Mathematical Methods for the General Relativistic Two-body Problem

11 Aug 2025–15 Aug 2025

August 7, 2025

Abstracts

TBA

12 Aug
9 am

Laura Bernard
Observatoire de Paris-PSL, France

TBA

Dynamical Tidal Resonances in EMRIs

14 Aug
9 am

Béatrice Bonga
Radboud University, Netherlands

Resonances are ubiquitous in nature. In this talk, I will focus on hierarchical triple systems comprising of an EMRI orbited by an external perturber. For such systems, resonances are the dominant way in which the perturber affects the EMRI. By probing their influence on the EMRI waveform, we can in principle extract information about the environmental tidal field of the EMRI system, albeit at the cost of a more complicated EMRI waveform model.

TBA

15 Aug
2 pm

Alexander Burke
University of Glasgow, UK

TBA

Fast EMRI Waveforms: Fast Waveform Generation for Asymmetric-mass Binaries

15 Aug
9 am

Christian Chapman-Bird
University of Birmingham, UK

Asymmetric-mass binary systems with mass ratios greater than 10, such as intermediate/extreme-mass-ratio inspirals (I/EMRIs), are information-rich gravitational-wave (GW) sources observable by both existing and future detectors, but their analysis requires accurate and efficient waveform models. Gravitational self-force techniques, combined with a two-timescale expansion, provide a viable route to achieving the required accuracy. In this talk, I will outline the current state of the FastEMRIWaveforms (FEW) framework, which leverages this theoretical foundation to generate million-cycle EMRI waveforms in less than a second using interpolation of pre-computed data and hardware acceleration techniques. As an example of FEW in action, I will present a recently-developed model for fully-relativistic waveforms for eccentric equatorial inspirals into spinning central objects at adiabatic order, and discuss methods for quantifying the impact of systematics on the model accuracy. I will conclude with an overview of future directions for FEW development, including batched waveform generation and the incorporation of post-adiabatic effects.

Hybrid Post-Newtonian/Self-force inspiral and Transition-to-plunge Waveforms

12 Aug
10 am

Geoffrey Compere
Université Libre de Bruxelles, Belgium

With the upcoming third-generation gravitational wave detectors comes the need of producing complete, faithful and fast-to-evaluate waveform models for asymmetric mass ratio black hole binaries. In this talk, based on work with Loïc Honet, Lorenzo Küchler and Adam Pound, l will explain how post-Newtonian and self-force results on the inspiral of quasi-circular compact binaries can be combined to produce waveforms that are more faithful than each method considered alone. After reviewing some key elements in the construction, I will display how the resulting hybrid waveforms compare with simulations from the SXS catalog and improve purely post-Newtonian waveforms and purely self-force waveforms. I will also show comparisons with SEOB waveforms which indicates that mismatches are comparable for mass ratios from 1 to 15. In the second part of the talk, I will discuss the multiscale framework suited to derive waveforms in the transition-to-plunge phase. I will present the implementation for quasi-circular binaries with primary spin at next-to-next-to-leading order. I will also explain how the choice of transition variable allows to improve the composite waveforms assembled from matching the inspiral and transition-to-plunge waveforms. The resulting waveforms will be finally compared with SXS simulations.

Building an Efficient EMRI Search Algorithm

15 Aug
10 am

Curt Cutler

Jet Propulsion Laboratory, USA

Building an efficient EMRI search algorithm is currently the greatest obstacle facing the gravitational-wave data analysts who are currently working to construct the full LISA data analysis pipeline. I describe the difficulties one faces in constructing an efficient EMRI search and then review past and ongoing efforts to overcome those problems. I also present my recent work on a Chebyshev-based, phenomenological template family, which adds another tool to our toolbox.

Metric Reconstruction on Kerr Spacetime in Lorenz Gauge

14 Aug
4.30 pm

Sam Dolan

The University of Sheffield, UK

I will describe progress towards calculating high-quality metric perturbation data: a key input for 2GSF/1PA calculations that will underpin accurate waveform modelling for LISA. The approach is based on metric reconstruction in Lorenz gauge from six Teukolsky-like variables that satisfy decoupled, separable equations in the frequency domain. At present, we have a general formulation for computing the non-static modes sourced by secondaries on generic (non-circular, non-equatorial) bound orbits, and implementation is underway. However, the static sector requires additional consideration. I will describe a new method that uses the fact that the secondary is confined to a worldline, which I call "Nature Adores a Vacuum". In principle, this method provides a way to calculate the metric perturbation entirely from homogeneous solutions, and without any knowledge of sources in the frequency domain.

