Extreme-scale Simulation of Supernovae and Magnetars from Realistic Progenitors
Year 3 - CY2020 Allocation Renewal

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Project Status Summary:

Core-collapse supernovae (CCSNe) are the most extreme laboratories for nuclear physics in the universe. Stellar core collapse and the violent explosions that follow give birth to neutron stars and black holes, and in the process synthesize most of the elements heavier than helium throughout the universe. The behavior of matter at supranuclear densities is crucial to the CCSN mechanism, as are strong and weak interactions. Beyond Standard Model behavior of neutrinos may also impact the CCSN mechanism. Despite the key role CCSNe play in many aspects of astrophysics, and decades of research effort, *we still do not fully understand the details of the physical mechanism that causes these explosions.* This leaves frustratingly large uncertainty in many key aspects of our theoretical understanding of the universe, and also makes it difficult to constrain uncertain nuclear physics with data from CCSNe.

Our INCITE project is an end-to-end, multi-year investigation of CCSNe that includes the effects of rotation, magnetic fields, and progenitor asphericity. So far we have 1) Executed a high-fidelity parameter study of 3D magnetorotational CCSNe. We explored the impact of rotation and magnetic fields on the CCSN mechanism by varying the rotation rate and field strength of the initial conditions across multiple 3D simulations. 2) Simulated 3D iron core collapse in massive stars. This includes the first-ever 3D simulation of a CCSN progenitor to include rotation and magnetic fields. We have made significant progress in improving our simulation application for this effort. 3) Executed the highest-resolution, high-fidelity global simulation of magnetorotational turbulence in CCSN ever. We are now analyzing this simulation in detail and comparing it to lower-resolution simulations. 4) Extended our 3D magnetorotational CCSN simulations to late times, nearing 500 ms post-bounce.

During the remainder of Year 2 and in Year 3, we will pursue the following goals. 1) Execute a high-resolution *global* simulation of the magnetorotational instability and dynamo in the proto-neutron star. 2) Simulate additional 3D magnetorotational CCSN progenitors to the point of core collapse. 3) Carry out additional CCSN mechanism simulations using the 3D progenitors produced as part of this project using newly-improved neutrino physics. 4) Execute a magnetorotational CCSN parameter study using several different progenitor masses with state-of-the-art physical fidelity on *Theta*.