantly on the coupling function of the scalar field. Linear mode stability of the black holes is addressed for some of the coupling functions. It is shown that the inclusion of an additional coupling to the curvature scalar leads to quadrupole and hexadecupole instabilities of the radially stable static black holes.

64

A unified framework for magnetic field amplification in binaries involving neutron stars

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One of the most significant open questions in the theoretical understanding of neutron stars and black hole–neutron star binaries is the amplification of magnetic fields in the remnant. This amplification initially occurs on small scales via a turbulent dynamo, primarily driven by the Kelvin–Helmholtz instability. This turbulent phase is followed by a large-scale reorganization of the field, driven by magnetic winding and possibly by other mechanisms such as the magnetorotational instability. Although current full GRMHD simulations, with typical resolutions of O(10m), are not yet capable of resolving all relevant scales, large-eddy simulation techniques—employing the gradient subgrid-scale model—allow us to accurately capture the magnetic field amplification during the firsts tens of milliseconds following remnant formation.
In this work, we discuss two key outcomes of our simulations. First, we find evidence for a form of "universality" in the magnetic field strength of the newborn hypermassive neutron stars formed in BNS mergers. Second, we observe that the amplification mechanisms in the remnant disks of BH–NS mergers exhibit strong similarities to those in BNS mergers, suggesting a unified picture for magnetic field growth in both scenarios.

65

Tidal effects in gravitational waves from neutron star binary inspirals in scalar-tensor gravity

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Neutron stars are useful laboratories for many areas of physics, including subatomic physics and the coupling of nonlinear gravity with matter. To gain further insights into the fundamental information contained in observable neutron star properties and potential degeneracies between modifications to different sectors of physics, it is useful to consider theories of gravity beyond General Relativity. A feature of many such theories is the presence of extra fields, as also motivated by proposed scenarios for inflation, dark energy, or dark matter. This talk will focus on features of neutron stars in a class of scalar-tensor theories of gravity involving a scalar field. I will discuss consequences for gravitational-wave signals from binary inspirals, focusing on matter signatures from a richer set of tidal interactions that arise due to the presence of the scalar field, the associated characteristic parameters and expected imprints in gravitational waves.

66

Numerical Relativity beyond General Relativity

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We will explore the long path from Einstein's equations to computational simulations. I will discuss how Numerical Relativity can serve as a tool to study nonlinear dynamics in alternative theories of gravity. In this talk, I will consider two subclasses of the broader Horndeski theory: those that have a screening mechanism and those involving scalar-Gauss-Bonnet gravity. In particular, I will discuss the rich phenomenology that can be learned, the challenges that must be overcome to extend Numerical Relativity, and the future of relativistic numerical simulations in these theories.

67

Precessing binary black holes and mirror (a)symmetry in the Universe

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Precessing binary black hole mergers can potentially excite photons from the quantum vacuum in such a way that total helicity is not preserved in the process. I will show that precessing binary black hole systems in astrophysics generate a flux of circularly polarized gravitational waves which, in turn, provides the required helical background that triggers this quantum effect. Solving the fully nonlinear Einstein's equations with numerical relativity we explored the parameter space of binary systems and extract the detailed dependence of the quantum effect with the spins of the two black holes. We also introduce a set of diagrammatic techniques that allows us to predict when a binary black hole merger can or cannot emit circularly polarized gravitational radiation, based on mirror-symmetry considerations. According to the cosmological principle, such emission must average to zero across all binary mergers in our Universe to preserve mirror-reflection symmetry at very large scales. I will briefly discuss a new independent gravitational-wave test of this hypothesis.

68

Sparse-dictionary algorithms for GW reconstruction: applications

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Sparse dictionary learning (SDL) techniques have demonstrated strong potential for extracting astrophysical signals from noise in gravitational-wave (GW) astronomy. In this talk, I will provide an overview of SDL algorithms and discuss their application to a range of GW data analysis challenges. Examples will include glitch mitigation, classification of the equation of state in binary neutron star mergers, and signal detection in the context of the LISA mission. I will highlight both recent advances and open questions, emphasizing how SDL methods can contribute to the next generation of gravitational-wave discovery.

69

Stress-energy tensor in neutron-star matter

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I will provide a quick overview of the status of our understanding concerning neutron star matter, relevant to test gravity with the densest objects available in the present-day universe, and some steps which we are taking so that quantum computing may one day help.

70

Measuring the shadows of Kerr and non-Kerr compact objects

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In this talk, we will discuss the formation of black hole shadows and how some cases of non-Kerr compact objects can produce distinctive non-Kerr shadows with fractal structures. We will also discuss how these shadows can be illuminated by accretion and explore the possibilities for measuring the properties of the spacetime.