This talk is based on collaborative work with Barry Wardell, Chris Kavanagh, Leanne Durkan and Kevin Cunningham.

Why Matter Matters: Astrophysical Environments of EMRIs

12 Aug
3.30 pm

Lisa Drummond

California Institute of Technology, USA

EMRIs are powerful probes of strong-field gravity and galactic nuclei. While often modeled in vacuum, real EMRIs form and evolve in complex astrophysical environments. This talk reviews the role of matter (including accretion disks, dark matter, and stellar backgrounds) in shaping EMRI dynamics and gravitational wave signals. I highlight recent progress and open questions, and discuss the implications for detection with LISA. I also explore the emerging connection between EMRIs and quasi-periodic eruptions (QPEs), whose timing may encode signatures of inspiraling compact objects interacting with accretion disks.

The Prospects and Challenges of Science with LISA EMRI Observations

11 Aug
10 am

Jonathan Gair

Albert Einstein Institute, Germany

In the dense stellar environments surrounding massive black holes in the centres of galaxies, a range of astrophysical processes can deposit compact stellar remnants on orbits that are tightly bound to the central black hole. These processes including stellar scattering (relaxation) in the stellar cusp, tidal splitting of binary star systems, tidal stripping of giant stars or in-situ formation within an accretion disc around the black hole. The subsequent evolution of these systems is dominated by gravitational wave emission which drives the stellar compact object to inspiral toward and eventually plunge into the central black hole. These extreme-mass-ratio inspirals (EMRIs) are a key source for the space-based gravitational wave detector LISA and have tremendous scientific potential for understanding the astrophysics of these systems, for probing the cosmological expansion history of the Universe and for testing the fundamental physical properties of these systems. In this talk I will describe our current understanding of how EMRIs might form, our expectations for the the events that we will observe with LISA and the science applications of these observations. I will then finish by discussing some of the significant challenges that LISA data analysis will pose which will have to be overcome if this science is to be realised.

TBA

13 Aug
2 pm

Anna Heffernan
University of Balearic Islands, Spain

TBA

Putting the Hype in Hyperbolic Black Hole Scattering

14 Aug
3.30 pm

Oliver Long
Albert Einstein Institute, Germany

The study of unbound binary-black-hole encounters provides a gauge-invariant approach to exploring strong-field gravitational interactions in two-body systems, which can subsequently inform waveform models for bound orbits. In this talk, I will motivate the study of black hole scattering, including the prospects for detecting these burst events. I will then present the current state-of-the-art in modelling such systems, highlighting results from the EOB, NR, PM, and SF approaches, and discussing how these methods complement one another.

The DDPC and EMRI Waveform Modelling: Structure, Roles, and Roadmap

13 Aug
2.30 pm

Phillip Lynch
Albert Einstein Institute, USA

As part of the LISA mission, ESA is developing the Distributed Data Processing Centre (DDPC), one of two independent ground segments responsible for processing data from the mission into a catalogue of gravitational wave sources. This talk will provide an overview of the DDPC's structure, focusing on the Coordination Units (CUs) and their respective responsibilities. Particular attention will be given to the Waveform CU (CU Wav), which is tasked with producing and validating gravitational waveform models, including those for Extreme Mass Ratio Inspirals (EMRIs). I will outline the current plans for the EMRI subunit within CU Wav, including anticipated timelines, deliverables, and opportunities for collaboration. This presentation aims to clarify how the DDPC will support and interact with the EMRI modelling community in preparation for the LISA mission.

The Hyperboloidal Framework in Black Hole Perturbation Theory

13 Aug
10 am

Rodrigo Panosso Macedo
Niels Bohr Institute, Denmark

Over the past decades, the hyperboloidal framework has established itself as a crucial strategy in black hole perturbation theory. The framework has its conceptual roots in Penrose's seminal work on the "Conformal Treatment of Infinity", providing a fundamental geometrical understanding of wave phenomena. Combined with robust numerical techniques from spectral methods, the hyperboloidal framework is a key approach to meet the demands of the upcoming era of high-precision gravitational wave astronomy. In this talk, I will review the main geometrical and numerical concepts of the framework, present examples of its applications in black hole perturbation theory, and discuss future directions, with a focus on the gravitational self-force programme.

