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Computational Astrophysics at the Bleeding Edge: Simulating Core Collapse Supernovae

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Core collapse supernovae are the single most important source of elements in the Universe, dominating the production of elements between oxygen and iron and likely responsible for half the elements heavier than iron. They result from the death throes of massive stars, beginning with stellar core collapse and the formation of a supernova shock wave that must ultimately disrupt such stars. Past, first-principles models most often led to the frustrating conclusion the shock wave stalls and is not revived, at least given the physics included in the models. However, recent progress in the context of two-dimensional, first-principles supernova models is reversing this trend, giving us hope we are on the right track toward a solution of one of the most important problems in astrophysics. Core collapse supernovae are multi-physics events, involving general relativity, hydrodynamics and magnetohydrodynamics, nuclear burning, and radiation transport in the form of neutrinos, along with a detailed nuclear physics equation of state and neutrino weak interactions. Computationally, simulating these catastrophic stellar events presents an exascale computing challenge. I will discuss past models and milestones in core collapse supernova theory, the state of the art, and future requirements. In this context, I will present the results and plans of the collaboration led by ORNL and the University of Tennessee.