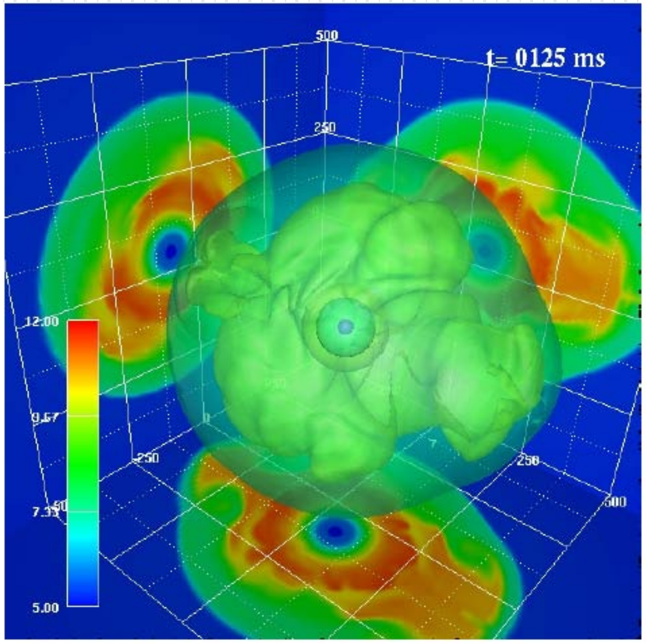
超新星爆発の３Ｄシミュレーション

Takiwaki, T., Kotake, K., & Suwa, Y. 2011, submitted to ApJ; arXiv:1108.3989
and recent result

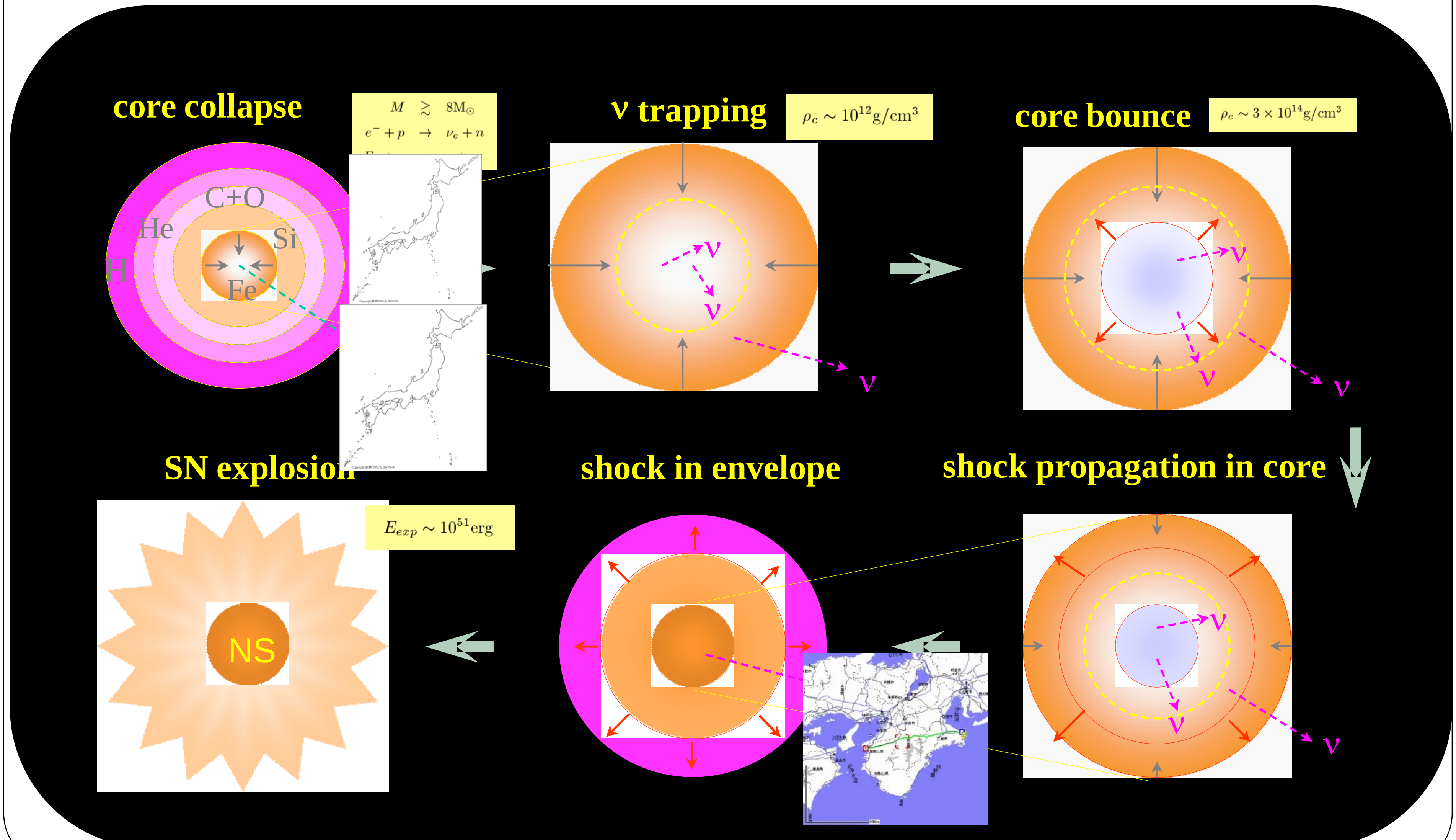


Tomoya Takiwaki

National Astronomical Observatory of Japan

HPCI researcher

Supernovae
neutrino driven explosion

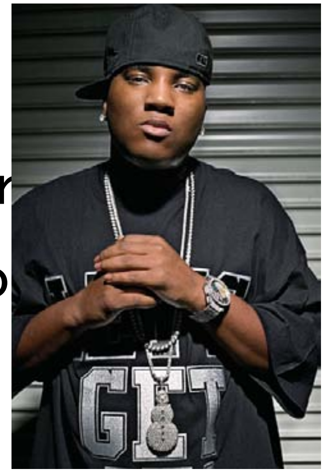


History of supernovae studies

- ase(Colgate & 6)