71

Black holes with primary hair

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In the context of higher order scalar tensor theories we will find explicit solutions with primary scalar charge evading classical no hair theorems. The large class of theories at hand are ultra violet departures from GR and will be given by specific analytic functions and will have certain symmetries. The scalar charge will be shown to be related to a conserved Noether charge associated to the global shift symmetry of the theories at hand. At a certain limit in between the mass and charge regular black holes will be constructed and properties of the solutions will be discussed. We will then discuss axial perturbations of these theories. The effective metric thus constructed will be shown to be a very particular extension of the Einstein frame. Axial gravitons will propagate in this frame quite different to the luminous frame. We will discuss the effects of this and what bounds can be put on the hair for stability.

72

The spectrum of quasinormal modes of rapidly rotating Einstein-Gauss-Bonnet-dilaton black holes

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In this talk we will discuss the quasinormal mode spectrum of rapidly rotating black holes in Einstein-Gauss-Bonnet-dilaton theory, which is crucial for understanding the ringdown phase that follows from a black hole merger. Unlike previous studies that relied on pproximations, we compute the QNM spectrum non-perturbatively, providing robust results even for large coupling constants. Using a spectral decomposition of the metric and scalar field perturbations, we solve a system of coupled partial differential equations to determine the spectrum. We will discuss some properties of the spectrum, such as the breaking of isospectrality and dependence of the modes on the angular momentum and coupling parameter of the theory.

73

Gravitational Waves signatures from non-trivial realisations of the Cosmological Principle

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The Cosmological Principle is one of the pillars of the standard model of cosmology and it is commonly realised in a trivial way with homogeneous SO(3)-scalars. I will discuss several scenarios where the matter sector realises the Cosmological Principle in a non-trivial manner by resorting to combinations of spacetime and internal symmetries. A natural consequence of some of these scenarios is the appearance of a second helicity-2 mode in the cosmological perturbations that produces oscillations of gravitational waves with distictive signatures.

74

Black holes and spacetime energy in teleparallel gravity

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Teleparallel gravity employs independent connection that is curvature free but can be characterised by torsion and nonmetricity. While it is possible to formulate families of teleparallel theories that have field equations equivalent to general relativity and only differ from it by the boundary term in the action, the extensions like scalar-tensor start to stand apart from their respective counterparts already at the level of the field equations. The talk will provide an overview of the search for nontrivial black hole solutions in extended teleparallel gravities, relevant methods and results. The last part of the presentation will briefly report the definition and calculation of quasi-local spacetime energy for Kerr spacetimes in general parallel relativity.

75

Asymmetric binaries: a tale of two sides

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In this talk I will discuss in which cases black holes carry a scalar charge, and the implications when the latter scales with the black hole mass. I will talk about the phenomenological consequences of these insights for the physics of compact binaries, and how asymmetric systems evolving in the LISA band are ideal sources for searches of new fundamental fields coupled to gravity. I will lay out the framework for modelling such binaries in an effective field theory approach, and present some first forecasts on LISA's ability to constrain the properties of scalar fields from future gravitational wave observations

76

General stationary axisymmetric spacetimes: circularity and beyond

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I will discuss properties of general stationary and axisymmetric spacetimes, with a particular focus on circularity - an accidental symmetry enjoyed by the Kerr metric, and therefore widely assumed when searching for rotating black hole solutions in alternative theories of gravity as well as when constructing models of Kerr mimickers. It can be shown the local existence of a Kerr-like gauge, specified by six free functions. Within this gauge the differential circularity conditions can be solved to translate them into algebraic relations among the metric components. This result opens the way to investigating the consequences of circularity breaking in a controlled manner. In particular, I will show two simple analytical examples of non-circular deformations of the Kerr spacetime and discuss their properties.

77

Numerical relativity: Exploring new capabilities with binary black holes

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Numerical relativity has been spectacularly successful during the past decades, with numerous contributions toward gravitational wave astrophysics for binary black holes and neutron stars. Despite all accomplishments, the increasing sensitivity of gravitational wave detectors and the broader bandwidth of future detectors require significant further improvements of the numerical codes, both for black holes and neutron stars. In this talk, I will use the vacuum case of binary black holes to illustrate several dimensions along which such improvements are being pursued within the SXS collaboration. These dimensions include extension of the parameter space coverage to eccentric binary black holes and hyperbolic encounters, new computational algorithms, as well as the study of BHs in alternative theories of gravity.

78

The phenomenological waveforms program: challenges, recent results, and future prospects

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This talks reviews challenges in the modelling of the waveforms of coalescing compact binaries as the GW community prepares for the next generation of GW observatories, and the current status and future prospects for the phenomenological waveforms program. The talk reports in particular recent progress in modelling eccentric binaries, spin precession, the memory effect, and the LISA response.

79

Challenges in the observation of gravitational waves from the collapse of massive stars

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After the first detections of gravitational waves from the collision of compact merging binaries, including both black holes and neutron stars, the next great new discovery from LIGO-Virgo-KAGRA detectors could be associated with the collapse of massive stars. With a galactic event rate of about

2-3 per century, core-collapse supernovae (CCSNe) are a primary candidate for gravitational wave detectors and their observation could unveil the mechanism for this powerful explosions as well as help us understanding the properties of matter at high densities. Unfortunately these events are extremely weak and their detection present a great challenge. I will present recent results on how to infer the properties of the nascent neutron star based in the gravitational wave signal and how these properties could be used to improve the detectability of CCSNe.

