26th Capra Meeting on Radiation Reaction in General Relativity

Report of Contributions

https://indico.nbi.ku.dk/e/1894

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

Welcome

Monday, 3 July 2023 08:50 (10 minutes)

Presenters: VAN DE MEENT, Maarten (Niels Bohr Institute); CARDOSO, Vitor

Session Classification: General

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

New Hyperboloidal Discontinuous Numerical Algorithm in the time domain for self-force applications

Wednesday, 5 July 2023 14:40 (20 minutes)

In 2034 LISA is due to be launched, which will provide the opportunity to extract physics from stellar objects and systems that would not otherwise be possible, among which are EMRIs. Unlike previous sources detected at LIGO, these sources can be simulated using an accurate computation of the gravitational self-force. Whereas the field has seen outstanding progress in the frequency domain, metric reconstruction and self-force calculations are still an open challenge in the time domain. Such computations would not only further corroborate frequency domain calculations/models but also allow for full self-consistent evolution of the orbit under the effect of the self-force . Given we have a priori information about the local structure of the discontinuity at the particle, we will show how we can construct discontinuous spatial and temporal discretizations by operating on discontinuous Lagrange and Hermite interpolation formulae and hence recover higher order accuracy. We will show how this technique in conjunction with well-suited conformal (hyperboloidal slicing) and numerical (discontinuous time symmetric) methods can provide a relatively simple method of lines numerical recipe approach to the problem. We will focus on updating on our progress providing a full generic solution and sharing our results for both the scalar and gravitational self-force cases for a particle in a circular orbit on a Schwarzschild background, (spoiler alert for those who attended last year's Capra: fluxes finally fixed!).

Presenter: GOMES DA SILVA, Lidia J. (Queen Mary University of London)

Session Classification: Wednesday Afternoon

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

Radiation Reaction in Post-Minkowskian Approximation

Tuesday, 4 July 2023 09:20 (20 minutes)

High-accuracy theoretical predictions for the motion of compact binary systems are the most fundamental tools for interpreting data from present and future detectors, such as the LIGO-Virgo-Kagra, the Einstein Telescope and the LISA. I will talk about a novel framework aiming at efficiently calculating gravitational observables by employing cutting-edge technology from Quantum Field Theory and modern mathematics. I will focus mostly on the analytic development for the gravitational dynamics of inspiralling binaries in the post-Minkowskian approximation.

Presenter: Dr LIU, Zhengwen (NBIA, Niels Bohr Institute)

Session Classification: Tuesday Morning

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

Spinning binaries from quantum fields

Tuesday, 4 July 2023 10:00 (20 minutes)

I will describe the application of scattering amplitudes in quantum field theory to the description of the dynamics of binaries of spinning black holes or other compact objects

Presenter: LUNA, Andres (Niels Bohr International Academy)

Session Classification: Tuesday Morning

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

Fast eccentric and inclined inspirals into a rotating black hole

Tuesday, 4 July 2023 14:20 (20 minutes)

Extreme mass ratio inspirals (EMRIs) are a prime gravitational wave source for the upcoming LISA mission and are expected to be both eccentric and inclined with respect to the equatorial plane of the primary. To this end, we develop a model for these inspirals using an action angle formulation of the method of osculating geodesics and a toy model of the gravitational self force (GSF). The resulting equations of motion take hours to solve numerically for a typical EMRI. To overcome this difficulty, we employ near-identity (averaging) transformations (NITs) to remove the rapidly oscillating orbital phases from the equations of motion while accurately modelling the secular evolution of the system to the post-adiabatic accuracy required by the LISA science objectives. However, this averaging technique breaks down when the radial and polar frequencies are an integer ratio of each other and form an orbital resonance. Thus, when in the vicinity of an orbital resonance, we modify the NIT procedure to average out all phase contributions to the equations of motion except those proportional to the resonant phase and when no resonance is present, we switch back to the original NIT procedure. This allows us to model generic inspirals with transient resonances with post-adiabtic accuracy in a matter of seconds.

Presenter: LYNCH, Philip (Max Planck Institute for Gravitational Physics (Albert Einstein Institute))

Session Classification: Tuesday Afternoon

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

Flux-balance laws from an effective stress-energy tensor

Monday, 3 July 2023 15:40 (20 minutes)

The trajectory of a point particle can be represented by a series of geodesics whose constants of motion slowly evolve over the inspiral. Flux-balance laws give the (averaged) evolution of these "conserved quantities" in terms of fluxes of conserved currents through the horizon and at null infinity. In the specific case of conserved quantities coming from spacetime isometries (for example, energy and axial angular momentum in Kerr), there is an intuitive picture for non-gravitational field theories, due to the conservation of the stress-energy tensor. This suggests that such flux-balance laws, for the gravitational self-force, could be derived from the "effective" stress-energy tensor that sources higher-order metric perturbations. In this talk, we discuss such a derivation, using the two-timescale formulation of the gravitational self-force, that applies at first and second order.

Presenter: GRANT, Alexander (University of Virginia)

Session Classification: Monday Afternoon

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

Comparison of post-Minkowskian and self-force expansions: Scattering in a scalar charge toy model

Tuesday, 4 July 2023 11:20 (20 minutes)

The asymptotic nature of hyperbolic orbits provides a clean environment for comparisons between different methods of calculating scattering observables. In this talk, we present details of a (numerical) calculation of the scalar self-force correction to the scattering angle and compare with analytical expressions up to fourth post-Minkowskian order obtained using scattering-amplitude methods. This example provides a nontrivial, high-precision test of both calculation methods, and illustrates the complementarity of the two approaches in the context of the program to provide high-precision models of gravitational two-body dynamics.

Presenter: LONG, Oliver (Max Planck Institute for Gravitational Physics (Albert Einstein Institute))

Session Classification: Tuesday Morning

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

Applying the effective-source approach to frequency-domain self-force calculations for eccentric orbits

Monday, 3 July 2023 11:40 (20 minutes)

Extreme mass-ratio inspirals (EMRIs) are expected to have considerable eccentricity when emitting gravitational waves (GWs) in the LISA band. Developing GW templates that remain phase accurate over these long inspirals requires the use of second-order self-force theory. Practical second-order self-force calculations are now emerging for quasi-circular EMRIs. These calculations rely on effective-source regularization techniques in the frequency domain that presently are specialized to circular orbits. In this talk we make a first step towards more generic second-order calculations by extending the frequency domain effective-source approach to eccentric orbits. We use a new method of extended effective-sources to overcome the slow convergence of the Fourier sum. We develop our computational technique within the context of a toy scalar-field problem which is conceptually similar to the gravitational case.

Presenter: LEATHER, Benjamin (Max Planck Institute for Gravitational Physics (Albert Einstein Institute))

Session Classification: Monday Morning

Contribution ID: **38** Type: **not specified**

Perturbations of spinning black holes beyond General Relativity using Modified Teukolsky formalism

Friday, 7 July 2023 16:20 (20 minutes)

Black hole (BH) perturbation theory is crucial in computing the quasinormal modes (QNMs) emitted by general binary BH merges and the gravitational waves (GWs) of extreme-mass-ratio-inspirals (EMRIs). These GWs carry essential information about the geometry around BHs and any potential deviations from General Relativity (GR). In recent years, there have been extensive studies of perturbations of BHs in modified gravity, but only for non-rotating or slowly rotating BHs. Building on the Teukolsky formalism in GR, I will present a new formalism developed in arXiv:2206.10652 to study perturbations of BHs with arbitrary spin in modified gravity. I will first prescribe how to derive the modified Teukolsky equation following an effective field theory description of gravity theories beyond GR. I will then discuss the connection between this formalism in beyond-GR theories to the nonlinear Teukolsky formalism in GR, the latter of which has been applied extensively to study radiation reaction and self-force. More specifically, I will discuss how these pre-developed techniques, such as metric reconstruction, in the study of radiation reaction in GR can be applied to studying BH perturbations in modified gravity. At the end of my talk, I will show how one may use this formalism to compute QNMs and study EMRIs in some specific modified gravity theories.

Presenter: LI, Dongjun (California Institute of Technology)

Session Classification: Friday Afternoon

Contribution ID: **39** Type: **not specified**

Comparing effective-one-body and gravitational self-force results for black hole binaries with a spinning secondary

Wednesday, 5 July 2023 09:20 (20 minutes)

Building on previous work comparing effective-one-body (EOB) and gravitational self-force (GSF) waveforms for nonspinning black hole binaries on quasi-circular equatorial orbits, I will present an extension of this comparison to binaries with a spinning secondary. In particular, the comparison involves binaries with mass ratios ranging from 1:15 to 1:50000, and dimensionless spin on the secondary ranging from 0.1 to 0.95 (both positive and negative). As done before, the agreement between the EOB waveforms and the GSF ones is probed both by alignment in the time domain and by means of a gauge-invariant function of the waveform frequency. The outcome of this comparison also suggests some changes in the EOB spin-orbit sector.

