1st Trieste meeting on the physics of gravitational waves

Report of Contributions

Contribution ID: **1** Type: **not specified**

Opening

Monday, June 5, 2023 8:50 AM (10 minutes)

Contribution ID: **2** Type: **not specified**

E. Dones: Tidal effects on gravitational waveforms in massless scalar-tensor theories of gravity (WP1)

Monday, June 5, 2023 9:00 AM (40 minutes)

The arrival of third-generation gravitational wave detectors in 2030-2035, such as the Einstein Telescope and the space-based LISA detector, promises major advances in our understanding of the theory of gravity and of compact objects. However, the very high precision of the expected data presents us with new challenges, including distinguishing, when analyzing gravitational wave data, between effects due to a change in the theory of gravity and those coming from the matter of neutron stars. Therefore, it is necessary to develop very accurate waveforms for the analysis that consider both effects at the same time. In this talk, I will introduce how the post-Newtonian framework, initially developed to describe the inspiral phase of a compact binary coalescence in GR, has been adapted for massless scalar-tensor theories of gravity. I will show how to incorporate tidal effects in our models and also discuss how likely we will be observing these effects in the future.

Contribution ID: **3** Type: **not specified**

M. Boskovic: Aspects of kinetic screening - UV completion and the two-body problem (WP1)

Monday, June 5, 2023 9:40 AM (40 minutes)

New light scalar degrees of freedom may alleviate the dark matter and dark energy problems, but if coupled to matter, they generally mediate a fifth force. In order for this fifth force to be consistent with existing constraints, it must be suppressed close to matter sources, e.g. through a non-linear screening mechanism. The focus of this talk will be shift-symmetric scalar-tensor theories that exhibit kinetic screening (k-essence). First, I will briefly comment on how the theoretical consistency of such theories should be addressed. In particular, whether screening is compatible with the standard UV completion. Most of the talk will focus on the non-relativistic two-body problem in k-essence. I will show how the Helmholtz decomposition of the Noether current associated to the shift symmetry allows for the analytic understanding of the two-body problem in a good agreement with the numerical results. In particular, the fifth force is screened slightly more efficiently in equal-mass systems than in extreme mass-ratio ones. However, systems with comparable masses also exhibit regions where the screening is ineffective. These descreened spheroidal regions (bubbles) could in principle be probed in the solar system with sufficiently precise space accelerometers.

Contribution ID: **4** Type: **not specified**

Discussion Session WP1 (Bernard)

Monday, June 5, 2023 10:50 AM (1h 30m)

Contribution ID: **5** Type: **not specified**

D. Hilditch: The threshold of gravitational collapse in vacuum (WP2)

Monday, June 5, 2023 2:00 PM (40 minutes)

Working within the space of solutions of GR and tuning to the threshold of black hole formation, we arrive at extreme spacetimes which are generally expected to contain naked singularities. In the spherical setting such configurations have been accurately studied by numerical work for three decades. This resulted in a beautiful understanding of the threshold of collapse through a mathematical analogy to critical phenomena in statistical physics. Relaxing these symmetry assumptions, the story becomes more challenging numerically, and phenomenologically much more complicated. In my talk I will review both the development of the topic and the current state of the art in tackling the problem for gravitational waves.

Contribution ID: **6** Type: **not specified**

E. Gasperin: The good-bad-ugly system near spatial infinity on flat spacetime (WP2)

Monday, June 5, 2023 2:40 PM (40 minutes)

A model system of equations that serves as a model for the Einstein field equation in generalised harmonic gauge called the good-bad-ugly system is studied in the region close to null and spatial infinity in Minkowski spacetime. This analysis is performed using H. Friedrich's cylinder construction at spatial infinity and defining suitable conformally rescaled fields. The results are translated to the physical set up to investigate the relation between the polyhomogeneous expansions arising from the analysis of linear fields using the spatial-infinity-cylinder framework and those obtained through a heuristic method based on Hormander's asymptotic system.

