Self-consistent two-dimensional core-collapse simulations of SN1987A progenitor

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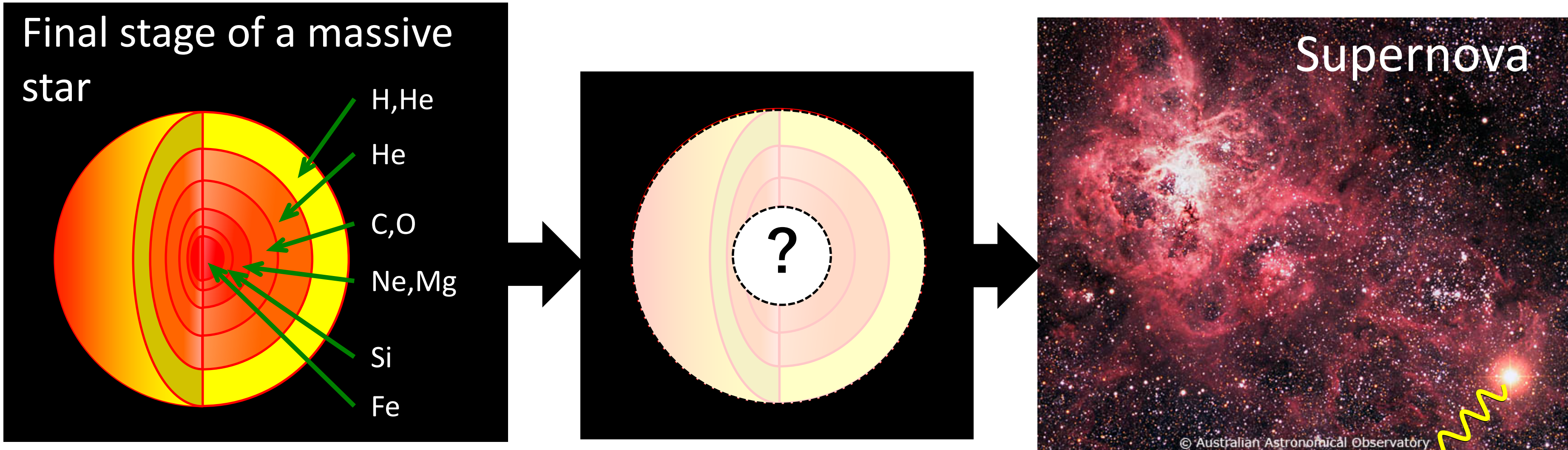
Final stage of massive stars to core-collapse SN (CCSN)



Basic equations：

$$\frac{d\rho}{dt} + \rho \nabla \cdot \mathbf{v} = 0$$

$$\rho \frac{d\mathbf{v}}{dt} = -\nabla P - \rho \nabla \Phi$$

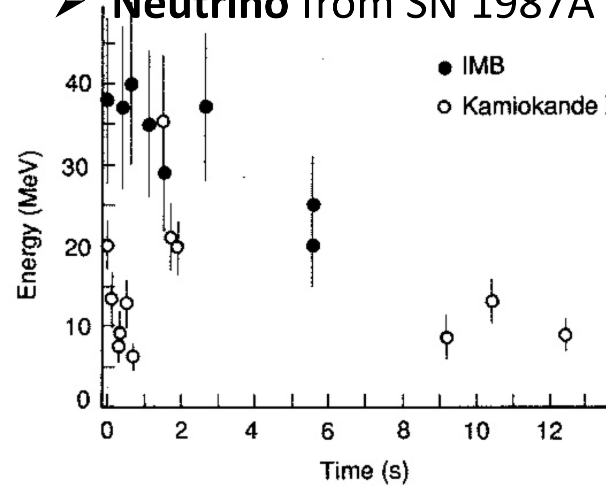
$$\frac{\partial e^*}{\partial t} + \nabla \cdot [(e^* + P)\mathbf{v}] = -\rho \mathbf{v} \cdot \nabla \Phi + Q_E$$

$$\frac{dY_e}{dt} = \Gamma_N$$

Energy and electron fraction change due to neutrino interactions.

$$\triangle \Phi = 4\pi G \rho$$ + EOS.