  nulation

  ce of neutr



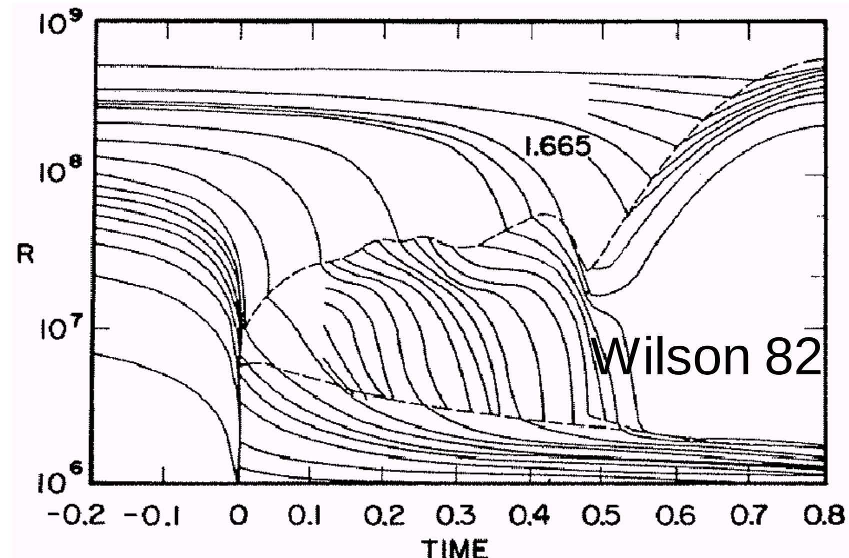
- Young Phase (Wilso

  sion

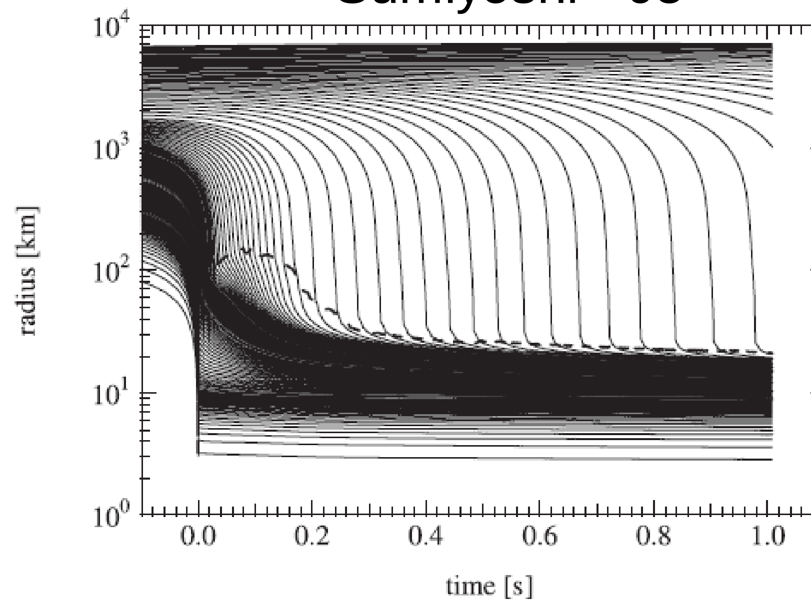
- hi et al. ’05)

  imulation could

  the supernovae



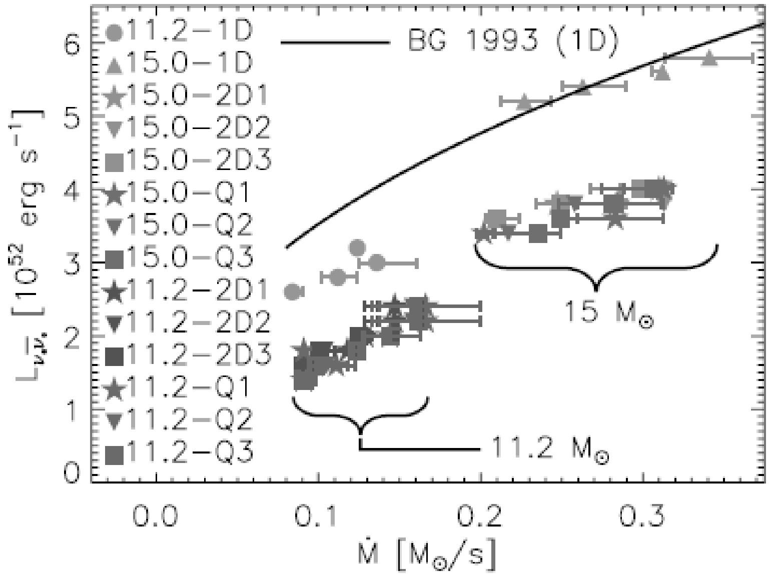
Sumiyoshi+ 05



Supernovae modelers devote about 50 years to solve neutrino transport with adequate accuracy.