Contribution ID: **7** Type: **not specified**

F. Corelli: Fate of Radiating Black Holes With Minimum Mass in Einstein-dilaton-Gauss-Bonnet Theory of Gravity (WP2)

Monday, June 5, 2023 3:50 PM (40 minutes)

Einstein-dilaton-Gauss-Bonnet (EdGB) is a theory of modified gravity in which a dilaton-type scalar field is nonminimally coupled to quadratic curvature terms via an exponential function. Black holes (BHs) in this theory are particularly interesting since they possess a critical configuration with minimum mass and finite Hawking temperature. This means that a critical BH loses mass due to Hawking's radiation, but it is not clear what is its fate after this process, since it cannot reach a final configuration with lower mass. In a recent work we studied this problem by means of fully nonlinear numerical evolutions of spherically symmetric BH spacetimes. Specifically, by simulating the collapse of wave packets of a phantom scalar field we have been able to dynamically reduce the BH mass, reproducing the effect of Hawking's evaporation.
In this talk I will present our results with a particular focus on the case in which the BH mass falls below the critical value. In particular, I will show that a high-curvature elliptic region emerges from the apparent horizon, and I will discuss how this could hint to an incompatibility between EdGB gravity and Hawking evaporation. I will also mention some alternative scenarios for a stable evolution, and future possible research directions.

References:
Corelli, De Amicis, Ikeda, and Pani, Phys. Rev. Lett. 130, 091501 and Phys. Rev. D 107, 044061

Contribution ID: **8** Type: **not specified**

G. Lara: Matter coupling in k-essence and dynamics in UV completions (WP2)

Monday, June 5, 2023 4:30 PM (40 minutes)

In this talk, I will present a study of the qualitative features of stationary solutions with kinetic screening for different couplings to matter. As for the dynamics, I will illustrate with an explicit example how different "completions" of k-essence can allow for stable time evolutions with numerical relativity. The latter, despite the original theory appearing to be ill (which is a commonplace situation in many alternatives to GR). Finally, I close with comments on some challenges that remain for other types of completions and mention some new directions of research for other alternative theories of gravity.

Contribution ID: **9** Type: **not specified**

Discussion Session WP2 (Gualtieri)

Monday, June 5, 2023 5:10 PM (50 minutes)

Contribution ID: **10** Type: **not specified**

Board Meeting

Monday, June 5, 2023 6:00 PM (1 hour)

Contribution ID: **11** Type: **not specified**

F. Duque: GWs from EMRIs in Astrophysical Environments (WP3)

Tuesday, June 6, 2023 9:00 AM (40 minutes)

Third-generation gravitational-wave detectors and the space-based LISA mission will observe binaries in galactic centers involving supermassive black holes with millions of solar masses. These binaries can interact gravitationally with accretion disks, dark matter halos and other compact objects. The role these astrophysical structures play in the evolution and gravitational-wave signature of binary systems remains largely unexplored and previous studies have often relied on ad-hoc Newtonian approximations. In this talk, we will develop the first fully-relativistic framework capable of studying gravitational wave emission in non-vacuum environments. We apply it to galactic black-hole binaries surrounded by different dark matter environments and draw consequences for the future of gravitational-wave astronomy.

Contribution ID: **12** Type: **not specified**

A. Maselli: Quasi normal mode spectroscopy beyond Kerr: agnostic vs theory based tests with 3G detectors (WP3)

Tuesday, June 6, 2023 9:40 AM (40 minutes)

Black-hole spectroscopy is one of the most promising tools to test gravity in extreme regimes and to probe the nature of black holes. However, tests based on ringdown observations are currently limited by the lack of parametrization that are both robust and accurate, able to capture generic modifications of the Kerr spectrum. In this talk I will present a new observable-based parametrization of the ringdown of spinning black holes beyond general relativity, ParSpec, and its application to future detections by 3G interferometers. I will discuss projected measurements on the ringdown parameters, and how to map such agnostic constraints on bounds on the fundamental couplings of
modified theories of gravity. Finally I will exploit ParSpec to discuss generic limitations of ringdown tests.

Contribution ID: **13** Type: **not specified**

Discussion Session WP3 (Cardoso)

Tuesday, June 6, 2023 10:50 AM (1h 30m)

Contribution ID: **14** Type: **not specified**

C. Pacilio: Testing GR with large catalogs: the cosmic variance of hierarchical tests (WP4)

Tuesday, June 6, 2023 2:00 PM (40 minutes)

Testing the strong gravity regime of general relativity is a primary goal of gravitational wave detectors. While it is expected that corrections to GR are small and unlikely to be identified with individual events, third generation GW detectors will allow detection of tens-of-thousands of events per year. Therefore, they will pave the way to precision tests by carefully stacking all the detected events. In this talk, I will first present the prospects of performing black hole spectroscopy with third generation detectors, showing that the number of detections and the precision in their measurements make it a relevant science case for testing GR. Then, I will show that biases away from GR can arise within hierarchical tests from a population of events, even when stacking very large catalogs. Finally, I will discuss statistical methods to mitigate these biases and avoid false claims of GR violations.