Presenter: ALBERTINI, Angelica (Astronomical Institute of the Czech Academy of Sciences)

Session Classification: Wednesday Morning

Contribution ID: **40** Type: **not specified**

Symmetric integration of the 1+1 Teukolsky equation on hyperboloidal foliations of Kerr spacetimes

Wednesday, 5 July 2023 14:00 (20 minutes)

This talk outlines a fast, high-precision time-domain solver for scalar, elec- tromagnetic, and gravitational perturbations on hyperboloidal foliations of Kerr space- times. Time-domain Teukolsky equation solvers have typically used explicit methods, which numerically violate Noether symmetries and are Courant-limited. These re- strictions can limit the performance of explicit schemes when simulating long-time extreme mass ratio inspirals, expected to appear in the LISA band for 2-5 years. We outline work on using symmetric (exponential, Padé, or Hermite) integrators, which are uncon- ditionally stable and known to preserve certain Noether symmetries and phase-space volume. For linear hyperbolic equations, these implicit integrators can be cast in ex- plicit form, making them well-suited for long-time evolution of black hole perturba- tions. The 1+1 modal Teukolsky equation is discretized in space using polynomial collocation methods and reduced to a linear system of ordinary differential equations coupled via mode-coupling arrays and discretized differential operators. We use a matricization technique to cast the mode-coupled system in a form amenable to a method-of-lines framework, simplifying numerical implementation and enabling efficient parallelization on CPU and GPU architectures. We present tests of our numerical code on late-time tails of Kerr spacetime perturbations in the sub-extremal and extremal cases.

Presenter: BRAY, Sean (Queen Mary University London)

Session Classification: Wednesday Afternoon

Contribution ID: **41** Type: **not specified**

Modeling the ringdown of binary black hole mergers

Friday, 7 July 2023 14:40 (20 minutes)

The post-merger gravitational-wave waveform of binary black hole mergers can be well modeled by quasinormal modes during the late ringdown phase. The theoretical spectrum of modes that could be present in the ringdown is extensive, but in practice only a subset of them will be significantly excited. Focusing on non-precessing mergers, we determine the relevancy of different ringdown modes by extracting their amplitudes from numerical relativity simulations with minimal assumptions a priori. We find that in addition to the standard fundamental mode and overtones, other modes such as nonlinear modes, retrograde modes and mirror modes could also be relevant. Furthermore, we identify the time at which the quasinormal-mode model starts to be an adequate description of the ringdown, and we present fits of the amplitude of different modes as a function of the simulation parameters. Our results could be used to build a model for the ringdown.

Presenter: CHEUNG, Mark (Johns Hopkins University)

Session Classification: Friday Afternoon

Contribution ID: **42** Type: **not specified**

Extended-body motion, local symmetries, and Petrov types

Friday, 7 July 2023 10:00 (20 minutes)

To a first approximation, objects in general relativity move along geodesics. Looked at more closely, a body's internal structure affects its motion, causing different objects to fall in different ways. This talk will explore which extended-body effects are possible and which are not. For example, can an appropriately-engineered spacecraft escape from a bound orbit without the use of a rocket? Indeed it can. There are constraints, however. It has long been known that Killing fields provide some such constraints. This talk nevertheless introduces a much weaker notion of symmetry which constrains extended-body effects. This includes Killing fields, conformal Killing-Yano tensors, and more. Many of the relevant constraints depend on the algebraic structure of the Weyl tensor (i.e., the Petrov type), and this is discussed as well.

Presenter: HARTE, Abraham (Dublin City University)

Session Classification: Friday Morning

Contribution ID: **43** Type: **not specified**

Analytic Solutions to Plunging Geodesics in Kerr.

Tuesday, 4 July 2023 14:40 (20 minutes)

Geodesic motion plays a fundamental role in the gravitational self-force approach to solving the relativistic dynamics of binary black holes. In this scheme, the zeroth approximation to the motion of the lighter secondary component is given by a geodesic in the Kerr geometry generated by the (heavier) primary black hole. At higher orders, this motion is corrected by an effective force term, the gravitational self-force, causing the system to evolve. During the inspiral phase, this evolution can be solved using a 2-timescale formalism, adiabatically evolving the system along a sequence of bound geodesics. EMRIs are expected to have mass ratios of order 10^5, and will therefore spend hundreds of thousands of orbits in the strong field regime of the inspiral phase. Consequently, the handful of orbits represented by the transition and plunge phases are generally expected to provide a negligible contribution to the total signal. However, over time evidence has mounted suggesting that the self-force formalism can produce accurate results at much higher mass ratios, and possibly even for comparable mass binaries. The growing applicability for modeling intermediary mass ratio inspirals has inspired further investigations of both the transition regime and the gravitational waves produced during the plunge and subsequent ringdown. In this talk I will present recent work supporting the latter, in which we derive analytic closed form solutions to generic plunges in Kerr.

Presenter: DYSON, Conor (Niels Bohr Institute)

Session Classification: Tuesday Afternoon

Contribution ID: **44** Type: **not specified**

Self-Force in Scalar-Tensor Theories of Gravity: Perturbative Approach Beyond Linear Order (Remote)

Thursday, 6 July 2023 11:40 (20 minutes)

For precise measurements of EMRIs with LISA data, first-post-adiabatic accuracy EMRI models will be required. Great effort is being expelled in pursuing first-post-adiabatic models in General Relativity. However, to test our fundamental theory of gravity, we also need models in alternative theories. Scalar fields are ubiquitous in alternative theories of gravity. In this talk, we provide a framework for modelling EMRIs to first-post adiabatic accuracy in general scalar-tensor theories of gravity. In our perturbative approach, the background spacetime can be treated as Kerr, as discussed in the preceding talks and Ref. [PRL. 125, 141101]. Additionally, we produce an ansatz for the action of a point particle experiencing a scalar self-force. From these assumptions, we derive field equations for the metric and scalar field perturbations to second order. Moreover, we derive the equations of motion of the compact object to second order. Crucially, our formalism builds on inputs from the General Relativity calculation, and the additional contributions are no more challenging to calculate than the General Relativity self-force contributions.

Presenter: SPIERS, Andrew (University of Nottingham)

Session Classification: Thursday Morning

Contribution ID: **45** Type: **not specified**

Can we predict Self-Force from Numerical Relativity?

Wednesday, 5 July 2023 11:00 (20 minutes)

It has long been stated that in order to perform precision tests of general relativity (GR) by comparing gravitational wave (GW) models from black hole perturbation theory with observations, one must calculate the phase to the next-to-leading order in the small mass ratio (SMR) expansion. The extent to which this statement is true however needs to be tested. That is, how far can the SMR expansion be pushed towards equal mass ratios before higher-order terms become non-negligible? Comparisons between SMR and numerical relativity (NR) waveforms have been done for quasicircular, equatorial orbits on a Schwarzschild background, during the inspiral with excellent results. The SMR expansion recovers the results of NR for mass ratios of ~1:10, and even produces results comparable to those of NR at equal mass ratios. The SMR model is therefore a promising candidate for producing fast and accurate waveforms for both intermediate mass ratio inspirals (IMRIs) and extreme mass ratio inspirals (EMRIs), for which SMR models were originally intended. Recent progress has been made to obtain complete SMR waveforms through the transition to plunge, vital for IMRI modelling. We will present new work comparing SMR and NR waveforms during the transition to plunge for quasicircular orbits on a Schwarzschild background.

Presenter: DURKAN, Leanne (University of Texas at Austin)

Session Classification: Wednesday Morning

Contribution ID: **46** Type: **not specified**

Eternal Binaries

Tuesday, 4 July 2023 16:40 (20 minutes)

The two-body problem is extensively studied in open systems and asymptotically flat spacetimes. However, there are many systems where radiation is trapped: they range from radiating charges in cavities to low-energy excitations of massive degrees of freedom, to anti-de Sitter spacetimes. Here, we study the problem of motion of a pointlike particle orbiting a massive compact object inside a cavity. We first show that - assuming circular motion - there are initial conditions for which the self-force vanishes and the binary is eternal. We then consider the evolution of the system under radiation reaction in a toy model which we argue captures the essentials of orbiting particles. We show that eternal circular binaries may exist. We also show that the presence of cavity modes leads to chaos in regimes of strong coupling or when the system is initialized close enough to a resonance. Our results have implications for physics in anti-de Sitter spacetimes and possibly for binaries evolving within dark matter haloes, if it consists on massive fundamental fields.