Breakthrough by 2D simulations

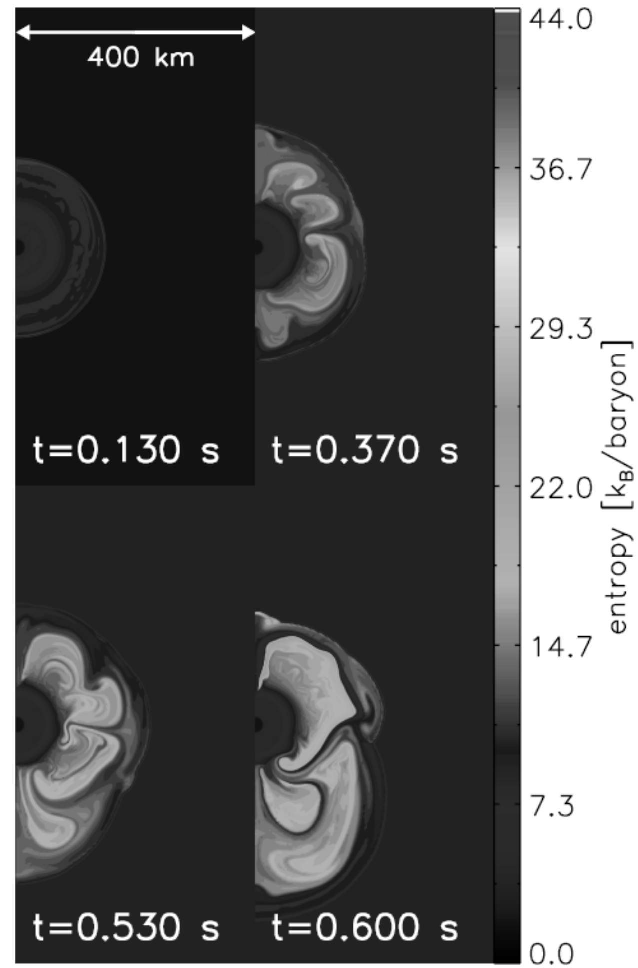
Luminosity



Mass accretion rate

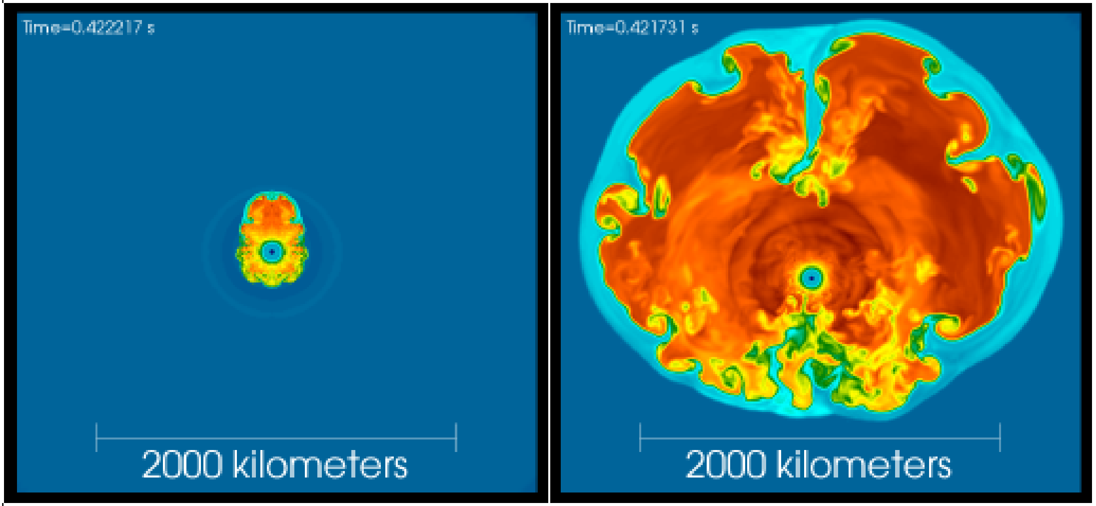
In 2D simulations, the neutrino luminosity required for reviving shock is reduced !

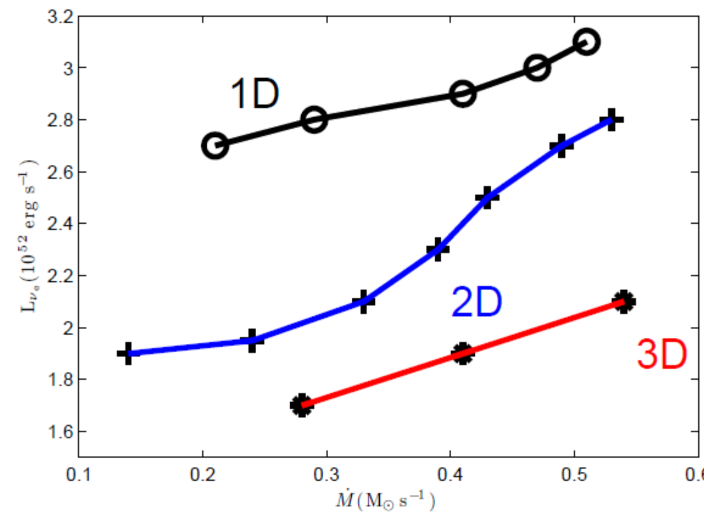
Murphy & Burrows 2008



Is 3D simulation key for successful explosion?

Nordhaus et al. 2010





2D Cylindrical(Left) vs 3D Cartesian

(Right) Gray Luminosity Adaptive mesh refinement is used

3D simulation require less luminosity compared to 2D!

Counter argument is presented by Hanke et al 2011. 3D model might not be always good for explosion.

Under a realistic situation, is 3D good or bad?

Anyway… nature is 3D.

The feature of our study

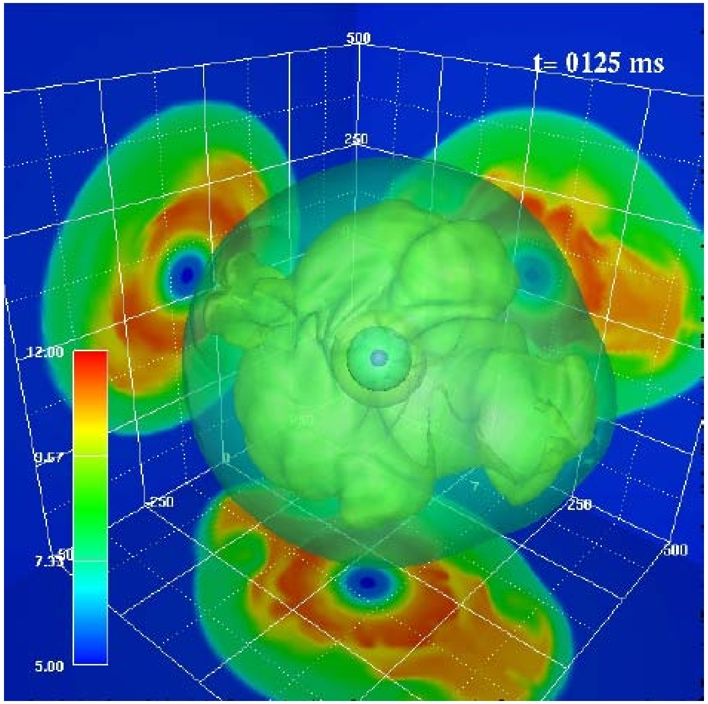
- previous works

  2D with spectral neutrino transport (Buras 2006, Marek &Janka 2009, Suwa et al. 2010) or

  3D with simple assumption of neutrino luminosity (Iwakami et al 2008, Nordhaus et al. 2010)