Computational Advances in Self-force: Building a Bridge between Theory and Waveform Modeling

13 Aug
9 am

Zachary Nasipak
University of Southampton, UK

The multiscale self-force framework provides an efficient method for modeling compact binaries with disparate masses. However, its practical implementation requires a computationally intensive offline stage, in which self-force quantities are precomputed across a large domain of the orbital parameter space. This precomputed data serves as input for the subsequent online evolution of the inspiral, enabling accurate and efficient waveform generation. In this talk, I will outline how recent computational advances are bridging the gap between this theoretical framework and practical waveform models. I will review which specific self-force quantities need to be computed — including fluxes, secondary spin effects, and redshift corrections — and discuss the numerical infrastructure supporting their computation. In particular, I will highlight recent efforts to construct second-order perturbations in Kerr spacetime, which are necessary for achieving waveforms with subradian (i.e., first post-adiabatic) phase accuracy. I will also discuss key challenges that remain.

Second-order Self-force: State of Play

11 Aug
3.30 pm

Adam Pound

University of Southampton, UK

It is well understood that to achieve target accuracy for LISA, EMRI models must be carried to first post-adiabatic order (1PA) in a multiscale expansion. This requires solving at least part of the Einstein field equations at second perturbative order in the binary's mass ratio. Over the past 15 years, significant progress has been made in overcoming conceptual and technical challenges in this endeavour, leading to the production of a 1PA waveform model for nonspinning, quasicircular binaries in 2021. More recently, theoretical advances have been made to resolve errors in that model, and further progress has been made in extending them to the realistic case of a spinning, Kerr primary. In this talk I summarize the current state of play.

Fix the Frame, Resolve the Memory: The Bondi–Sachs Gauge in Black Hole Perturbation Theory

14 Aug
2 pm

Andrew Spiers

University of Nottingham, UK

Understanding gauge and frame dependence is crucial for comparing binary models and extracting physical observables. Black hole perturbation theory calculations are extending to second-order, where increased gauge dependence brings new challenges: gauge-invariant quantities at linear order become gauge-dependent at second-order, and nonlinear source terms can produce infrared divergences. Additionally, gravitational wave memory, a frame-dependent effect, appears at second order and will be detectable with next-generation detectors. In this talk, I briefly review second-order black hole perturbation theory, the Bondi–Sachs gauge, the BMS frame, and memory effects; by combining these elements, I construct a gauge invariant second-order field equation associated with an asymptotically flat gauge with the appropriate frame to extract the memory.

Memory and Hybridization for Connecting the Numerical and Analytical Two-body Problem

11 Aug
2 pm

Leo Stein

The University of Mississippi, USA

We need numerical solutions to the relativistic two-body problem where analytical methods break down: the late inspiral, merger, and onset of ringdown. I will first give a brief overview of the third numerical relativity waveform catalog from the SXS collaboration. But numerics have their own limitations, so to create a complete solution we need to combine numerical and analytical information into a "hybrid" solution. The process of hybridizing creates its own challenges: What gauges are we using? How do numerical and analytical parameters map onto each other? I will detail some challenges arising in hybridization, including the importance of gravitational memory and BMS frames.

Integrability of the Relativistic Two-body Problem

12 Aug
2 pm

Vojtech Witzany

Charles University in Prague, Czech Republic

Integrability is a useful property of conservative dynamical systems, as it ensures well-behaved evolution and allows the equations of motion to be separable in an appropriate set of variables. The conservative dynamics of two non-spinning compact objects are known to be integrable due to the symmetries of the system. However, once spin and possibly other "internal" degrees of freedom are introduced, the dynamics become more complex. For the system to remain integrable, these new degrees of freedom require additional integrals of motion, which are not guaranteed by any fundamental symmetry. Remarkably, various "hidden symmetries" exist that provide perturbative integrability in the large-mass-ratio and weak-field limits. However, an important question is also how (non-)integrability manifests in the physically relevant case of non-conservative evolutions, that is, binary inspirals. In this context, resonances play a central role, and I will touch upon this issue in addition to the topics mentioned above.

Probing Formation Channels of Extreme Mass-ratio Inspirals

Huan Yang

Tsinghua University, China

In this talk, I will discuss the measurements of eccentricity, inclination and componennt mass which provide critical information to distinguish different formation channels and probe detailed formation mechanisms. Focusing on the dry and wet extreme mass-ratio inspirals, we establish the theoretical expectation of these observables in each formation channel. We also discuss how their distributions can be used to probe disk lifetime and turbulence level of Active Galactic Nuclei, accretion patterns of massive black holes and distributions of stellar-mass black holes within nuclear star clusters.
