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Far-from-equilibrium relativistic hydrodynamics in neutron-star mergers

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In binary neutron-star mergers, violent changes in density drive the proton fraction out of equilibrium at timescales of milliseconds, comparable to those required by weak interactions to restore beta equilibrium. As a result, the pressure evolves out of phase with the density oscillations, giving rise to dissipative work that can be modeled as an effective bulk-viscous correction [1,2]. Near beta equilibrium, the correction to the pressure is known to follow an Israel-Stewart-like equation of motion, with transport coefficients determined by the equation of state outside beta equilibrium and weak-interaction rates [2]. However, it is not clear if that is the regime that actually occurs in neutron star mergers [3]. In this work, we shed new light on this problem in the following way. First, we show how this hydrodynamic description can be extended far from equilibrium, without approximations, allowing us to model neutron star matter that is arbitrarily far from beta equilibrium. We find that for realistic equations of state [4], the linear approximation in deviations from equilibrium commonly assumed in the field [1] has very limited applicability and, thus, realistic neutron star mergers are indeed in the far-from-beta equilibrium regime. We calculate the resulting far-from-equilibrium transport coefficients for equations of state that satisfy the latest constraints from multi-messenger observations from LIGO/VIRGO and NICER. Our results pave the way for novel systematic studies of viscous effects in numerical simulations of binary mergers [3].

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Category

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