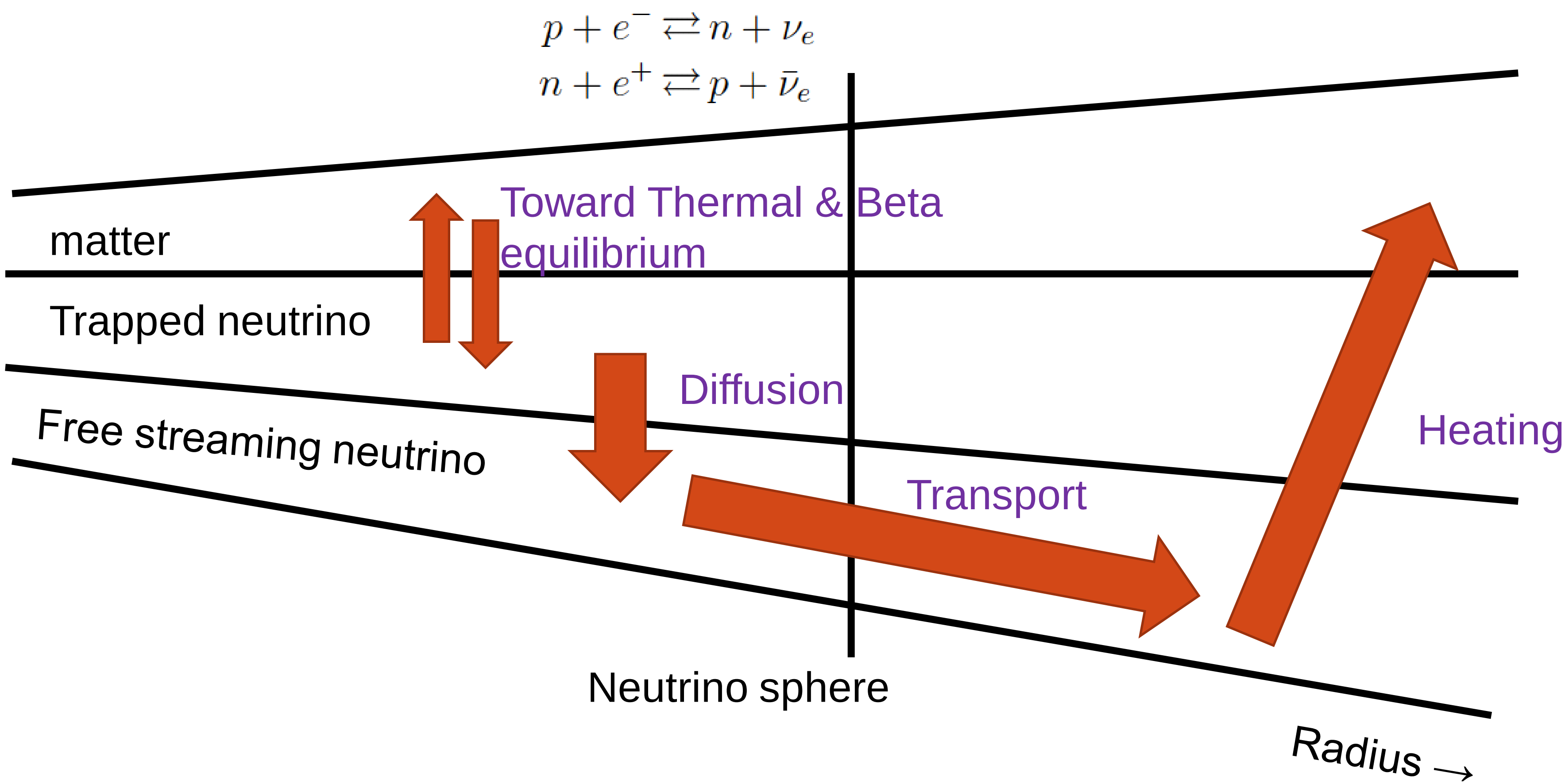
- this work

  combining with good feature of the previous work, 3D simulation with spectral neutrino transport is presented!



Takiwaki, T., Kotake, K., & Suwa, Y. 2011, submitted to ApJ; arXiv:1108.3989

Neutrino transport, concept



IDSA(isotropic diffusion source approximations)
Dividing neutrino into two parts, trapped and free streaming
For v_X, simple leakage scheme

Neutrino transport, trapped part

$$\frac{df}{cdt} + \mu\frac{\partial f}{\partial r} + \left[\mu\left(\frac{d\ln\rho}{cdt} + \frac{3v}{cr}\right) + \frac{1}{r}\right](1-\mu^2)\frac{\partial f}{\partial \mu}$$
$$+ \left[\mu^2\left(\frac{d\ln\rho}{cdt} + \frac{3v}{cr}\right) - \frac{v}{cr}\right]E\frac{\partial f}{\partial E}$$
$$= j(1-f) - \chi f + \frac{E^2}{c(hc)^3}$$
$$\times \left[(1-f)\int Rf' d\mu' - f\int R(1-f')\, d\mu'\right].$$

f(x,y,z,E,theta,phi)
6 dimensional varable

Trapped Particle

Angular integration

Diffusion term

$$\frac{df^{t}}{cdt} + \frac{1}{3}\frac{d\ln\rho}{cdt}E\frac{\partial f^{t}}{\partial E} = j - (j+\chi)f^{t} - \Sigma.$$

Energy integration

$$Y^{t} = \frac{m_b}{\rho}\frac{4\pi}{(hc)^3}\int f^{t}E^2 dE d\mu$$
$$Z^{t} = \frac{m_b}{\rho}\frac{4\pi}{(hc)^3}\int f^{t}E^3 dE d\mu,$$

$$\frac{\partial}{\partial t}(\rho Y^{t}) + \frac{\partial}{r^2\partial r}(r^2 v\rho Y^{t})$$
$$= m_b\frac{4\pi c}{(hc)^3}\int [j - (j+\chi)f^{t} - \Sigma]E^3 dE.$$

Determined parameter for Fermi-Dirac distribution by Y and Z

$$f_l^{t}(E) = \{\exp[\beta_l(E - \mu_l)] + 1\}^{-1},$$

Neutrino transport, free streaming part

$$
\begin{aligned}
&\frac{df}{cdt} + \mu\frac{\partial f}{\partial r} + \left[\mu\left(\frac{d\ln\rho}{cdt} + \frac{3v}{cr}\right) + \frac{1}{r}\right]\left(1-\mu^2\right)\frac{\partial f}{\partial \mu} \\
&+ \left[\mu^2\left(\frac{d\ln\rho}{cdt} + \frac{3v}{cr}\right) - \frac{v}{cr}\right]E\frac{\partial f}{\partial E} \\
&= j\left(1-f\right) - \chi f + \frac{E^2}{c\left(hc\right)^3} \\
&\times\left[\left(1-f\right)\int Rf' d\mu' - f\int R\left(1-f'\right)d\mu'\right].
\end{aligned}
$$