Presenter: REDONDO YUSTE, Jaime (Niels Bohr Institute)

Session Classification: Tuesday Afternoon

Contribution ID: **47** Type: **not specified**

Motion of spinning particles near Schwarzschild black holes: exact solution

Friday, 7 July 2023 09:20 (20 minutes)

The spin of the secondary in large mass ratio inspirals contributes to the inspiral phasing at the same order as the conservative self-force. Hence, treating the secondary spin at least to linear order is important for precise waveforms from these systems. In this talk I will present solutions of general motion of spinning test particles near a Schwarzschild black hole to linear order in spin in the form of elliptic integrals. I will also comment on how this relates to the generic Kerr problem and the prospect of obtaining similar results in more general spherically symmetric space-times.

Presenter: WITZANY, Vojtech (Charles U., Prague)

Session Classification: Friday Morning

Contribution ID: **48** Type: **not specified**

Progress toward complete inspiral-merger-ringdown waveforms at 1PA order

Monday, 3 July 2023 14:00 (20 minutes)

The only available 1PA waveform model, developed by the Southampton-UCD collaboration, is currently limited to the strong-field inspiral stage of quasicircular binaries. In this talk, I discuss progress toward developing a complete model that includes the early inspiral and the final merger and ringdown. A companion talk by Lorenzo Kuchler will provide further details of how we model the merger phase.

Presenter: POUND, Adam (University of Southampton)

Session Classification: Monday Afternoon

Contribution ID: **49** Type: **not specified**

A discontinuous Galerkin method for the distributionally-sourced s=0 Teukolsky equation

Wednesday, 5 July 2023 14:20 (20 minutes)

With the detection of first gravitational waves in 2015 by the laser interferometers at Laser Interferometer Gravitational wave Observatories (LIGO) located in Hanford and Livingston that was followed by a Nobel prize, there is an urgent need of more template waveforms for a bigger parameter space. The upcoming space borne detector Laser Interferometer Space Antenna (LISA) is primarily sensitive to Extreme Mass Ratio Inspirals (EMRI) where the mass ratio between two black holes lies between 10 to 10^7solar masses. LIGO uses a method known as match filtering where the detector tries to match the incoming signals with the existing waveforms simulated from Numerical Relativity (NR) or other numerical techniques. NR is only useful to model systems where the mass ratio is less than 10 as the problem becomes computationally expensive for larger ratios. Hence, there is a need to use a different method to simulate the EMRI systems. This is where Discontinuous Galerkin method comes into the play as it is the best suited for such kind of systems. It can incorporate the point particle behavior of the smaller black hole in the form of a delta function and due to the discontinuous nature of the scheme it is inherently highly parallelizable and thus generates highly accurate waveform in very short amount of time compared to the other methods. In this project, we intend to explore the application of discontinuous Galerkin method in the EMRI systems. We reduce the Teukolsky equation to a set of coupled 1+1D wave equations and apply the dG method to it with a delta source term, acting like the secondary black hole in an EMRI system.

Presenter: VISHAL, Manas (UMass Dartmouth)

Session Classification: Wednesday Afternoon

Contribution ID: **50** Type: **not specified**

Resonances and Chaos in EMRI Dynamics

Tuesday, 4 July 2023 16:20 (20 minutes)

Extreme mass ratio inspirals (EMRIs) are one of primary targets of space-borne gravititional wave detectors like LISA. Due to the long inspiral time and the large accumulated orbital phase of EMRIs in the LISA sensitive band, EMRIs are ideal tools for testing the fundmamental laws of gravity. Many previous studies have pointed out possible chaos of EMRI dynamics in non-GR gravity or non-Kerr spacetime. In this talk, I will point out that resonances have often been mistaken as chaos previously, explain how to distinguish chaos from resonances and how to incorporate them into EMRI waveform modeling.

Presenter: PAN, Zhen (T.D. Lee Institute and Shanghai Jiaotong University)

Session Classification: Tuesday Afternoon

Contribution ID: **52** Type: **not specified**

Gravitational wave memory for small mass ratio binaries

Thursday, 6 July 2023 16:00 (20 minutes)

I have calculated gravitational wave memory effects generated by small mass ratio inspirals at second order in Schwarzschild spacetime and first order in Kerr spacetime. This is a step towards generating complete waveform templates for LIGO and LISA. I will present my results along with comparisons to PN results.

Presenter: CUNNINGHAM, Kevin (University College Dublin)

Session Classification: Thursday Afternoon

Contribution ID: **53** Type: **not specified**

Detecting scalar charge with EMIRIs

Thursday, 6 July 2023 11:00 (20 minutes)

I will first discuss under which circumstances can black holes carry a scalar charge and what this implies for how that charge scales with the mass of the black hole. I will then use this insight to argue that EMRIs are an ideal system for searches of new fundamental scalars. I will lay out the framework for modelling EMRIs in this context and and present some first forecasts on LISA's ability to measure scalar charge.

Presenter: SOTIRIOU, Thomas (University of Nottingham)

Session Classification: Thursday Morning

Contribution ID: **54** Type: **not specified**

EMRIs in ultralight bosonic environments

Thursday, 6 July 2023 10:00 (20 minutes)

New ultralight fields are an exciting candidate for dark matter and can solve some of the small-scale tension between the standard CDM paradigm and observations. With the upcoming space-based LISA mission there is the prospect of detecting compact binaries in galactic centers, where dark matter structures are expected to be present. In this talk, we will present the first fully relativistic framework to study inspirals in non-vacuum environments and apply it to extreme-mass-ratio inspirals evolving inside a boson star composed of these putative fields. We confirm and correct previous results obtained in the Newtonian regime and discuss consequences for gravitational-wave astronomy.

Presenter: DUQUE, Francisco (CENTRA, Instituto Superior Técnico, Universidade de Lisboa)

Session Classification: Thursday Morning

Contribution ID: **55** Type: **not specified**

Extreme mass-ratio inspiral of a spinning body into a Kerr black hole

Friday, 7 July 2023 11:00 (20 minutes)

Accurate models of large mass-ratio systems must include post-geodesic corrections, which account for forces driving the small body away from the geodesic. An important post-geodesic effect is gravitational self-force, which describes the small body's interaction with its own spacetime curvature. This effect includes the backreaction due to gravitational-wave emission that leads to the inspiral of the small body into the black hole. When a spinning body orbits a black hole, its spin couples to the curvature of the background spacetime. This introduces another post-geodesic correction called the spin-curvature force. We use osculating element integration to generate a spinning-body inspiral that includes both the backreaction due to gravitational waves and spin-curvature forces. We apply a near-identity transformation which eliminates dependence on the orbital phases, allowing for very fast computation of completely generic worldlines of spinning bodies. Finally, we calculate the gravitational waveforms and examine the dephasing of the waveform due to the presence of spin-curvature forces.

Presenter: DRUMMOND, Lisa (Massachusetts Institute of Technolohy)

Session Classification: Friday Morning

Contribution ID: **56** Type: **not specified**

Distributional sources for the second-order Einstein and Teukolsky equations

Monday, 3 July 2023 14:40 (20 minutes)

To date, the only existing second-order self-force calculations have used some variant of a puncture scheme. In this scheme, one replaces the small object with a local singularity possessing the same curvature structure. This puncture field is truncated at some suitable distance from the particle and is then used as a source to solve for the residual field. From this, one can reconstruct the physical field. This method has been used due to the non-integrability of the second-order Einstein equations when in a generic gauge. However, recent work (2101.11409) formulated well-defined field equations in certain classes of gauges. However, while demonstrating the existence of well-defined field equations and a well-defined stress-energy tensor (the Detweiler stress-energy tensor), the field equations were not in a practical form to enable one to solve for the physical field. In this talk, we will present a more practical description of the second-order field equations and discuss how this could be implemented. We will also discuss how to use the distributional definitions adopted in 2101.11409 to derive the distributional part of the source for the second-order Teukolsky equation.