Contribution ID: **15** Type: **not specified**

A. Foschi: Constraining bosonic clouds at the Galactic Center (WP4)

Tuesday, June 6, 2023 2:40 PM (40 minutes)

The motion of S2, one of the stars closest to the Galactic Center, has been measured accurately and used to study the compact object at the centre of the Milky Way. It is commonly accepted that this object is a supermassive black hole but the nature of its environment is open to discussion. In this talk I'm going to show how the motion of S2 can be used to investigate the possibility that dark matter in the form of an ultralight scalar field "cloud" clusters around SgrA*. I will explain the theoretical setup, the tools used to fit the available data and finally the results and the constrains we can get from the Galactic Center. In the final part, I'm also going to extend the analysis to vector clouds and show some preliminary results

Contribution ID: **16** Type: **not specified**

M. Crisostomi: Neural Posterior Estimation with guaranteed exact coverage: the ringdown of GW150914 (WP4)

Tuesday, June 6, 2023 3:50 PM (40 minutes)

I will present the analysis of the ringdown phase of the first detected black-hole merger, GW150914, using a simulation-based inference pipeline based on masked autoregressive flows. We obtain approximate marginal posterior distributions for the ringdown parameters, namely the mass, spin, and the amplitude and phases of the dominant mode and its first overtone. Thanks to the locally amortized nature of our method, we are able to calibrate our posteriors with injected simulations, producing posterior regions with guaranteed (i.e. exact) frequentist coverage of the true values. For GW150914, our calibrated posteriors provide only mild evidence (~ 2 sigma) for the presence of an overtone, even if the ringdown is assumed to start at the peak of the amplitude.

Contribution ID: **17** Type: **not specified**

TBA (WP4)

Contribution ID: **18** Type: **not specified**

Discussion Session WP4 (Barausse)

Tuesday, June 6, 2023 4:30 PM (1h 30m)

Contribution ID: **19** Type: **not specified**

Welcome (Barausse)

Wednesday, June 7, 2023 9:15 AM (15 minutes)

Contribution ID: **20** Type: **not specified**

S. Hughes: Overview of this workshop and its goals

Wednesday, June 7, 2023 9:30 AM (20 minutes)

This short talk will present a brief overview of the problem that motivates this workshop, and our goals for what we hope to get out of our time together.

Contribution ID: **21** Type: **not specified**

L. Barack: Status of post-adiabatic EMRI modelling

Wednesday, June 7, 2023 10:15 AM (30 minutes)

I will review recent work (by others) on post-adiabatic models for EMRIs and IMRIs, illustrating the remarkable effectiveness of the small-mass-ratio expansion even at mass ratios that are not so small. Interesting synergies with NR and EOB calculations will be discussed. Whether one thinks of environmental effects as signals to be extracted or as noise to be removed, it is crucial to have at hand 1PA-accuracy models of clean EMRIs.

Contribution ID: **22** Type: **not specified**

L. Sberna: EMRIs in realistic and exotic environments

Wednesday, June 7, 2023 11:15 AM (45 minutes)

Gravitational-wave observations of extreme mass ratio inspirals (EMRIs) hold incredible potential to probe gravity, astrophysical and exotic environments. On the astrophysical side, the gas disks of active galactic nuclei can induce detectable "migration"torques on the binary. Within a Bayesian framework, we find that LISA could detect migration for a wide range of disk viscosities and accretion rates, and could distinguish between different disk models. In ongoing work, we are testing whether these results are robust against fluctuations in the disk torques and modelling uncertainties. On the exotic side, EMRIs can interact with clouds of bosonic fields supported by the central black hole. We use novel perturbation theory tools to model these interactions, going beyond the non-relativistic approximation.

Contribution ID: **23** Type: **not specified**

V. Witzany: Environments acting on EMRIs, EMRIs acting on environments

Wednesday, June 7, 2023 2:00 PM (45 minutes)

The “vanilla” extreme mass ratio inspiral (EMRI) is a compact object spiraling onto a perfectly isolated massive black hole in general relativity. I will discuss how this can change due to an astrophysical environment and what needs to be done to faithfully and frugally capture these effects in waveforms. In the second half, I will turn attention to the fact that EMRIs may also act on the environments they occur in. In fact, we may even be already observing this now in the electromagnetic spectrum. Specifically, the astronomical community recently uncovered X-ray variability of active galactic nuclei that may well be due to EMRIs of the type LISA will observe, which I will also briefly discuss.

