Physical, Numerical, and Computational Challenges of Modeling Neutrino Transport in Core-Collapse Supernovae

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Core-collapse supernovae (CCSNe), the explosive evolutionary end stage of massive stars, are key sites of heavy-element production. They emit electromagnetic radiation, neutrinos, and gravitational waves, which can provide clues to the physical processes operating in and driving these events. Computational models play an essential role in sharpening our understanding of the supernova explosion mechanism and predicting observational signatures. CCSNe are truly multiphysics events, and their modeling involves solving coupled systems of nonlinear partial differential equations, governing the evolution of reacting fluids, gravitational and electromagnetic fields, and neutrinos. Due to their weak coupling with matter, neutrinos demand a kinetic description, which contributes to the large computational cost of supernova models. In this talk I will motivate the computational study of CCSNe to address fundamental questions in nuclear astrophysics, provide a summary of models for neutrino transport, emphasizing challenges faced when developing numerical methods to approximate solutions to the equations, and discuss our efforts within the U.S. Department of Energy's (DOE) Exascale Computing Project to develop computational tools to model CCSNe utilizing the resources available at DOE leadership computing facilities.