*Death of Massive Stars: Supernovae and Gamma-Ray Bursts*
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# 3D hydrodynamic core-collapse SN simulations for an 11.2 $M_{\odot}$ star with spectral neutrino transport

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**Abstract.** We have performed three-dimensional (3D) hydrodynamical simulations of core-collapse supernovae (SNe) with multigroup neutrino transport to study non-axisymmetric effects in the context of neutrino heating explosion mechanism. By comparing one- (1D) and two dimensional (2D) results with those of 3D, we study how the increasing spatial multi-dimensionality affects the postbounce SN dynamics. The calculations were performed with an energy-dependent treatment of the neutrino transport that is solved by the isotropic diffusion source approximation scheme. In agreement with previous studies, our 1D model does not produce explosions for the $11.2M_{\odot}$ star, while the neutrino-driven revival of the stalled bounce shock is obtained both in the 2D and 3D models. Our results show that convective matter motions below the gain radius become much more violent in 3D than 2D, making the neutrino luminosity larger for 3D. Enhanced by the large neutrino luminosity, the shock of the 3D model expands faster than that of the 2D. Our results show that the evolution of the shock is sensitive to the employed numerical resolutions. To draw a robust conclusion, 3D simulations with much higher numerical resolution and more advanced treatment of neutrino transport and gravity is needed.

**Keywords.** Supernovae:general, neutrinos, hydrodynamics

## 1. Introduction

Pushed by mounting observations of the SN blast morphology (e.g., Wang *et al.* 2001, Maeda *et al.* 2008), it is now almost certain that the breaking of the spherical symmetry is the key to solve the SN problem. So far, a number of 2D (axi-symmetric) hydrodynamic simulations have shown that hydrodynamic motions associated with convective overturn (e.g., Burrows *et al.* 1995) and the Standing-Accretion-Shock-Instability (SASI, e.g., Blondin *et al.* 2003) can help the onset of the neutrino-driven explosion.

It is natural to wonder how 3D convection affects the explosion. Nordhaus *et al.* (2010) argued that the critical neutrino luminosity for producing neutrino-driven explosions becomes smaller in 3D than 2D (an objection was proposed by Hanke *et al.* 2011). Encouraged by that work, we explore in this study possible 3D effects in the SN mechanism by performing 3D, multigroup, radiation hydrodynamic core collapse simulations.

## 2. Result

We focus here on the evolution of an $11.2M_{\odot}$ star of Woosley *et al.* (2002). Figure 1 shows the blast morphology for our 1D (left), 2D (middle), and 3D (right) model,

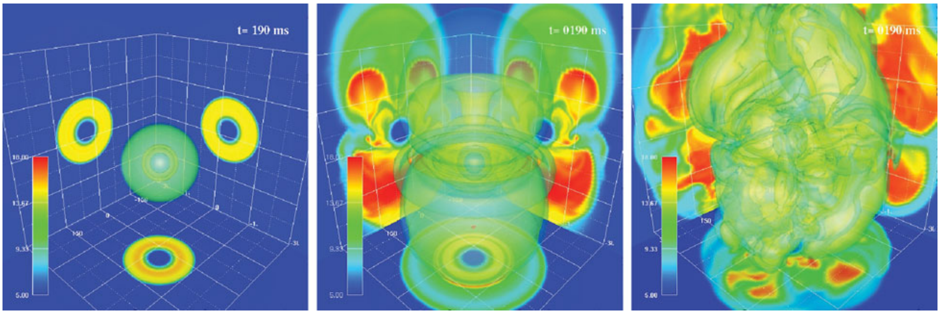


**Figure 1.** Blast morphology for 1D (left), 2D (middle), and 3D (right) model.

respectively. The shock of the 1D has already stalled but that of the 2D and 3D has not. The matter in the 2D and 3D receives neutrino heating promoted by the convective overturn and SASI.

We compare the evolution of the shocks in the left panel of Figure 2. The 1D and the other models are completely different. The convection significantly affects the shock. The shock of the 3D model goes faster than that of the 2D since the neutrino luminosity of the 3D is larger than the 2D as shown in the right panel of Figure 2.

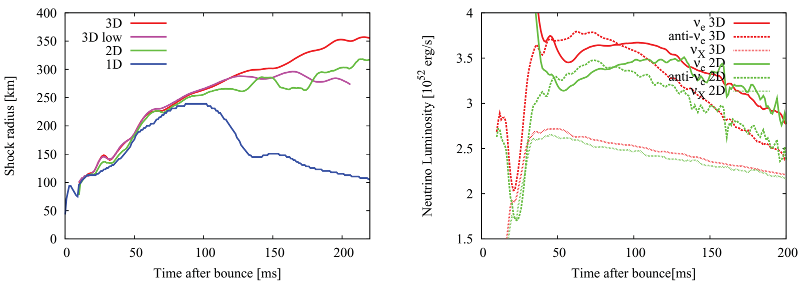


**Figure 2.** *Left*: Evolution of the average shock radius. *Right*: Evolution of the neutrino luminosity. While the red line is the 3D model with the zone of $320(r)$x$64(\theta)$x$128(\phi)$, the green line is the 2D axi-symmetric model with the zone of $320(r)$x$64(\theta)$ and the blue line is the 1D spherical model with a radial zone of $320(r)$. The purple line corresponds to the 3D low-resolution model of $200(r)$x$32(\theta)$x$64(\phi)$

Our results show that the evolution of the shock is sensitive to the employed numerical resolution. To draw a robust conclusion, 3D simulations with much higher numerical resolution are necessary.

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