Contribution ID: **24** Type: **not specified**

R. Vicente: Black hole binaries in ultralight dark matter environments

Wednesday, June 7, 2023 2:45 PM (45 minutes)

Ultralight dark matter is an exciting alternative to the standard cold dark matter paradigm, reproducing its large scale predictions, while solving most of its potential tension with small scale observations (like the "cusp-core" and "missing satellites" problems). If dark matter is made of some new ultralight bosonic particle, relatively dense and large structures are expected to form at the center of galaxies, like solitonic cores or superradiant clouds around spinning massive black holes. These non-trivial environments may affect the evolution of black hole or neutron star binaries, opening the possibility for using future space-borne gravitational-wave observatories to probe the nature of dark matter. In this talk I will discuss some recent efforts on the modelling of black hole coalescences in ultralight dark matter environments: from numerical relativity simulations of mergers of equal-mass binaries, to (relativistic) perturbation theory approaches to the (adiabatic) evolution of extreme mass-ratio inspirals.

Contribution ID: **25** Type: **not specified**

Discussion: EMRIs as probes of fundamental physics (Maselli, Pani)

Wednesday, June 7, 2023 4:00 PM (1 hour)

Contribution ID: **26** Type: **not specified**

A. Albertini: Towards an effective-one-body model for extreme-mass-ratio inspirals

Friday, June 9, 2023 9:30 AM (45 minutes)

The effective-one-body (EOB) approach is based on a mapping between the two-body problem in GR and the motion of a single body in an effective metric. This approach already efficiently provides templates for the comparable-mass compact binary coalescences observed by the LVK collaboration, but is also flexible enough to reach a wider coverage of the parameter space. If for comparable-mass binaries EOB models have been tuned and benchmarked with respect to numerical relativity simulations, when going to higher mass ratios it is natural to use gravitational-self-force (GSF) results as a benchmark. We thus present a comparison of EOB and GSF waveforms for quasi-circular nonspinning binaries for a set of intermediate to extreme mass ratios, and show how by some simple yet impactful modifications, the EOB model can successfully match the GSF one. We then discuss the next relevant features to be added to the model, from the inclusion of a spinning secondary to environmental effects.

Contribution ID: **27** Type: **not specified**

A. Sesana: Dynamical evolution of supermassive black hole binaries

Friday, June 9, 2023 10:45 AM (45 minutes)

I will discuss the evolution of SMBHBs from kpc down to final coalescence including the dynamical friction, stellar and gaseous hardening and gravitational wave phases. In particular I will focus on how the properties of very massive systems observable with pulsar timing arrays.

Contribution ID: **28** Type: **not specified**

S. Kejriwal: More Realistic Inference of EMRI Environments

Friday, June 9, 2023 11:30 AM (30 minutes)

Extreme-mass-ratio inspirals (EMRIs) will allow precise measurements of trajectories of a compact object in the strong-gravity regime around a supermassive black hole, making the detection of beyond-GR effects possible. However, environmental effects such as an accretion disk, can give rise to dephasing effects in the compact object's trajectories, with the potential to raise false alarm in the search for deviations from GR. Thus, the modeling of all dominant environmental effects becomes essential to ensure unbiased measurements of EMRI parameters via the upcoming LISA gravitational wave observatory. Current state-of-the-art estimates of dephasing caused by environmental effects in EMRIs (i) assume a simplistic EMRI with Schwarzschild spacetime with the secondary on a quasi-circular and equatorial orbit, (ii) only give leading-order estimates with respect to the gravitational wave self-force, and (iii) do not analyze two or more environmental effects together. In this presentation, we propose studies of environmental effects in more realistic EMRIs addressing the three limitations mentioned above with a significant focus on analyses of two or more environmental effects together for the first time ever.