81

TBA

83

Black holes and wormholes in semiclassical gravity

A black hole quantum state (Hartle-Hawking, Boulware or Unruh) is usually defined in a fixed background of a classical black hole. In my talk I will discuss the corresponding space-time geometry when the back-reaction is taken into account. The important questions include: does the back-reacted geometry always contain a horizon?; how it depends on the choice of the quantum state? and what is the right choice for the quantum state for the non-physical fields such as ghosts? I will answer these and other questions in the context of a two-dimensional dilaton gravity.

84

TBA

87

TBA

90

Advances in the Parametrized QNM Framework and New Perspectives from Bound States

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Black hole spectroscopy, applied to the ringdown phase of compact binary mergers, is one of the most promising tools to test the nature of black holes. It allows us to quantify whether black holes and their perturbative dynamics are well described by general relativity and, thus, serve as a magnifier to explore fundamental physics. The parametrized quasi-normal mode framework has been developed as a powerful tool to capture small changes in black hole dynamics caused by small deviations from general relativity. It provides a unique role to mediate between theory-specific approaches and fully agnostic data-driven ones. In this talk, I will first review some of the seminal works and contributions

of the framework. Then, I will focus on recent progress, including the framework's first systematic study in the time domain and its extension to rotating black holes. Finally, I will use the intriguing idea to relate quasi-normal modes with the bound states of an inverted potential to address ongoing discussions of spectral stability and the excitation of quasi-normal modes.

91

Excision scheme for black hole numerical simulations

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I will present developments and recent applications of the excision technique in the case of the Fully Constrained Formalism. I will focus on spherically symmetric spacetimes representing the collapse of a neutron star to a black hole. I will also present a more general set up of boundary conditions to be imposed at the excised surface, an arbitrary coordinate sphere inside the apparent horizon, where a new parameter can control some physical properties. I will show exponential convergence toward the stationary solution and stable long-term evolution of the newly formed black hole. Finally, I will show the application of this technique in recent general core-collapse simulations.

92

Black holes in modified gravity theories with large-curvature corrections

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The direct observation of gravitational waves gives us the opportunity to test gravity in the highly dynamical, strong curvature regime probed by coalescing black hole binaries. In particular, gravitational wave detectors are sensitive to large-curvature corrections of general relativity, mostly unconstrained by other astrophysical observations. However, theoretical consistency imposes significant constraints and limitations to the form and to the scale of these corrections. I will discuss our present understanding of the large-curvature corrections to general relativity which can leave a signature observable by present and near-future gravitational wave detectors. In particular, I will discuss some recent developments in our understanding of this fascinating family of modified theories of gravity.

93

Black holes with scalar hair: from no-hair theorems to non-linear dynamics

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According to General Relativity, astrophysical black holes are remarkably simple and their properties are determined by just two quantities, their mass and their angular moment. Gravitational waves and other strong gravity observations promise to probe the nature of black holes more precisely that ever before. Any observed deviation from the simple description General Relativity provides can reveal the existence of new fundamental fields, which would signal a paradigm shift in theoretical physics, astrophysics, and cosmology. I will use the well-studied case of an additional new scalar field, coming from either an extension of the Standard Model or of General Relativity itself, as a case study to discuss 3 questions: Can new physics leave an imprint on black holes? If yes, which observations are more sensitive to this new physics? And, are all black holes the same?

94

Gravitational Perturbations of Noncommutative Kerr Black Holes

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We investigate gravitational perturbations of a rotating (Kerr) black hole within a noncommutative geometry framework for quantum gravity. Using a Drinfeld twist that deforms the spacetime symmetries (a semi-Killing twist), we formulate a noncommutative extension of Einstein field equations and derive the effective potential for axial (odd-parity) gravitational perturbations of a noncommutative Kerr black hole. Our analysis assumes a slow-rotation approximation and treats the noncommutativity parameter perturbatively, extending earlier noncommutative Schwarzschild (2409.01402) results to the Kerr case. We then compute the quasinormal mode spectrum of the deformed Kerr black hole.

95

Modeling the strong-field dynamics of binary neutron stars

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Binary neutron star mergers (BNSM) are associated with powerful gravitational and electromagnetic astronomical transients. Multimessenger observations of BNSMs promise to deliver unprecedented insights on fundamental physics questions, including constraints on dense matter models and the production of heavy elements. Detailed theoretical predictions of the merger dynamics are crucial for extracting information from such observations. This talk reviews recent progress in the modeling of BNSMs using simulations in 3+1 numerical general relativity. I will first discuss the first predictions for the complete (inspiral-merger-postmerger) gravitational-wave spectrum and their application in gravitational-wave astronomy. Afterwards, I will focus on recent results on the merger remnants and mass ejecta, the mechanisms behind kilonova light and their application to the analyses of astrophysical data.