Three-Dimensional Hydrodynamic Core-Collapse Supernova Simulations for an 11.2 $M_\odot$ Star with Spectral Neutrino Transport

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Core-collapse supernovae have long drawn the attention of astrophysicists because they have many aspects playing important roles in astrophysics. They are the mother of neutron stars and black holes; they play an important role for acceleration of cosmic rays; they influence galactic dynamics triggering further star formation; they are gigantic emitters of neutrinos and gravitational waves. They are also a major site for nucleosynthesis, so, naturally, any attempt to address human origins may need to begin with an understanding of core-collapse supernovae.

Ever since the first numerical simulation of Colgate & White (1996), the neutrino-heating mechanism, in which a stalled bounce shock is revived by neutrino energy deposition to trigger explosions, has been the working hypothesis of supernova theorists for these ~50 years. However, one important lesson we have learned from the pioneering simulations that implemented the best input physics and numerics to date, is that the mechanism fails to blow up canonical massive stars in spherical symmetric (1D) simulations. Pushed by mounting supernova observations of the blast morphology, it is now almost certain that the breaking of the spherical symmetry is the key to solve the supernova problem.

In fact, the neutrino-driven explosions have been obtained in the following state-of-the-art two-dimensional (2D) simulations. Using the MuDBaTH code which includes one of the best available neutrino transfer approximations, Buras et al. (2006) firstly reported explosions for a non-rotating low-mass (11.2 $M_\odot$) progenitor of Woosley et al. (2002), and then for a 15 $M_\odot$ progenitor of Woosley & Weaver (1995) with a moderately rapid rotation imposed by Marek & Janka (2009).

To go up the ladders beyond 2D simulations, we explore in this study possible 3D effects in the supernova mechanism by performing 3D, multigroup, radiation-hydrodynamic core-collapse simulations. For the multigroup transport, the IDSA scheme (Liebendörfer et al. (2009)) is implemented, which can be done rather in a straightforward manner by extending our 2D modules to 3D.

We focus here on the evolution of the 11.2 $M_\odot$ star. By comparing with our 1D and 2D results, we study how the increasing multi-dimensionality could affect the postbounce supernova dynamics.

In agreement with previous study, our 1D model does not produce explosions for the 11.2 $M_\odot$ star, while the neutrino-driven revival of the stalled bounce shock is obtained both in the 2D and 3D models. Their result indicates that violent convective matter motions promote the neutrino heating for successful explosions.

For detail, see the original paper of Takiwaki et al. (2012).

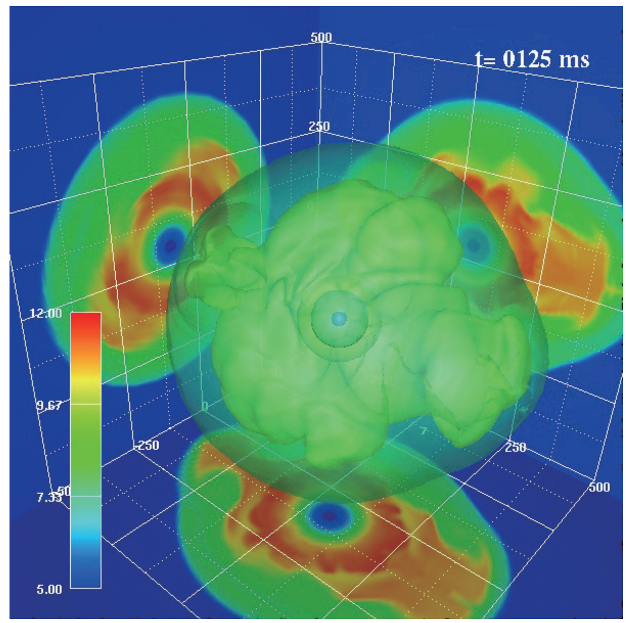

Figure 1: Time snapshot of the 3D model. The surfaces of constant entropy are depicted in the center and cutted colour contour of entropy is pasted on the side walls.

References

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