Presenter: UPTON, Samuel (Astronomical Institute of the Czech Academy of Sciences)

Session Classification: Monday Afternoon

Contribution ID: **57** Type: **not specified**

Detecting massive scalar fields with Extreme Mass Ratio Inspirals and LISA

Thursday, 6 July 2023 11:20 (20 minutes)

Extreme Mass Ratio Inspirals (EMRIs), binary systems with a secondary stellar mass compact object inspiralling into a massive black hole, are among the main targets for LISA, as they harbour the potential for precise strong gravity tests. Although the description of these systems in modified theories of gravity can be drastically complex, for a vast class of theories with additional scalar fields great simplifications occur. At leading order in the binary mass ratio, the primary scalar charge is suppressed, so that the background spacetime is simply described by the Kerr metric. Moreover, the imprint of the scalar field on the waveform is fully captured by the scalar charge of the secondary and by the mass of the scalar field. In this talk I will show how these parameters affect the EMRI's orbital evolution, and how such changes get imprinted on the emitted waveforms. By analysing such signals, I will finally present the results on the LISA's detectability of the scalar charge and mass, which render EMRIs encouraging probes of new fundamental fields.

Presenter: BARSANTI, Susanna (Sapienza University of Rome)

Session Classification: Thursday Morning

Contribution ID: **58** Type: **not specified**

Asymptotic gravitational-wave fluxes from a spinning test body on generic orbits around a Kerr black hole

Friday, 7 July 2023 11:20 (20 minutes)

This work provides gravitational wave energy and angular momentum asymptotic fluxes from a spinning body moving on generic orbits in a Kerr spacetime up to linear in spin approximation. To achieve this, we have developed a new frequency domain Teukolsky equation solver that calculates asymptotic amplitudes from generic orbits of spinning bodies with their spin aligned with the total orbital angular momentum. However, the energy and angular momentum fluxes from these orbits in the linear in spin approximation are appropriate for adiabatic models of extreme mass ratio inspirals even for spins non-aligned to the orbital angular momentum. To check the newly obtained fluxes, they were compared with already known frequency domain results for equatorial orbits and with results from a time domain Teukolsky equation solver called Teukode for off-equatorial orbits. The spinning body framework of our work is based on the Mathisson-Papapetrou-Dixon equations under the Tulczyjew-Dixon spin supplementary condition.

Presenter: SKOUPÝ, Viktor (Astronomical Institute of the Czech Academy of Sciences; Charles University)

Session Classification: Friday Morning

Contribution ID: **59** Type: **not specified**

2nd-order self-force: mode decomposition of the 1st-order puncture

Monday, 3 July 2023 16:00 (20 minutes)

As part of computing the 2nd order gravitational self-force in Schwarzschild (see talks by Pound, Wardell, Upton, and others), we need to decompose the 1st-order puncture field into Barack-Lousto-Sago (BLS) tensor-spherical-harmonic components. Conceptually this is easy: we just integrate the puncture field against each BLS basis function. In practice, there are many thousands of such integrals, and computing them numerically is both expensive and ill-conditioned. In this talk I'll discuss how these integrals can be computed analytically.

Presenter: THORNBURG, Jonathan

Session Classification: Monday Afternoon

Contribution ID: **60** Type: **not specified**

Frequency-domain approach to self-force in hyperbolic scattering

Tuesday, 4 July 2023 11:00 (20 minutes)

Calculations of the scatter angle in hyperbolic black hole encounters have been of recent cross-disciplinary interest, driven by its potential to advance post-Minkowskian theory and the effective-one-body model of binary dynamics. In this talk I will present our frequency-domain method for calculating the self-force acting on a scalar charge on a fixed scattering geodesic in Schwarzschild spacetime. Existing frequency-domain methods, which are tailored for bound orbits, are inadequate here for several reasons. One must account for the continuous spectrum in the scattering problem, deal with slowly-convergent radial integrals that are hard to evaluate numerically, and confront the inapplicability of the standard EHS method, which only works for compactly supported sources. I will describe solutions to each of these issues in turn, and then present a full numerical implementation, in which we calculate the self-force correction to the scatter angle due to scalar-field back-reaction. Validation is achieved using regularization tests, as well as comparisons with the existing time-domain code. Finally I will discuss the merits and remaining limitations of our method, and outline directions for future work.

Presenter: WHITTALL, Christopher (University of Southampton)

Session Classification: Tuesday Morning

Contribution ID: **61** Type: **not specified**

Exploring the remnant properties of precessing black hole binaries by combining numerical relativity and extreme mass ratio data sets

Wednesday, 5 July 2023 16:00 (20 minutes)

For the foreseeable future, numerical relativity waveforms for calibrating waveform models will be sparse in the parameter space of precessing (even more so for generic) black hole binaries, especially at high mass ratios. It is however well known that the extreme mass ratio limit can provide useful information even for the comparable mass ratio regime, and it can be hoped that using such information can reduce the number of numerical relativity waveforms that are needed for calibrating waveform models. In this work, we present two key steps toward this goal: First, we construct a consistent heterogeneous dataset for quasi-circular precessing binaries, which combines numerical relativity waveforms from different codes, numerical solutions of the Teukolsky equation, and information from Kerr geodesics. Second, we discuss models of the remnant properties for single spin precessing binaries, which cover all mass ratios. To accurately understand the region where no NR information is available, we rely on approximations based on Kerr geodesics, which turn out to provide valuable information up to comparable masses.

Presenter: PLANAS LLOMPART, Maria de Lluc (University of the Balearic Islands)

Session Classification: Wednesday Afternoon

Contribution ID: **62** Type: **not specified**

The Black Hole Perturbation Toolkit: an update

Friday, 7 July 2023 15:00 (20 minutes)

Presenter: WARBURTON, Niels (University College Dublin)

Session Classification: Friday Afternoon

Contribution ID: **63** Type: **not specified**

Kerr self-force via elliptic PDEs

Monday, 3 July 2023 12:00 (20 minutes)

We are pursuing Lorenz gauge Kerr self-force calculations based on an m-mode scheme in the frequency domain. Prior hyperbolic partial differential equation (PDE) formulations encountered numerical instabilities involving unchecked growth in time; our method is based on elliptic PDEs, which do not exhibit instabilities of that kind. For proof of concept we calculated the self-force acting on a scalar charge in a circular orbit around a Kerr black hole, and progress towards the gravitational case will be discussed.

Presenter: OSBURN, Tommy (State University of New York at Geneseo)

Session Classification: Monday Morning

Contribution ID: **64** Type: **not specified**

Orthogonality and transitions between black-hole quasibound states

Friday, 7 July 2023 14:20 (20 minutes)

Linear perturbations around black hole spacetimes can be quasinormal, quasibound or even superradiantly unstable, depending on the fields involved and the system's parameters. Recently, a bilinear form on perturbations of Kerr was proposed, and shown to give rise to an orthogonality relation between quasinormal modes. In this work, we extend the definition of the bilinear form and the orthogonality relation to quasibound and superradiant states of massive scalar fields. As a first application, we evaluate the bilinear form numerically for massive scalar perturbations in Schwarzschild, and confirm numerically the orthogonality between quasibound states of different quantum numbers. We then use the bilinear form to compute the excitation of modes due to a perturbation to the black hole potential, due e.g. to an extreme-mass-ratio companion. We show that the corresponding level mixing between quasibound modes can differ by $\mathcal{O}(10)\%$ compared to the commonly employed non-relativistic (or hydrogenoid) approximation.

Presenter: SBERNA, Laura (Max Planck Institute for Gravitational Physics (Albert Einstein Institute), Potsdam)

Session Classification: Friday Afternoon

Contribution ID: **65** Type: **not specified**

Multi-domain spectral method for self-force calculations

Monday, 3 July 2023 11:20 (20 minutes)

We present a multi-domain elliptic solver in 2D based on spectral methods to solve typical self-force equations in an Effective Source m-mode scheme. The domain decomposition exploits two features to enhance accuracy. With a reference centred at the black hole, the horizon and wave zone regions are treated with a hyperboloidal approach, allowing asymptotic regions to be included in the numerical grid. However, The effective source is obtained in a reference frame centred at the particle position, allowing a relatively quick and effective scheme for calculating high-order puncture fields. The code is benchmarked for the scalar self-force of a particle on a circular orbit in the Schwarzschild spacetime.