f(x,y,z,E,theta,phi)
6 dimensional varable

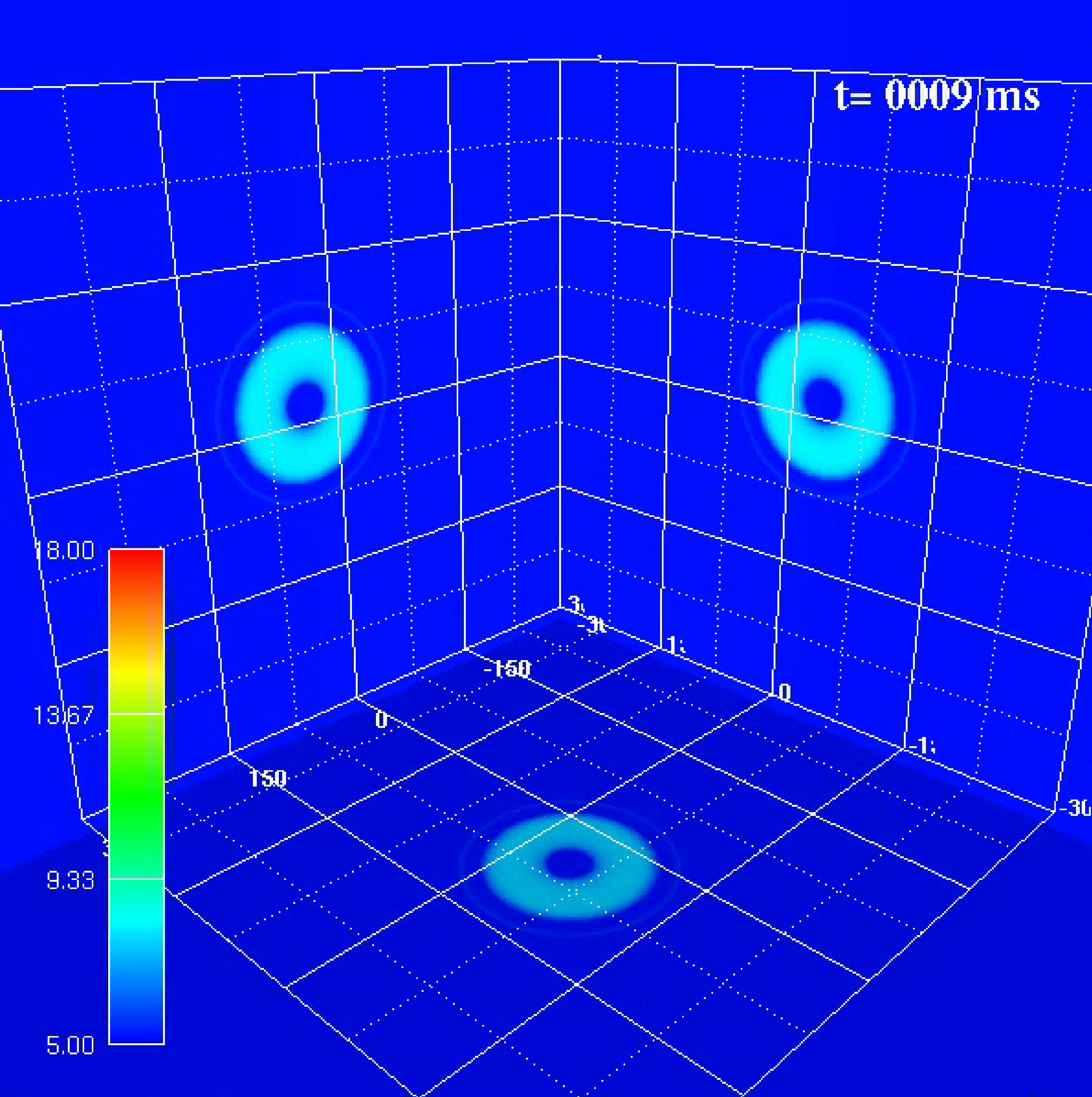
Weak coupling

$$
\frac{\partial \hat{f}^s}{c\partial \hat{t}} + \hat{\mu}\frac{\partial \hat{f}^s}{\partial r} + \frac{1}{r}\left(1-\hat{\mu}^2\right)\frac{\partial \hat{f}^s}{\partial \hat{\mu}} = -\left(\hat{j} + \hat{\chi}\right)\hat{f}^s + \hat{\Sigma}.
$$

Angular integration is performed.

Different from the original IDSA,
We treat the LHS explicitly and the RHS implicitly.

Newton Method is used for solving RHS.
No message passing during the iteration.



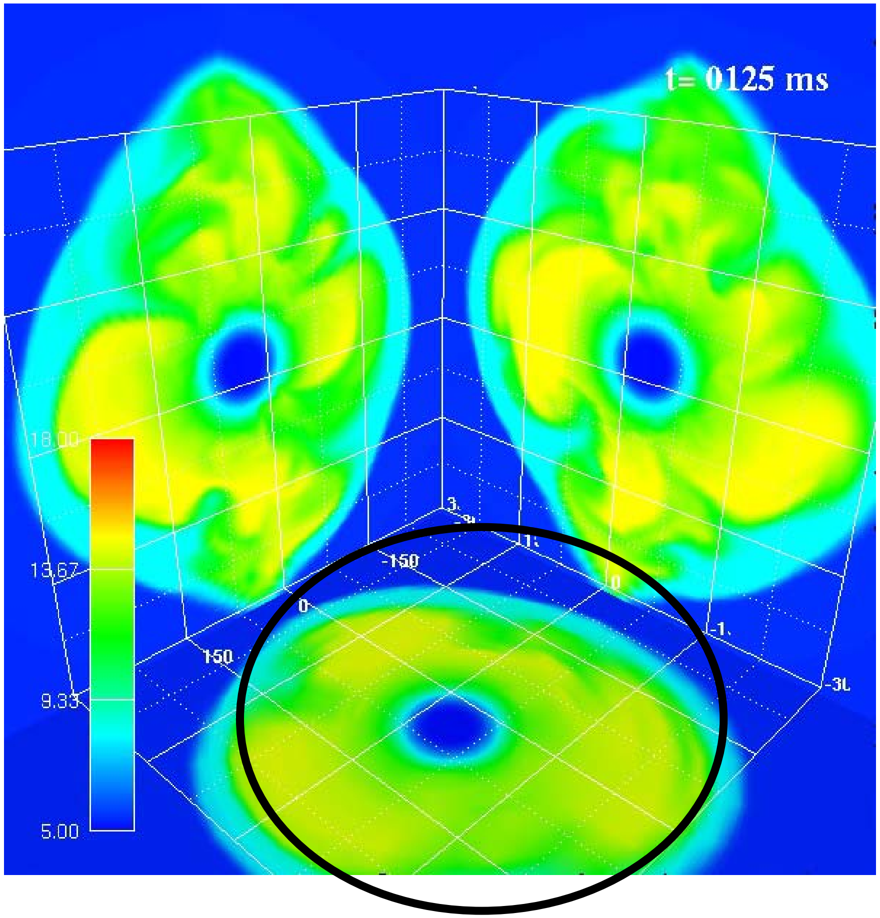
Result!

