CORE-COLLAPSE SUPERNOVA SIMULATIONS: SIMULATING THE BRIGHTEST OBJECTS IN THE SKY AND THE SOURCE OF LIFE'S BUILDING BLOCKS

Allocation: Illinois/1,000 Knh
PI: Roland Haas[1]
Co-PIs: Edward Seidel[1], Luke Roberts[2], Philipp Moesta[3], Eliu Huerta[4]
Collaborators: Erik Schnetter[5], Christian Ott

[1]University of Illinois at Urbana-Champaign
[2]Michigan State University
[3]University of California, Berkeley
[4]National Center for Supercomputing Applications
[5]Perimenter Institute for Theoretical Physics

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EXECUTIVE SUMMARY

Core-collapse supernovae explosions are cosmic engines that enrich the interstellar medium with the ashes of thermonuclear fusion inside massive stars. Their shock waves can shut off and trigger star formation and regulate the gas budget of galaxies. They are the birth sites of neutron stars and stellar mass black holes. In this project, we aimed to understand the influence of properties of the star just before the onset of explosion on the supernova and the signals that will be observed from the next supernova in the Milky Way.

RESEARCH CHALLENGE

Supernovae play a crucial role in the evolution of galaxies such as the Milky Way, and understanding the mechanism that makes them explode is of key interest to astronomers and astrophysicists.

METHODS & CODES

Our simulation code, Zelmani, is built on the Cactus framework and uses Berger–Oliger-type adaptive mesh refinement with full subcycling in time, HDF5 output for all data, hybrid OpenMP+MPI parallelization, and SIMD vectorization for the spacetime evolution. The magnetohydrodynamics use high-resolution, shock-capturing finite volume methods, and the neutrino transport code ZelmaniM1 currently employs an analytic closure.

RESULTS & IMPACT

We have published a first set of results in [1] where we present a study of the progenitor dependence of a three-dimensional neutrino mechanism of core-collapse supernovae. Our results suggest a complex, nonmonotonic dependence on progenitor parameters necessitating more detailed numerical studies to fully understand these effects and hinting at a complex interplay between multiple proposed explosion mechanisms.

WHY BLUE WATERS

Without Blue Waters, this research would have been impossible. Fully three-dimensional general-relativistic radiation-magnetohydrodynamic simulations are simply too demanding of computational resources for any but a leadership-class facility to support them. Our simulations require the use of hundreds of compute nodes to provide sufficient memory for the simulation's state vector. The exceptional speed of Blue Waters' network lets us scale to the number of nodes required.

PUBLICATIONS & DATA SETS

Ott, C.D., et al., The Progenitor Dependence of Core-collapse Supernovae from Three-dimensional Simulations with Progenitor Models of 12–40 $M_\odot$. *Astrophys.J.,* 855 (2018). DOI:10.3847/2041-8213/aaa967.

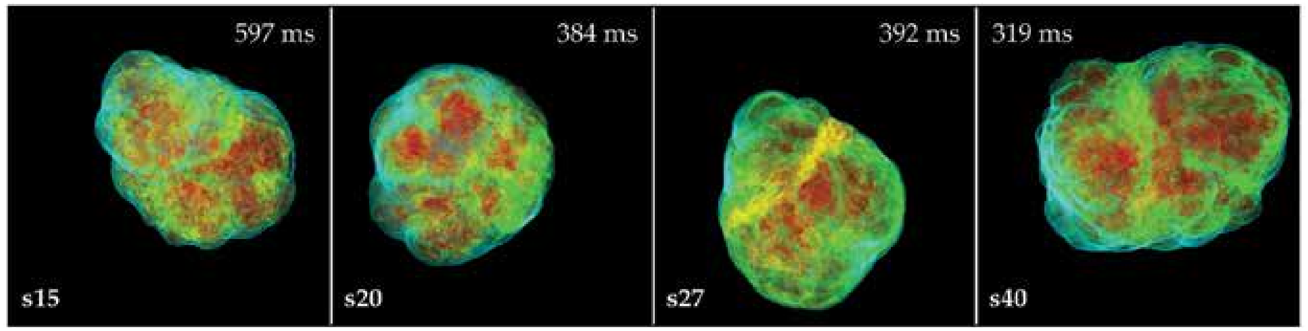

Figure 1: Volume rendering of the strongly aspherical supernova shock (in blue) for different progenitor stars at the end of the simulations. Yellow and red colors indicate hotter gas behind the shock. Figure taken from [1].

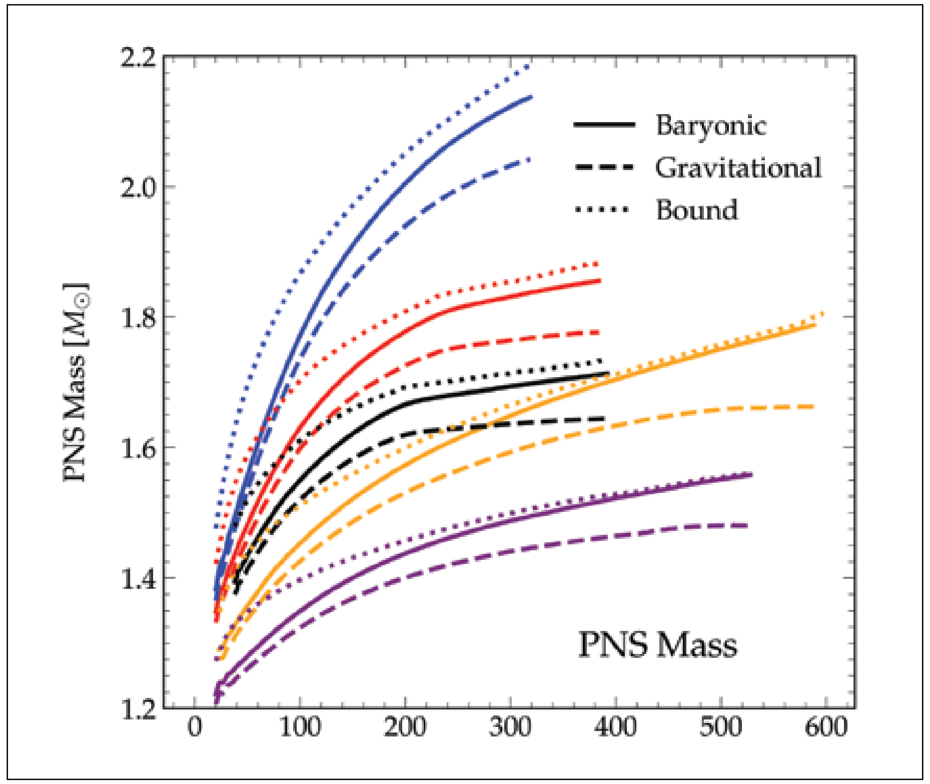

Figure 2: The mass of the neutron star forming at the center of the supernova for the different progenitor stars simulated in [1]. The highest mass simulation (in blue) is still accreting at 0.45 solar masses per second and will likely collapse to a black hole.