➢ **Neutrino** from SN 1987A



Explosion energy by numerical simulations (~10^{50}erg) does not reach typical explosion energy (~10^{51}erg).

Numerical scheme in this work

Initial condition：14 + 9 solar-mass model reported in Urushibata et al. (2018), MNRAS.
The model can nicely explain some observational features of SN1987A !
(e.g., the red-to-blue evolution in the HR diagram, the total mass inferred from nucleosynthesis observations)

Neutrino radiation-hydrodynamic code: Takiwaki et al. (2012) ApJ,Kotake et al. (2018) ApJ

- Hydro part: HLLE scheme Takiwaki et al. (2014) ApJ
- Radiation part：Isotropic-Diffusion-Source-Approximation (IDSA scheme)
  : Liebendoerfer et al (2009) ApJ, Kotake et al. (2018), ApJ

- Strangeness contribution (Melson et al. 2015)

$$g_a^s = -0.15 \pm 0.09$$

(e.g., Ahrens+(1987), Golan+(2013))

$$g_a^s = 0, -0.1, -0.2$$

- Resolution dependence

2D simulations

r = 0 ~ 100,000 km

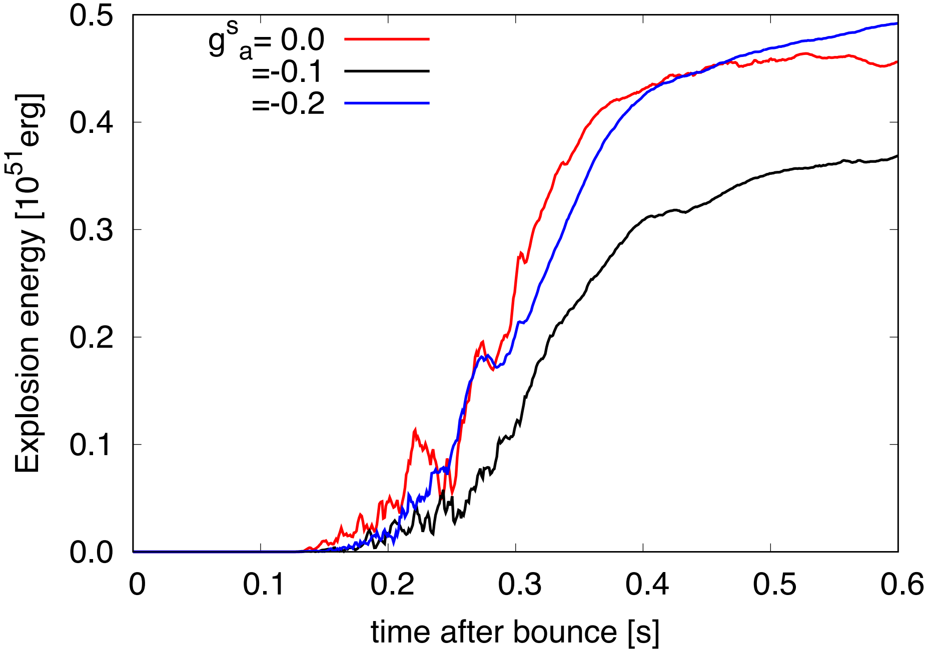
θ = 0 ~ π

$$n(\theta) = 64, 128, 256$$

Numerical Results: Explosion dynamics

- $\mathbf{g_a^s = 0, -0.1, -0.2}$

✓ "g_a^s" leads to the increase in the explosion energy only after the later postbounce phase (~ 400 ms p.b.) .



- $\boldsymbol{n(\theta) = 64, 128, 256}$

✓ Higher angular resolution assists the increase in the explosion energy.