Contribution ID: **29** Type: **not specified**

Discussion (Cardoso, Barausse, Hughes)

Friday, June 9, 2023 2:00 PM (1 hour)

Contribution ID: **30** Type: **not specified**

Hands on session (Speri)

Friday, June 9, 2023 3:00 PM (1h 45m)

Contribution ID: **31** Type: **not specified**

J. Gair: LISA data analysis challenges for constraining environmental effects

Thursday, June 8, 2023 9:30 AM (45 minutes)

LISA has the potential to place stringent constraints on the astrophysical environments of the black holes generating the gravitational waves it observes. However, this will only be possible with careful analysis of the LISA data stream, which poses significant challenges. I will give an overview of the current state of knowledge of LISA data analysis and then discuss outstanding challenges that may ultimately limit our ability to measure environmental and beyond-GR effects. These include confusion between sources of different types, lack of knowledge of the instrumental noise, calibration and transfer function and the presence of gaps and glitches in the data.

Contribution ID: **32** Type: **not specified**

A. Toubiana: Observing stellar-mass black hole binaries around AGNs with LISA

Thursday, June 8, 2023 10:45 AM (45 minutes)

Recent observations from the LIGO/Virgo/KAGRA collaboration have suggested that stellar-mass black hole binaries (SBHBs) could form in active galactic nuclei (AGN). If so, we expect the environment in which these binaries are embedded to leave an imprint on the gravitational wave signal they emit. These deviations from vacuum waveforms should be more important in the early inspiral, i.e. at early frequencies, exactly the regime LISA will observe SBHBs. In this talk I review some of the effects that are expected, due to the presence of matter and to the peculiar motion of the binary around the central black hole, and show how well LISA could constraint them. Then, I discuss the regime where the SBHB is so close to the central black hole that its orbital period is comparable to the observation time. In this case the GW signal is successively redshifted and blueshifted, an effect that cannot be captured with perturbative modifications to the waveform. I discuss how accounting for this effect will allow us to measure the properties of the central black hole if properly accounted for, but could also prevent us from detecting a signal in the opposite case.

Contribution ID: **33** Type: **not specified**

G. M. Tomaselli: Dynamical Friction in Gravitational Atoms

Thursday, June 8, 2023 11:30 AM (45 minutes)

Due to superradiant instabilities, clouds of ultralight bosons can spontaneously grow around rotating black holes, creating so-called "gravitational atoms". In this talk, we discuss their dynamical effects on binary systems. We first focus on open orbits, showing that the presence of a cloud can increase the cross section for the dynamical capture of a compact object by more than an order of magnitude. We then consider closed orbits and demonstrate that the backreaction of the cloud's ionization on the orbital motion should be identified as dynamical friction. Finally, we study for the first time eccentric and inclined orbits. We find that, while ionization quickly circularizes the binary, it barely affects the inclination angle. These results enable a more realistic description of the dynamics of gravitational atoms in binaries and pave the way for dedicated searches with future gravitational wave detectors.

Contribution ID: **34** Type: **not specified**

Speri

Contribution ID: **35** Type: **not specified**

Discussion (Babak)

Thursday, June 8, 2023 3:00 PM (1h 30m)

Contribution ID: **36** Type: **not specified**

A. Franchini: Electromagnetic signals from EMRIs and Massive Black Hole Binaries

Thursday, June 8, 2023 2:15 PM (45 minutes)

Gravitational wave sources typically evolve in gaseous environments and it is crucial to understand what are the possible emission signatures that derive from this interaction.
We produce synthetic X-ray light curves compatible with X-ray data from the four confirmed Quasi Periodic Eruption (QPEs) sources (GSN 069, eRO-QPE1, eRO-QPE2 and RX J1301.9+2747), using a semi-analytical model based on an extreme mass-ratio inspiral (EMRI) system where the secondary intersects a rigidly precessing accretion disc surrounding the primary massive black hole. Our model reproduces the diversity of QPE properties between the considered objects well, and is also able to account naturally for the varying QPE amplitudes and recurrence times in individual sources.
We further present possible electromagnetic (EM) counterparts of merging Massive Black Hole Binaries (MBHBs) that evolve through the interaction with a gaseous circumbinary disc towards the merger, using 3D hyper-Lagrangian hydrodynamical simulations with Post-Newtonian corrections to the binary dynamics.

Contribution ID: **37** Type: **not specified**

S. Hughes: Introduction to modeling extreme mass ratio inspirals

Wednesday, June 7, 2023 9:50 AM (25 minutes)

This talk will review how one models the evolution of extreme mass ratio binary systems and the gravitational waveforms which they produce. It is linked to the talk which follows by Leor Barack.