Presenter: PANOSSO MACEDO, Rodrigo (Niels Bohr Institute)

Session Classification: Monday Morning

Contribution ID: **66** Type: **not specified**

Adiabatically compressed wave dark matter halo and intermediate-mass ratio inspirals

Thursday, 6 July 2023 09:40 (20 minutes)

The adiabatic growth of a central massive black hole could compress the surrounding dark matter halo, leading to a steeper profile of the dark matter halo. This phenomenon is called adiabatic compression. We investigate the adiabatic compression of wave dark matter - a light bosonic dark matter candidate with its mass smaller than a few eV. Using the adiabatic theorem, we show that the adiabatic compression leads to a much denser wave dark matter halo similar to the particle dark matter halo in the semiclassical limit. The compressed wave halo differs from that of the particle halo near the center where the semiclassical approximation breaks down, and the central profile depends on dark matter and the central black hole mass as they determine whether the soliton and low angular momentum modes can survive over the astrophysical time scale without being absorbed by the black hole. Such a compressed profile has several astrophysical implications. As one example, we study the gravitational waves from the inspiral between a central intermediate-mass black hole and a compact solar-mass object within the wave dark matter halo. Due to the enhanced mass density, the compressed wave dark matter halo exerts stronger dynamical friction on the orbiting object, leading to the dephasing of the gravitational waves. The pattern of dephasing is distinctive from that of inspirals in the particle dark matter halo because of the difference in density profile and because of the relatively suppressed dynamical friction force, originating from the wave nature of dark matter. We investigate the prospects of future gravitational wave detectors, such as Laser Interferometer Space Antenna, and identify physics scenarios where the wave dark matter halo can be reconstructed from gravitational wave observations.

Presenter: XUE, Xiao (UHH & DESY)

Session Classification: Thursday Morning

Contribution ID: **67** Type: **not specified**

post-Newtonian expansions of equatorial eccentric Kerr EMRIs using the s = +2 Teukolsky functions

Tuesday, 4 July 2023 09:00 (20 minutes)

Calculations involving Kerr extreme-mass-ratio inspirals (EMRIs) often involve solving the s = -2 Teukolsky functions. In the cases where the s = +2 Teukolsky functions are warranted, they are usually obtained through the use of a Starobinsky transformation. In our work, we decided to directly construct post-Newtonian (PN) expansions of s = +2 Teukolsky functions using the MST method. First, as a check on our group's previous work with PN expansions using the s = -2 Teukolsky functions, and second, to develop a general toolkit for analytical PN expansions of the Teukolsky functions independent of the value of s. In this presentation, we discuss the changes needed to efficiently construct the PN expansion of the s = +2 Teukolsky functions, as well as a comparison of the PN expanded quantities that we extracted using both s = +2 and s = -2 Teukolsky functions, expanded up to 8 PN and e^{20}.

Presenter: CASTILLO, Jezreel (UNC Chapel Hill)

Session Classification: Tuesday Morning

Contribution ID: **68** Type: **not specified**

Slow-spin black hole perturbation theory

Monday, 3 July 2023 11:00 (20 minutes)

By deriving corrections to the Regge-Wheeler and the Zerilli equations up to second order in the spin, one can find that the two potentials are still isospectral, provided the correct choice of the tortoise coordinate. Isospectrality with slow-rotating Teukolsky equation is also verified. This result has huge implications since it provides an analytic way to perform the so-called metric recontruction.

Presenter: FRANCHINI, Nicola (APC)

Session Classification: Monday Morning

Contribution ID: **69** Type: **not specified**

Comparing different metric reconstruction procedures in Kerr spacetime

Monday, 3 July 2023 10:00 (20 minutes)

We compute the metric perturbation for a point particle on a bound geodesic in Kerr spacetime using the CCK and AAB reconstruction procedures. We discuss the numerical advantages and disadvantages of these different approaches, and present how other researchers can use the numerical tools from this work to construct their own Kerr metric perturbations.

Presenter: NASIPAK, Zachary (NASA Goddard Space Flight Center)

Session Classification: Monday Morning

Contribution ID: **71** Type: **not specified**

Self Force Resonance

Tuesday, 4 July 2023 16:00 (20 minutes)

Self-force resonance is a resonance phenomenon that occurs when the ratio of orbital frequencies becomes a simple rational number. Its contribution appears at 0.5 post-adiabatic order, making it the next-to-leading effect after the adiabatic radiation reaction. Moreover,it is estimated that almost all EMRI systems experience this type of resonance, and so its theoretical prediction is essential for future observations. The resonance contribution can be divided into a dissipative and a conservative part, as in the usual self-force calculations. The effect of the conservative part is expected to cause a jump across the resonance only in the Carter constant. The calculation of the conservative part is more involved since it requires regularization and is currently under development. In this study, a numerical implementation of the conservative part of the resonance is developed in a scalar field toy model using an alternative regularization method proposed in Isoyama et al. 2013, based on the point splitting. The advantage of this method is in its simplicity in deriving the counter terms, although its usefulness has never been demonstrated yet. Several difficulties that were not recognized prior to the actual implementation are found and their solutions are proposed. In Our goal is to examine the effectiveness of the Hamiltonian formalism with the point-splitting method, by extending the scalar toy model to the gravitational case.

Presenter: KAKEHI, Takafumi (Yukawa Institute for Theoretical Physics, Kyoto University)

Session Classification: Tuesday Afternoon

Contribution ID: **72** Type: **not specified**

The on-shell approach to radiation reaction

Tuesday, 4 July 2023 09:40 (20 minutes)

We describe an on-shell approach to discussing radiation reaction problems within the post-Minkowskian and self-force approximations to general relativity. In both cases, the notions of coherent states and eikonal exponentiation are key tools for accessing this physics in terms of on-shell amplitudes. We will explore a few applications and demonstrate how these tools can be used to relate amplitudes in vacuum to those on a given background, such as Schwarzschild.

Presenter: CRISTOFOLI, Andrea (University of Edinburgh - School of Mathematics)

Session Classification: Tuesday Morning

Contribution ID: **73** Type: **not specified**

EMRI accuracy requirements: How important are the post-adiabatic components of the self-force for parameter estimation?

Wednesday, 5 July 2023 09:40 (20 minutes)

It is commonly stated within the self force (SF) community that, in order to not significantly bias results, we require accurate tracking of the phase to within 1 radian. However, although frequently stated, this criterion is yet to be tested through a general Bayesian analysis. Armed with complete first order post-adiabatic (1PA) circular-Schwarzschild EMRI waveforms, we discuss the impact of neglecting this post-adiabatic information from a data analysis perspective. Within the view-point of the within-one-radian-of-phase criterion, we present results of our attempt to recover full 1PA waveforms simply using approximate 0PA waveforms using a fully Bayesian framework. For the class of source considered in this talk, we will conclude by discussing the potential impact on both astrophysics and tests of general relativity if the post-adiabatic components of the SF are neglected.

Presenter: BURKE, Ollie (Laboratoire des 2 Infinis (L2IT))

Session Classification: Wednesday Morning

Contribution ID: **74** Type: **not specified**

Enhancing the SEOBNRv5 effective-one-body waveform model with second-order gravitational self-force fluxes

Wednesday, 5 July 2023 09:00 (20 minutes)

We leverage recent breakthrough calculations using second-order gravitational self-force (2GSF) theory to improve both the gravitational-mode amplitudes and radiation-reaction force in effective-one-body~(EOB) waveform models. We achieve this by introducing new calibration parameters in the SEOBNRv5HM mode amplitudes, and matching them to the newly available 2GSF energy-flux multipolar data for quasicircular nonspinning binary black holes. We find that this significantly improves the SEOBNRv5HM energy flux, when compared to numerical-relativity (NR) simulations of binary black holes with mass ratios between 1:1 and 1:20. Moreover, we find that, once the conservative part of the SEOBNRv5 dynamics is calibrated, the SEOBNRv5HM waveform model with 2GSF information reproduces the binding energy of NR simulations more accurately, providing a powerful check of the consistency and naturalness of the EOB approach. While we only include nonspinning 2GSF information, the more accurate binding energy and energy flux carry over to the SEOBNRv5 waveform models for spinning binary black holes. Thus, our results improve the latest generation of SEOBNR waveform models (i.e., SEOBNRv5), which has been recently completed for use in the upcoming fourth observing (O4) run of the LIGO-Virgo-KAGRA Collaboration.

Presenter: POMPILI, Lorenzo (Max Planck Institute for Gravitational Physics (AEI Potsdam))

Session Classification: Wednesday Morning

Contribution ID: **75** Type: **not specified**

Exact tridiagonalization of Teukolsky's radial equation

Friday, 7 July 2023 14:00 (20 minutes)

Although solutions to Teukolsky's radial equation play a key role in black hole perturbation theory, there are limitations in our understanding that obscure our practical use and application of e.g. QNM overtone solutions. Towards addressing these limitations, I'll present a collection of results that conclude with the tridiagonalization of Teukolsky's radial equation. In particular, I'll develop a scalar product space for Kerr, novel polynomials native to the space, and then examples of the exact tridiagonalization of Teukolsky's radial equation for zero, moderate, and nearly extremal black hole spins.

