Analytical methods for gravitational waves (E8)

Non-Examinable (Graduate Level)

Tamanna Jain

A key ingredient for gravitational-wave observations is accurate theoretical predictions, which require source modelling in the framework of Einstein's theory of relativity. Due to the complexity of Einstein's field equations and the highly dynamical character of the physical systems under consideration, the calculation of such templates is a formidable challenge that requires the combination of analytic and numerical techniques. In this lecture course, we will discuss the theoretical foundations of two key analytic techniques: (i) post-Newtonian formalism, which describes slowly moving, weakly gravitating bound systems, and (ii) the Effective-One-Body formalism, which resums the post-Newtonian results to improve its accuracy. We will discuss the post-Newtonian expansion, the equations of motion, the generation of gravitational radiation, the resummation philosophy underlying Effective-One-Body, and the connection of these analytic models to gravitational-wave observations.

More specifically, the course will cover the following topics.

- The landscape of approximation methods for two-body problem in General Relativity, and the post-Newtonian expansion. [1 lecture]
- The post-Newtonian metric and the equations of motion, including the Einstein-Infeld-Hoffmann dynamics. [2 lectures]
- Conserved quantities, such as energy and angular momentum and gauge-invariant observables. [1 lecture]
- The generation of gravitational waves, the quadrupole formula, radiation reaction, and the inspiral chirp. [1 lecture]
- The effective-one-body formalism: the energy map, the deformed effective metric, and the conservative dynamics. [2 lectures]
- Effective-one-body waveforms, the inspiral–merger–ringdown construction, and calibration to numerical relativity. [1 lecture]

Prerequisites

This course assumes knowledge of Part III General Relativity. Some knowledge of Part III Black Holes and QFT will be helpful but not essential for following this course.

Literature

1. E. Poisson and C. M. Will, Gravity: Newtonian, Post-Newtonian, Relativistic. Cambridge University Press, 2014.
2. M. Maggiore, Gravitational Waves. Vols. 1 (Theory and Experiments) and 2 (Astrophysics and Cosmology), Oxford University Press, 2018.

3. L. Blanchet, Gravitational Radiation from Post-Newtonian Sources and Inspiralling Compact Binaries. Living Reviews in Relativity, 2014. See also https://arxiv.org/abs/1310.1528 .

4. A. Buonanno and T. Damour, Effective one-body approach to general relativistic two-body dynamics. Phys. Rev. D 59, 084006 (1999). See also https://arxiv.org/abs/gr-qc/9811091 .

5. T. Damour and A. Nagar, The Effective One Body description of the Two-Body problem. See https://arxiv.org/abs/0906.1769 .

Additional support

Two examples sheets will be provided and two associated examples classes will be given.