11.2M_s

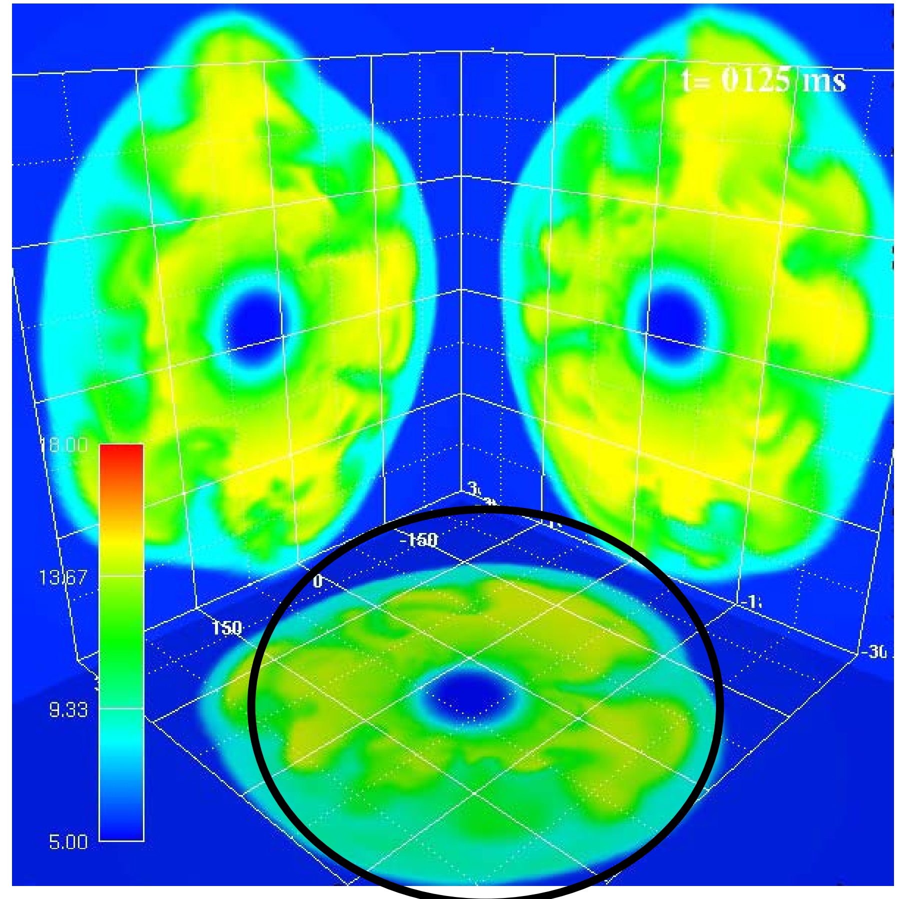
LS EOS

(K=180MeV)

Difference of Resolution



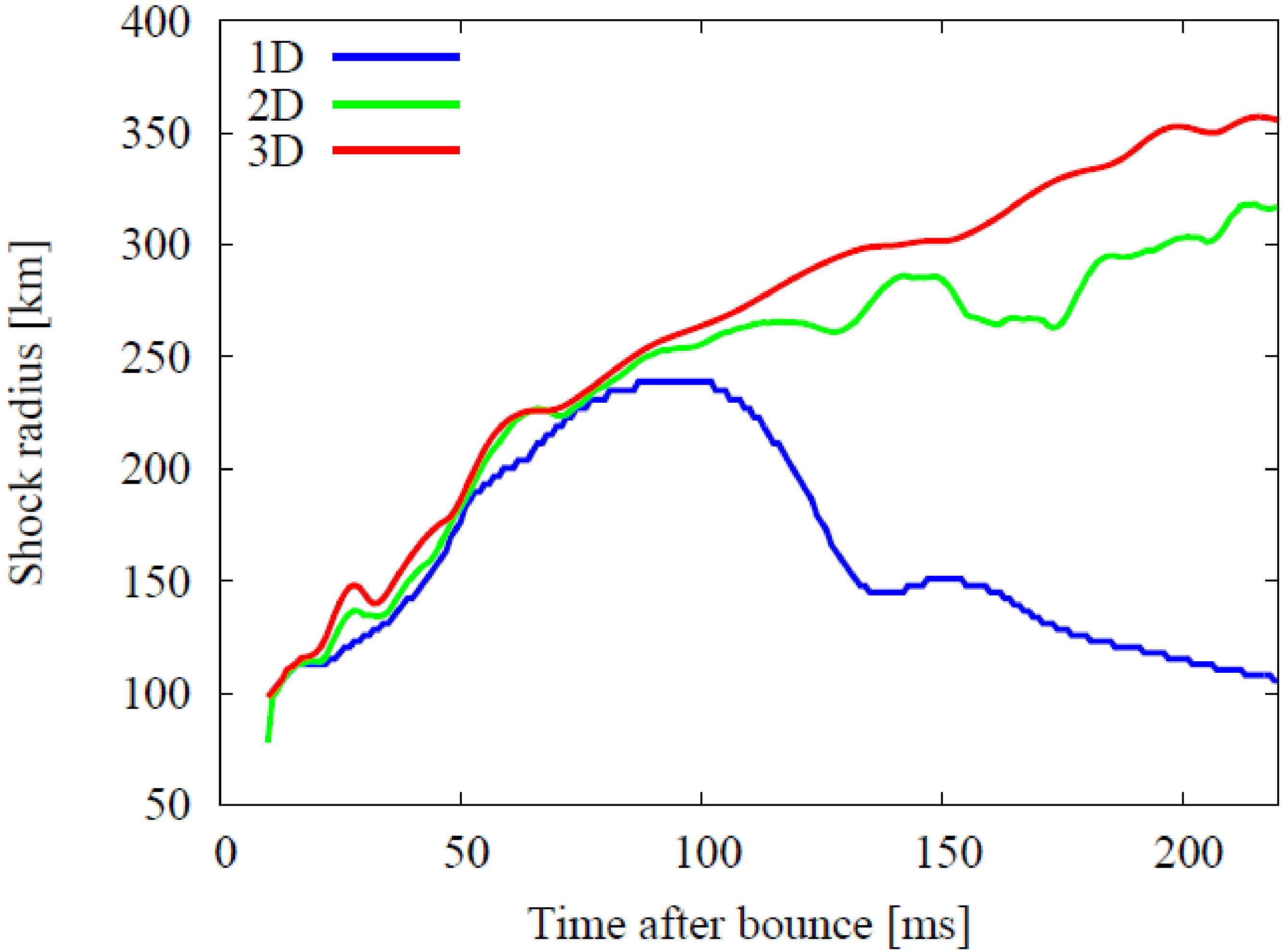
300x64x32



300x64x128

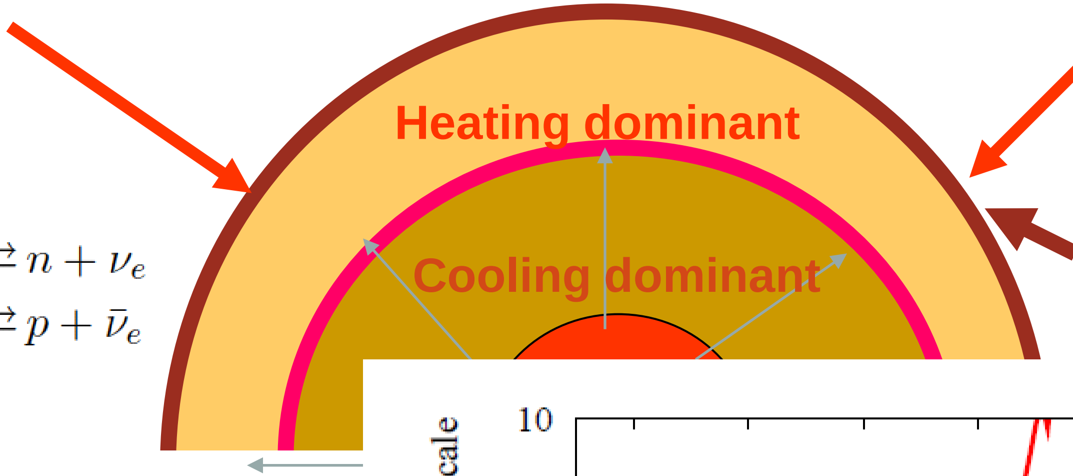
Fine structure inside the shock is produced in high-resolutional model!