Presenter: LONDON, Lionel (King's College London)

Session Classification: Friday Afternoon

Contribution ID: **76** Type: **not specified**

Tidal heating in eccentric and inclined orbits

Thursday, 6 July 2023 09:20 (20 minutes)

With the observation of the multiple binary inspirals, we begin to question whether the components of the binary are black holes or some exotic compact objects (ECOs). The black holeness or the deviation from it can be tested in several ways. The distinguishing feature of a black hole from ECOs in the presence of the horizon. This surface acts as a one-way membrane, that absorbs energy. Due to this different behavior from ECOs, in the last stages of an inspiral black holes exchange energy. These backreact on the orbit, transferring energy and angular momentum from their spin into the orbit. This effect is called tidal heating. I will discuss the impact of tidal heating due to the inclination and eccentricity of an orbit. It can be used as a test for the presence of the horizon. I will discuss how this will help us measure the reflectivity of the compact objects.

Presenter: DATTA, Sayak

Session Classification: Thursday Morning

Contribution ID: **77** Type: **not specified**

Application of the GHZ formalism in a puncture scheme

Monday, 3 July 2023 09:40 (20 minutes)

Extreme-mass ratio inspirals are identified as one of the key targets for the upcoming LISA mission. They will serve as unique probes of black-hole physics and enable tests of general relativity with unparalleled precision. Modelling these systems with sufficient accuracy requires the calculation of up to second-order metric perturbation due to a point particle orbiting a Kerr black hole. Currently, the linear perturbation is obtained via a so-called metric reconstruction procedure that puts it in a "no-string" radiation gauge, in which the perturbation is singular on a surface surrounding the central black hole. As a result, calculating physical quantities in such a gauge requires a subtle procedure of "gauge completion", as well as cancellations of very large numbers. These problems are further exacerbated at second-order. In parallel, a critical weakness of the current no-string construction is that it cannot be applied to spatially extended sources. This limits its utility not only for second-order, but even first-order self-force applications, since it is not applicable for example in a puncture scheme, one of the standard methods of self-force theory. A new reconstruction procedure, called the GHZ formalism, overcomes such limitations by allowing for non-pointlike sources. In this talk, I will summarise the GHZ formalism, and show for the first time its concrete implementation in a puncture scheme in the case of circular orbits in Schwarzschild.

Presenter: BOURG, Patrick (University of Southampton)

Session Classification: Monday Morning

Contribution ID: **78** Type: **not specified**

Action-Angle formalism for extreme mass ratio inspirals in Kerr spacetime

Thursday, 6 July 2023 16:20 (20 minutes)

We introduce an action-angle formalism for bounded geodesic motion in Kerr black hole spacetime using canonical perturbation theory. Namely, we employ a Lie series technique to produce a series of canonical transformations on a Hamiltonian function describing geodesic motion in Kerr background written in Boyer-Lindquist coordinates to a Hamiltonian system written in action-angle variables. This technique allows us to produce a closed-form invertible relation between the Boyer-Lindquist variables and the action-angle ones, while it generates in analytical closed form all the characteristic functions of the system as well. The expressed in the action-angle variable Hamiltonian system is employed to model an extreme mass ratio inspiral (EMRI), i.e. a binary system where a stellar compact object inspirals into a supermassive black hole due to gravitational radiation reaction. We consider the adiabatic evolution of an EMRI, for which the energy and angular momentum fluxes are computed by solving the Teukolsky equation in the frequency domain.

Presenter: POLCAR, Lukáš (Charles University)

Session Classification: Thursday Afternoon

Contribution ID: **79** Type: **not specified**

Intertwining numerical relativity, perturbation theory and gravitational self-force

Wednesday, 5 July 2023 11:20 (20 minutes)

We present a systematic comparison between gravitational waveforms emitted by quasi-circular non-spinning binary black holes in both comparable and large mass ratio regimes, generated with two different classes of waveform models: (i) second-order gravitational self-force (GSF) theory and (ii) numerical relativity (NR) informed point particle black hole perturbation theory (ppBHPT) waveforms as implemented in the BHPTNRSur1dq1e4 model, the cornerstone of BHPTNRSurrogate family of waveform models. The latter provides only adiabatically-driven waveforms whereas GSF includes first-order post-adiabatic corrections. However, BHPTNRSurrogate employs a simple linear scaling, known as the α-β scaling, to calibrate adiabatic-only ppBHPT waveforms to NR. We find that BHPTNRSur1dq1e4 waveforms closely match waveforms from second-order self-force theory everywhere in the mass ratio regime with the error dropping to ~ 10−3 for mass ratio q ≥ 10 - indicating the effectiveness of the α-β scaling. Our analysis then provides evidence for a simple scaling between the adiabatic-only and first-order post-adiabatic self-force waveform within GSF model and shows that the α-β scaling in BHPTNRSurrogate corrects for the missing higher-order self-force terms in adiabatic-only ppBHPT waveforms. This work helps to provide a physical interpretation to the α-β scaling in BHPTNRSurrogate and shows promise in guiding future higher-order self-force calculations.

Presenter: ISLAM, Tousif (University of Massachusetts Dartmouth)

Session Classification: Wednesday Morning

Contribution ID: **80** Type: **not specified**

Waveforms from plunges into a Schwarzschild black hole

Monday, 3 July 2023 14:20 (20 minutes)

Within general relativity, the planar motion of a small body around a supermassive Schwarzschild black hole admits a quasi-circular inspiral followed by a transition across the innermost stable circular orbit (ISCO) and a final plunge behind the event horizon. Waveforms from second-order self-force theory compare remarkably well with numerical relativity simulations in the regime of comparable-mass binaries. However, these 1PA templates break down at the ISCO. The transition and plunge regimes are expected to be crucial for modelling systems with intermediate mass ratios and nearly comparable masses, which have already been observed by the ground-based detectors of the LVK Collaboration during the latest O3b run. After presenting the transition approximation at last year's Capra meeting, in this talk I discuss the final plunge, obtaining a framework for complete waveforms in Schwarzschild spacetime that extend beyond the ISCO. I consider both the orbital motion and the field equations, and focus on enforcing the match with the late transition.

Presenter: KÜCHLER, Lorenzo (Université libre de Bruxelles - KU Leuven)

Session Classification: Monday Afternoon

Contribution ID: **81** Type: **not specified**

Existence of a Hamiltonian description of the self-force: new results and challenges

Thursday, 6 July 2023 16:40 (20 minutes)

We show that the motion of a spinning point particle in stationary spacetime is Hamiltonian when we include the spin-curvature coupling and the conservative piece of the self-force to first order in the mass ratio and spin of the secondary. We also report ongoing progress in attempts to extend this result to spinless particles at second order in the mass ratio. Problems involving the definition of a "conservative sector", as well as infrared divergences that arise at second order are discussed. This last topic is a collaboration with Adam Pound and Abe Harte.

Presenter: BLANCO, Francisco (Cornell University)

Session Classification: Thursday Afternoon

Contribution ID: **82** Type: **not specified**

Metric perturbations of Kerr spacetime in Lorenz gauge using separation of variables

Monday, 3 July 2023 09:00 (20 minutes)

I will describe a new separation-of-variables method for obtaining the metric perturbations of Kerr spacetime in Lorenz gauge. The metric perturbation is constructed in the frequency domain from (Teukolsky) scalars that satisfy decoupled *ordinary* differential equations. For the case of a particle moving on a circular equatorial orbit of Kerr spacetime, I will compare the results of the new method with existing numerical results from a 2+1D time-domain code. I will discuss the prospects of implementing this for generic orbits on Kerr. This talk is based on work with Barry Wardell, Chris Kavanagh and Leanne Durkan.

Presenter: DOLAN, Sam (University of Sheffield)

Session Classification: Monday Morning

Contribution ID: **83** Type: **not specified**

Worldtube excision method for intermediate-mass-ratio inspirals: scalar-field model in 3+1 dimensions

Wednesday, 5 July 2023 15:40 (20 minutes)

Binary black hole simulations become increasingly more computationally expensive with smaller mass ratios, partly because of the longer evolution time, and partly because the lengthscale disparity dictates smaller time steps. We explore a method for alleviating the scale disparity in simulations with mass ratios in the intermediate astrophysical range (10−4⩽q⩽10−2), where purely perturbative methods may not be adequate. A region (”worldtube”) much larger than the small black hole is excised from the numerical domain, and replaced with an analytical model approximating a tidally deformed black hole. We apply this idea to a toy model of a scalar charge in a fixed circular geodesic orbit around a Schwarzschild black hole, solving for the massless Klein-Gordon field. This is a first implementation of the worldtube excision method in full 3+1 dimensions. We demonstrate the accuracy and efficiency of the method, and discuss the steps towards applying it for evolving orbits and, ultimately, in the binary black-hole scenario.

