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Nicholas Metropolis Award for Outstanding Doctoral Thesis Work In Computational Physics Award Winner: Numerical Hydrodynamics at Gravity's Extremes

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Einstein's theory of general relativity is currently our best understanding of how gravity works. However, there are a very limited number of analytically-known solutions to the set of coupled, non-linear PDEs that make up the field equations. This means numerical methods are essential to understanding many interesting strong-field phenomena like black hole formation or the generation of gravitational waves. There has been great progress in the field of numerical relativity, especially in the past decade, not only in terms of being able to accurately simulate the mergers of compact objects like black holes or neutron stars, but beyond. I will discuss some recent work developing computational methods for simulating hydrodynamics coupled to Einstein gravity, and applying them to new regimes and problems in high-energy astrophysics, gravitational-wave astronomy, and theoretical general relativity. This includes developing flexible and robust methods for solving the constraint part of the Einstein field equations in order to specify initial data for an evolution, as well as an algorithm for efficiently evolving the full non-linear evolution equations when the solution is dominated by a known background solution. I will emphasize how these computational tools allow us to push the domain of numerical relativity into more extreme regimes of gravity: exploring mergers of black holes and neutron stars with high orbital eccentricity; simulating the extreme-mass-ratios involved in the tidal disruption of a star by a black hole using full relativity; and studying ultrarelativistic collisions, where the gravitational pull of kinetic energy is strong enough to form a black hole.