Astrophysical Sciences & Technology
Ph.D. Dissertation Defense

Brennan Ireland

Binary Black Holes in the Inspiral Regime: The Effect of Spins and Eccentricity on Spacetime Dynamics and Gravitational Radiation

Advisor: Manuela Campanelli

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Abstract:

Observations of black hole binaries via the emission of gravitational waves are one of the most exciting discoveries in physics in the past 50 years. The most generic black holes in nature are ones with spin, which may be misaligned with the orbital angular momentum of the binary, and also orbital eccentricity. This demands computationally inexpensive and accurate models of spinning binary black holes for hundreds of orbits as the binary inspirals.

This dissertation is divided into two projects, both of which focus on binary black holes with spin. In the first project, I construct and present a new global, fully analytic, approximate spacetime which accurately describes the dynamics of nonprecessing, spinning black hole binaries during the inspiral phase of the relativistic merger process. This approximate solution of the vacuum Einstein's equations can be obtained by asymptotically matching perturbed Kerr solutions near the two black holes to a post Newtonian metric valid far from the two black holes. This metric is then matched to a post Minkowskian metric even farther out in the wave zone. The procedure of asymptotic matching is generalized to be valid to all times, instead of a small group of initial hypersurfaces discussed in previous works. I then re-examine the asymptotic matching in the case of precession of the spins, allowing for generically spinning black hole binary metrics. This metric is well suited for long term dynamical simulations of spinning black hole binary spacetimes prior to merger, such as studies of circumbinary gas accretion which requires hundreds of binary orbits.

In the second project, I present a method for developing and calculating the gravitational waveforms from generically spinning, black hole binaries, with significant orbital eccentricity. I use the Lagrangian formulation of the post Newtonian equations of motion in the harmonic gauge for the generation of precessing, eccentric gravitational wave signatures. The equations of motion describing the black hole binary system are important to our understanding of fundamental relativity, for both the context of supermassive black holes and also stellar mass systems. If gravitational wave measurements are able to measure a non-negligible eccentricity from the binary, this may point to a unique formation model through relativistic 3-body interactions in dense stellar fields, which will impart occasionally significant eccentricity. This provides insight into the formation history of the binary, and explicitly the last dynamical effect the binary experienced before merging.