Presenter: WITTEK, Nikolas (Max Planck Institute for Gravitational Physics)

Session Classification: Wednesday Afternoon

Contribution ID: **84** Type: **not specified**

Regge-Wheeler-Zerilli formalism and metric reconstruction

Monday, 3 July 2023 09:20 (20 minutes)

We present an algebraic procedure for reconstructing the metric perturbation from scalar quantities in the Regge-Wheeler-Zerilli formalism. Starting with the work of Wald, and more recently through advances by Green, Hollands, and Zimmerman and others, the Teukolsky metric reconstruction formalism has been written in an elegant four-dimensional language of operator adjoints, Hertz potentials, circularity relations, and corrector tensors. In contrast, metric reconstruction in the RWZ formalism has largely remained in a more opaque form. We discuss how RWZ metric reconstruction (in vacuum or nonvacuum) can be recast in the modern, four-dimensional, operator-based language. Collaborators: Adam Pound, Jonathan Thompson, Barry Wardell

Presenter: SAM, Zeyd (University of Potsdam)

Session Classification: Monday Morning

Contribution ID: **85** Type: **not specified**

On the effective action of compact objects from full GR

Friday, 7 July 2023 09:40 (20 minutes)

Calculations involving compact objects, such as post-Newtonian (PN) or self-force calculations, are greatly simplified by treating the body as point particles. Going to higher orders in compactness introduces successively higher order multipolar structure to the compact object. Effective field theory methods provide a systematic tool to account for these finite size effects, by using an effective world-line action to describe the objects. This effective action has proven to work very effectively, but is a postulate that has not been derived from first principles. In this talk, we present such an effective action for compact objects in from first principles in General Relativity. For a spherically symmetric body, we show how a multipolar decomposition of the action recovers the traditional effective field theory action. In particular, this derivation provides a geometrical understanding of the effective action. Moreover, it shows us how the nature of the horizon leads to the vanishing of the Love number for Schwarzschild black holes. Additionally, it clarifies the relation between the Love numbers that enter PN calculations (via the effective action) and the Love numbers computed from the metric of a tidally deformed object.

Presenter: KHERA, Neev (University of Guelph)

Session Classification: Friday Morning

Contribution ID: **86** Type: **not specified**

Assessing the importance of first post-adiabatic terms for LISA data analysis of EMRIs and IMRIs

Wednesday, 5 July 2023 10:00 (20 minutes)

Extreme mass ratio inspirals (EMRIs) and Intermediate mass ratio inspirals (IMRis) are prime targets for future space-borne interferometers like LISA. It is well-known that waveforms suitable for LISA data analysis must be accurate up to first-order post-adiabatic (1PA) corrections for both sources. But is it always the case? In this talk, we will try to answer this question by presenting the results of a parameter estimation using the 1PA waveforms developed in arXiv:2112.12265 augmented with secondary spin contributions. Our analysis shows that, for mass ratios smaller than 10^(-3), 1PA terms do not affect the statistical errors on the parameters for circular, equatorial orbits in a Schwarzschild background. Moreover, it is possible to recover the injected parameters using just adiabatic waveforms in the EMRI regime, whereas neglecting 1PA terms induced significant systematic biases for mass ratios roughly larger than 10^(-4).

Presenter: PIOVANO, Gabriel Andres (University College Dublin)

Session Classification: Wednesday Morning

Contribution ID: **87** Type: **not specified**

Ringdown beyond Kerr

Friday, 7 July 2023 16:00 (20 minutes)

While challenging in practice, measurements of multiple black hole ringdown frequencies can provide clean tests of the nature of black holes. Going beyond null tests, however, requires predictions of the ringdown spectrum in theories beyond GR and in spacetimes beyond Kerr. Such predictions also allow for optimal combinations of a large number of weaker tests. In this talk I will outline a flexible approach for calculating the ringdown spectrum of spinning black holes in theories where deviations from GR are small, and discuss future prospects for predicting ringdown beyond Kerr.

Presenter: ZIMMERMAN, Aaron

Session Classification: Friday Afternoon

Contribution ID: **88** Type: **not specified**

High-order regularisation parameters for generic orbits in Kerr gravity.

We present the first high-order regularisation parameters for generic orbits in Kerr spacetime in the gravitational case. Such parameters enable a jump in efficiency for mode-sum self-force calculation and have been shown to be of particular importance in the case of resonances. We also present the updated Regularisation Mathematica Package which includes both the gravitational and electromagnetic parameters as part of the bhptoolkit.

Presenter: HEFFERNAN, Anna (University of Balearic Islands)

Session Classification: Wednesday Afternoon

Contribution ID: **89** Type: **not specified**

Reducing the computational cost of EMRI waveforms using machine learning

Tuesday, 4 July 2023 15:00 (20 minutes)

EMRI data analysis faces a number of challenges. One issue is the high computational cost of waveforms, which arises due to the need to model complex physics over long timescales. Recent innovations in relativistic EMRI waveform generation have enabled them to be computed in less than a second, but further improvements are required if EMRI studies are to be made practical. Potentially millions of waveforms would need to be calculated to infer the parameters for a single signal; the data stream may contain thousands of EMRIs, and to infer properties of the underlying astrophysical population, we must simulate selection effects for many tens of thousands of populations. Machine learning can mitigate the computational expense of EMRIs in data analysis studies, both by accelerating EMRI waveform evaluations and reducing the number of waveform evaluations required. I will outline the motivations for using machine learning in EMRI data analysis, and demonstrate that significant efficiency gains can be made without compromising accuracy in applications such as population inference.

Presenter: CHAPMAN-BIRD, Christian (University of Glasgow)

Session Classification: Tuesday Afternoon

Contribution ID: **90** Type: **not specified**

Detection and modelling of eccentric intermediate mass ratio inspirals

Wednesday, 5 July 2023 16:20 (20 minutes)

The first confirmed detection of a 150 solar mass black hole in the form of the gravitational wave event, GW190521, did put an end to decades long debate concerning the existence of intermediate mass black holes. Black holes with masses typically in the range of 100-10,000 solar masses, when paired with stellar or supermassive black holes, become one of the most interesting sources for planned space missions such as eLISA and B-DECIGO and are commonly classified as intermediate mass-ratio inspirals (IMRIs). While there have been remarkable developments in modeling sources with comparable mass components or with extreme mass ratios in the past, there has been relatively little progress in modeling IMRIs even for simplest of binary configuration such as those in circular orbits. We present an eccentric hybrid (inspiral-only) model obtained by combining the waveform inputs from post-Newtonian theory and black hole perturbation theory and find it suitable for analyzing IMRIs in orbits with eccentricities of 0.3 in DECIGO band. Detection of selected eccentric higher order modes in the context of DECIGO configuration is also explored. These models should prove to be useful in performing accurate comparisons with similar models from the self-force and other semi-analytical approaches such as EOB. Collaborators : Ryuichi Fujita (Otemon Gakuin University), Laxman M (IIT Madras), Estuti Shukla (Penn State University),

Presenter: MISHRA, Chandra Kant (Indian Institute of Technology Madras)

Session Classification: Wednesday Afternoon

Contribution ID: **91** Type: **not specified**

Towards a weak-field hybrid 2PA waveform model.

Tuesday, 4 July 2023 14:00 (20 minutes)

While it is well accepted that generic EMRI waveform models must be fully relativistic, early 'kludge' waveform models often relied on weak-field (and other) approximations. Kludges were created in the absence of fully relativistic EMRI models to inform the science case for LISA. While it may be hoped that generic adiabatic self-force models are right around the corner, the same cannot be said for generic 1PA self-force models in the short term. In this talk we will present progress towards a generic 2PA hybrid model motivated by: 1) The need for an updated generic EMRI model suitable for LISA preparatory studies. 2) The requirement for a model that qualitatively captures the leading 2PA error when truncating waveform models to 1PA order. 3) Improving our understanding of how to map between self-force and Post-Newtonian dynamics including generic spin effects.

