The impact of fundamental physics in extreme core-collapse supernovae

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Abstract

Massive stars at the end of their life typically experience the gravitational collapse of their iron core, leading to supernova explosions. These events not only generate compact stellar remnants, but also regulate the dynamics of their host galaxies and their chemical composition by producing new elements. In the most extreme cases where fast rotation and strong magnetic fields are both present, such stellar exposions can give rise to the most energetic transient phenomena (including long gamma-ray bursts and hypernovae) and lead to the nucleosynthesis of r-process elements.

Despite the great advances in the theoretical modeling of extreme stellar explosions (in particular, magneto-rotational core-collapse supernovae), it remains unclear how the current uncertainties in our knowledge of the equation of state of nuclear matter can affect the dynamical and multi-messenger predictions of extreme core-collapse supernovae. Moreover, numerical codes often adopt different approximations for fundamental physical ingredients such as neutrino-matter interactions and general relativistic effects, thus making more difficult to produce reliable quantitative estimates.

This work investigates the impact of modeling approximations in axisymmetric simulations of magnetorotational supernova explosions, incorporating magnetohydrodynamics, neutrino-matter interactions, nuclear equation of states, and the effects of general relativity. By applying different configurations (routinely used in the literature) using the same stellar progenitor, we quantify the sensitivity of key physical outcomes to these approximations. These study allows us to not only gauge the uncertainties of current state-of-the-art models of core-collapse supernovae, but also improve their quantitative estimates of gravitational waves and neutrino emission, the dynamics of the explosion, and the thermodynamic conditions where explosive nucleosynthesis occurs.