Evolution of Shock



3D model is better than 2D model !

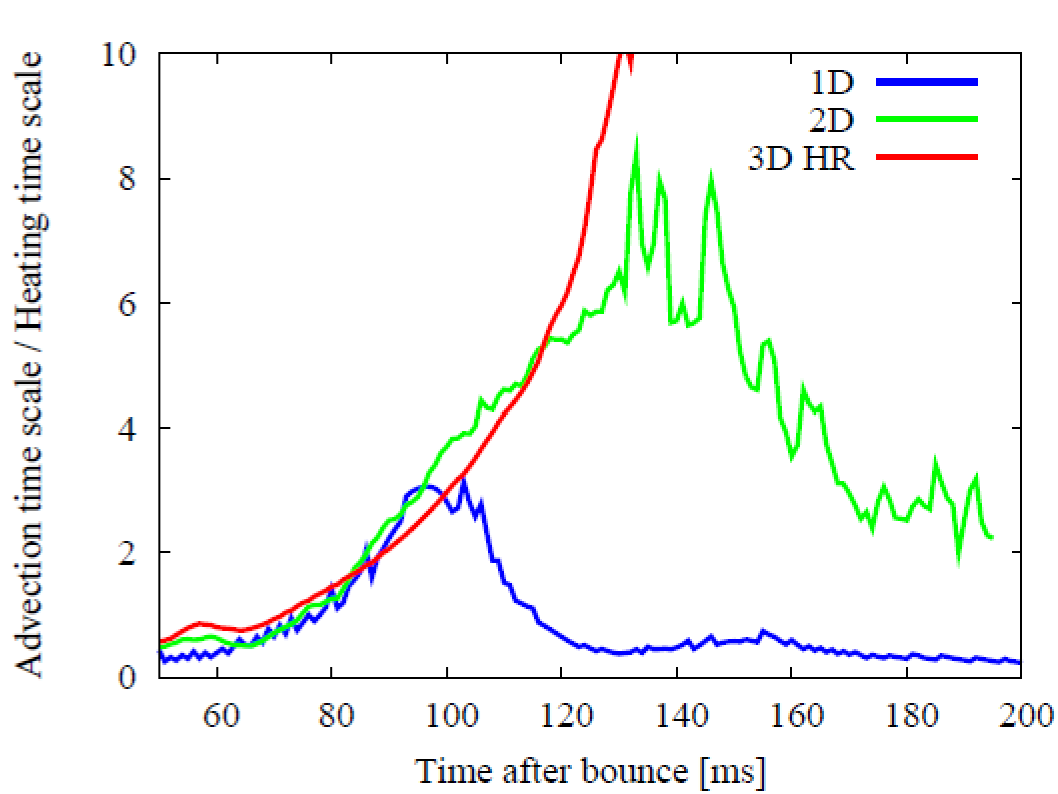
Advection time vs Heating time



$$p + e^- \rightleftarrows n + \nu_e$$
$$n + e^+ \rightleftarrows p + \bar{\nu}_e$$

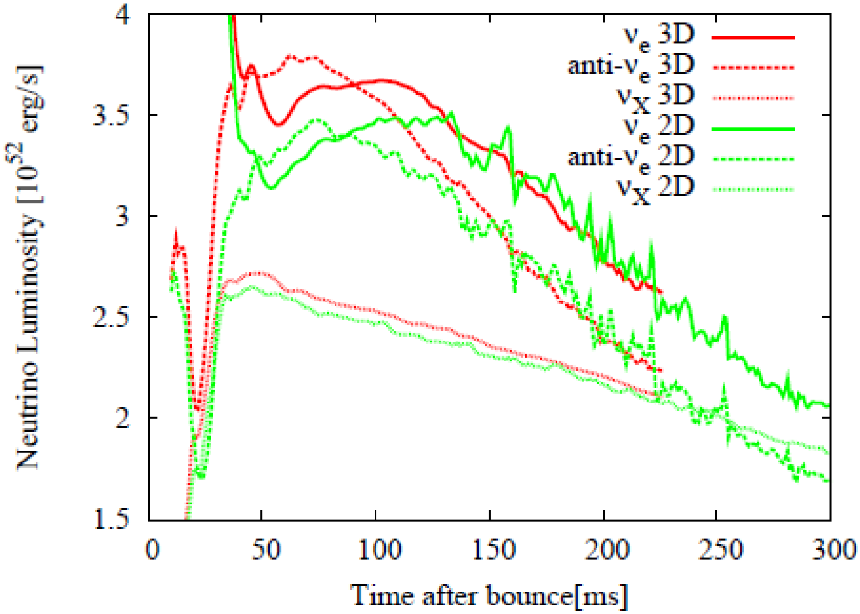
Advection time scale:
Accreted matter passes heat
dominant region in this time

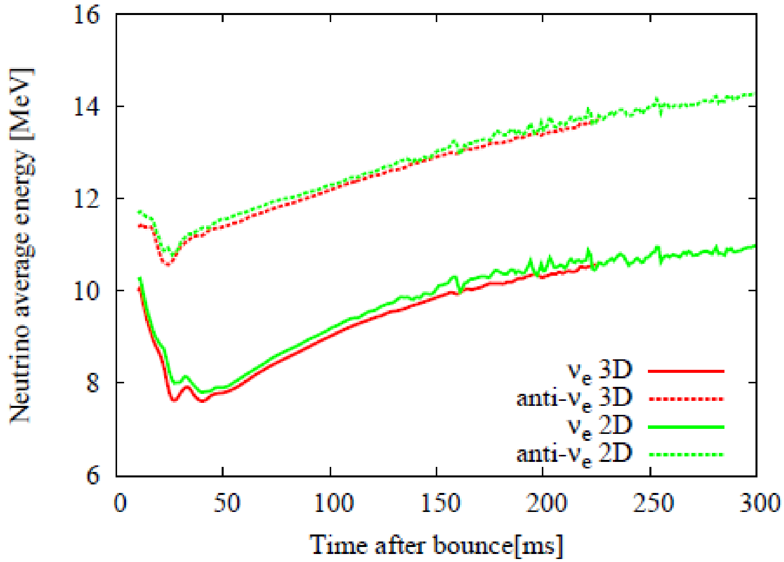
$$\tau_{\mathrm{adv}}(t) = -\int_{r_{\mathrm{gain}}(t)}^{r_{\mathrm{sh}}(t)} \frac{1}{v_r(r,t)}$$



