Astrophysical Sciences & Technology
Ph.D. Dissertation Defense

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Puncture Initial Data and Evolution of Black Hole Binaries with High Speed and High Spin

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Abstract:

This dissertation explores numerical models of the orbit, inspiral, and merger phases of black hole binaries. We focus on the astrophysically realistic case of black holes with nearly extremal spins, and on high energy black hole collisions. To study the evolution of such systems, we form puncture initial data by solving the four general relativity constraint equations using pseudo spectral methods on a compactified collocation point domain. The solutions to these coupled, nonlinear, elliptic differential equations represent the desired configuration at an initial moment. They are then propagated forward through time using a set of hyperbolic evolution equations with the moving punctures approach in the BSSNOK and CCZ4 formalisms. To generate realistic initial data with reduced spurious gravitational wave content, the background ansatz is taken to be a conformal superposition of Schwarzschild or Kerr spatial metrics. We track the punctures during evolution, measure their horizon properties, extract the gravitational waveforms, and examine the merger remnant. This new initial data is compared with the well known Bowen-York solutions, showing up to an order of magnitude reduction in the initial unphysical gravitational radiation signature. We perform a collision from rest of two black holes with spins near to the extremal value, in a region of parameter space inaccessible to Bowen-York initial data. We simulate nonspinning black holes in quasi-circular orbits, and perform high energy head-on collisions of nonspinning black holes to estimate the magnitude of the radiated gravitational energy in the limit of infinite momentum. We also evolve spinning black holes in quasi-circular orbits with unequal masses and different spin orientations. These models provide insight into the dynamics and signals generated by compact binary systems. This is crucial to our understanding of many astrophysical phenomena, especially to the interpretation of gravitational waves, which are expected to be detected directly for the first time within the next few years.