Presenter: MATHEWS, Josh (National University of Singapore)

Session Classification: Tuesday Afternoon

Contribution ID: **92** Type: **not specified**

Capra26 Wrap-up

Friday, 7 July 2023 16:40 (20 minutes)

Session Classification: General

Contribution ID: **93** Type: **not specified**

Symplectic mechanics of a spinning particle around a Schwarzschild black hole

Friday, 7 July 2023 09:00 (20 minutes)

I will present a new Hamiltonian analysis of the motion of a spinning particle orbiting a Scwharzschild black hole. First I will reduce the Mathisson-Papapetrou equations at linear order in spin to a Poisson system. Second, I will present a reduction of this system to a 6 degrees-of-freedom (dof), constrained Hamiltonian system. Third, specialising to the Schwarzschild spacetime, a reduction by invariants and by SSC constraints will be performed, using a new set of symplectic variables adapted to the underlying SO(3) and SO(1,3) symmetries in the problem. The whole dynamics are then showed to be governed by a very simple, integrable and decoupled 2 dofs system: the radial dynamics are solvable in terms of elliptic functions (as for the non-spinning case), while the rotational dynamics (orbital+spin) combine nicely into a single Hill's equation. All these results do not rely on any assumptions of circularity, spin-alignment and/or planarity, the latter cases being fixed points of the general dynamical system.

Presenter: RAMOND, Paul (Paris Observatory)

Session Classification: Friday Morning

Contribution ID: **94** Type: **not specified**

EDI Committee Updates

Thursday, 6 July 2023 14:00 (20 minutes)

Presenter: Dr THOMPSON, Jonathan (Caltech)

Session Classification: EDI Session

Contribution ID: **95** Type: **not specified**

Gender Equality Strategies at the NBI

Thursday, 6 July 2023 14:20 (50 minutes)

Presenter: BORUM RYDHAL, Rasmus (NBI)

Session Classification: EDI Session

Contribution ID: **96** Type: **not specified**

Tidal effects in GR and beyond: novel scalar-tensor Love numbers and dynamical response from scattering

Tuesday, 4 July 2023 15:20 (40 minutes)

Scalar-tensor theories are one of the long-standing alternatives to General Relativity (GR). These theories introduce an extra degree of freedom through a scalar field coupled to gravity, which affects the dynamics and internal composition of neutron stars. In this talk we use an effective field theory approach in order to describe an isolated body with size effects, characterised through the tidal deformability or, equivalently, the Love number. In particular, we introduce a novel tidal deformability and distinguish between different contributions to the induced multipole moments, clarifying the correct identifications with respect to previous literature. Additionally, we present a gauge-invariant method to extract the tidal response, the frequency-dependent tidal deformability, in GR using scattering. Our work is important for interpreting upcoming gravitational-wave data for subatomic physics of ultradense matter in neutron stars, probing black holes and gravity, and looking for beyond-standard-model fields.

Presenter: GRECI, Gastón (Utrecht University)

Session Classification: Poster session

Contribution ID: **97** Type: **not specified**

Prospects for observing extra dimensions in gravitational waves

Tuesday, 4 July 2023 15:40 (20 minutes)

For many years, the idea that there may be more than three spatial dimensions in our universe has attracted people's interest. The method by which extra dimensions are concealed, making spacetime essentially four-dimensional as far as known physics is concerned, is a key issue in multidimensional theories. Extra dimensions might be large or infinite, and they might then have consequences that can be seen through experiments. This has motivated us to explore the possibilities of inspecting the extra dimensions through extreme mass-ratio inspirals where the primary object is the braneworld black hole defined with a tidal charge. For such a system, I would discuss the role of the tidal charge parameter in view of hunting the extra dimensions with potential detectability through LISA observations.

Presenter: KUMAR, Shailesh (Indian Institute of Technology Gandhinagar)

Session Classification: Poster session

Contribution ID: **98** Type: **not specified**

A New Approach to Post-Newtonian Gravity

Tuesday, 4 July 2023 15:40 (20 minutes)

I will discuss the covariant non-relativistic expansion of general relativity in powers of 1/c, using as an example the case of a compact perfect fluid matter source that can radiate gravitational waves. This is a well-studied scenario in the literature that is conventionally done by using the approach developed, amongst others, by Blanchet and Damour. This approach uses the harmonic gauge and a rather strong set of boundary conditions. We are able to improve upon these points by using the covariant 1/c expansion of GR in combination with a vacuum multipolar post-Minkowskian expansion far away from the source. This allows us to do the post-Newtonian expansion in any gauge and to investigating the consequences of working with the weakest possible boundary condition that ensures that there is no incoming radiation at past null infinity. Making use of this, I will consider a Coulomb-like gauge and try to make the case that it is an interesting alternative to the usual harmonic gauge. Last but not least, this work paves the way to consider 1/c expansions around non-flat backgrounds. It is well-known that the covariant 1/c expansion works outside the context of a weak field expansion around flat space and so we would like to see if this can be used as a new approximation scheme in studying radiating sources.

Presenter: MUSAEUS, Jørgen (University of Edinburgh)

Session Classification: Poster session

Contribution ID: **99** Type: **not specified**

Radiation Reaction in de Sitter spacetime

Tuesday, 4 July 2023 15:40 (20 minutes)

I am interested in understanding radiation reaction(RR) and the post-Newtonian(PN) expansion in the presence of a cosmological constant. To this end, de Sitter spacetime provides a simple maximally symmetric background, where the in-in action that describes the RR can be computed. This in-in action has a natural interpretation through a 'doubled' static patch geometry associated with a particle. In particular, for a particle coupled to a scalar field in arbitrary dimensional de Sitter spacetime, we derive curvature corrections to the flat space RR action and the necessary counterterms for regularisation to all orders in the cosmological constant. The 'classical' part of the scalar RR force matches existing results in the literature (flat space as well as curvature corrections). At long times, our action describes the effect of Hawking radiation from the cosmological horizon.

Presenter: SHETYE, Omkar (International Centre for Theoretical Sciences (ICTS-TIFR), Bengaluru)

Session Classification: Poster session

Contribution ID: **100** Type: **not specified**

Electromagnetic tail and when it is negligible

Tuesday, 4 July 2023 15:40 (20 minutes)

We show that for the motion of elementary particles in vacuum metrics the DeWitt-Brehme equation can be reduced to the covariant form of the Landau-Lifshitz equation. Further we discuss the implications of this approach in the Schwarzschild and Kerr black hole metrics immersed into external uniform magnetic field. In the latter case one can observe energy gain of a radiating charged particle inside the black hole ergosphere, which comes at the expense of rotational energy of the black hole.

Presenter: TURSUNOV, Arman (Max Planck Institute for Radio Astronomy, Bonn)

Session Classification: Poster session

Contribution ID: **101** Type: **not specified**

Dipolar tidal effects in gravitational waves from scalarized black hole binary inspirals in quadratic gravity

Tuesday, 4 July 2023 15:40 (20 minutes)

As gravitational waves (GW) probe the strong field regime of gravity, they are an important tool for testing gravitational models. This requires an accurate description of the gravitational waveforms in modified gravity theories. In this work we focus on scalar Gauss Bonnet gravity (sGB), a promising extension of General Relativity (GR), to include finite size effects in the modelling of the inspiral of a black hole (BH) binary. sGB introduces on top of the Hilbert Einstein action, a topological invariant quadratic curvature term coupled to a scalar field, leading to the possibility of having black hole solutions with non zero scalar hair. We find that the scalar-induced tidal corrections related to the scalar Love number, contribute at the same PN order and scale the same with distance and frequency as the sGB correction to the gravitational wave (GW) phase. Finally, we investigate the dependency of the sGB correction and tidally induced correction on the physical properties of the binary and find that the tidal effects dominate over the sGB corrections for large separations of the black holes.

Presenter: VAN GEMEREN, Iris (Utrecht University, the Netherlands)

Session Classification: Poster session

Contribution ID: **102** Type: **not specified**

A perturbative approach to understanding ultrarelativistic motion using the Penrose limit

Tuesday, 4 July 2023 15:40 (20 minutes)

The local geometry around a null geodesic in an arbitrary spacetime resembles the geometry of a plane wave (PW) spacetime at leading order. This idea is called the Penrose limit. Families of curves that stay within this local neighbourhood of the null geodesic can be thought of as being "ultrarelativistic"in some suitable sense, and their motion is largely determined by the structure of the PW spacetime that results from the Penrose limit. Since PW spacetimes are highly symmetric, it is relatively easy to analyse the motion of a particular object in this PW spacetime. This talk describes how to appropriately define a family of ultrarelativistic objects, and how their equations of motion simply when mapped to the Penrose limit PW spacetime. Furthermore, I discuss a new perturbation theory, called the post plane-wave approximation (of which the Penrose limit is the leading order term) that can be used to simplify the equations of motion for ultrarelativistic objects.

Presenter: VASWANI, Aditya (Heidelberg University)

Session Classification: Poster session