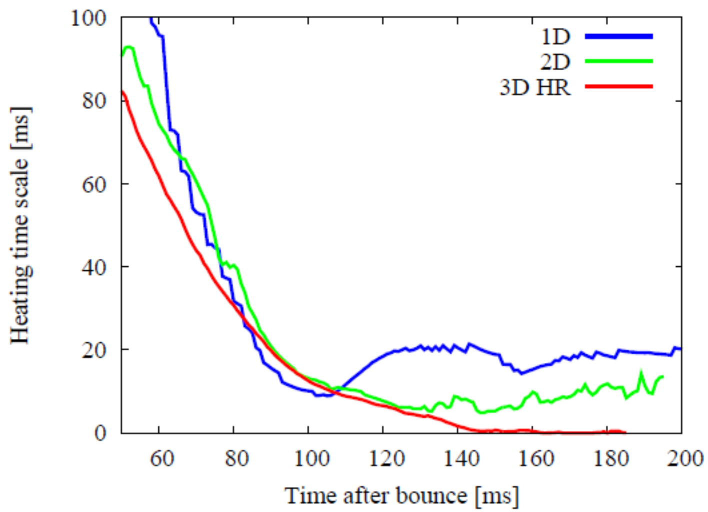
If advection time scale
explosion will succeed!

Neutrino Heating



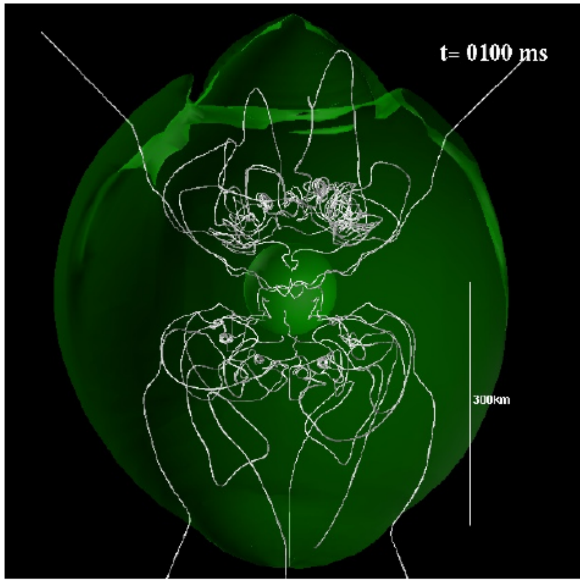


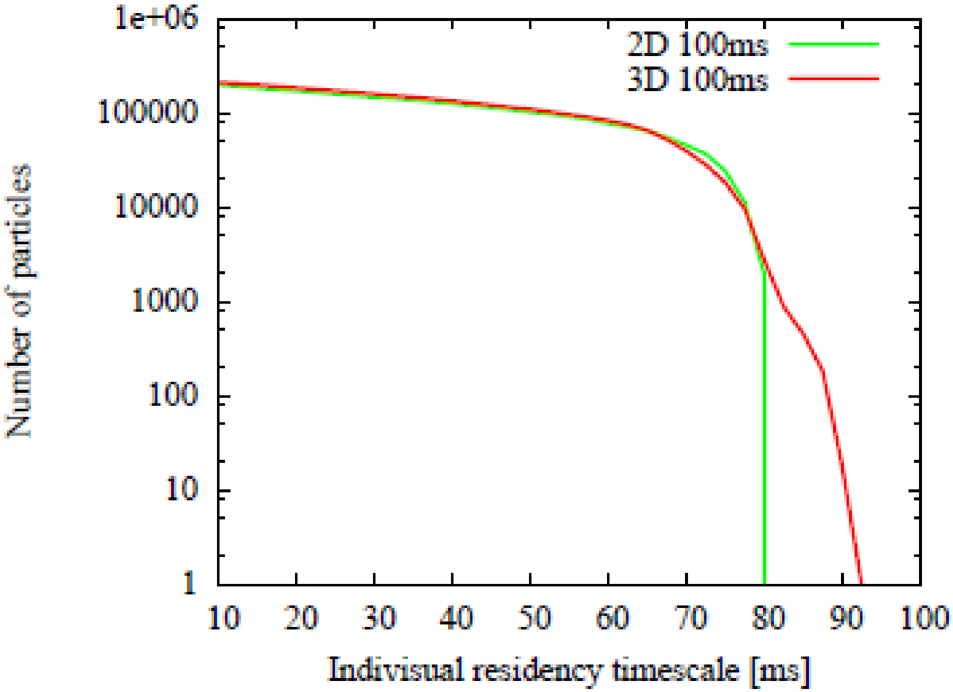
3D model is better than 2D model !



Advection timescale

(Sorry ! This slide is based on the previous work)





3D > 2D ! 3D is good for explosion

(Same analysis should be done at the new work)

Summary

We perform first 3-dimensional simulation with spectral neutrino transport.

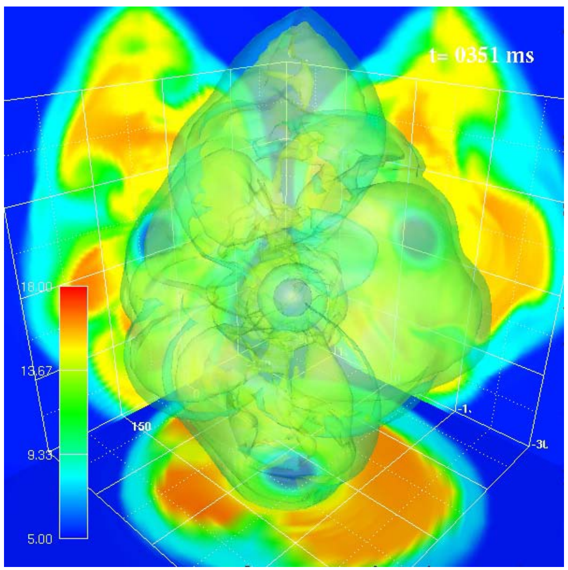
- Advection time scale of 3D model is longer than that of 2D. 3D is good for explosion.
- Neutrino luminosity of 3D model is bigger than 2D with same average energy.

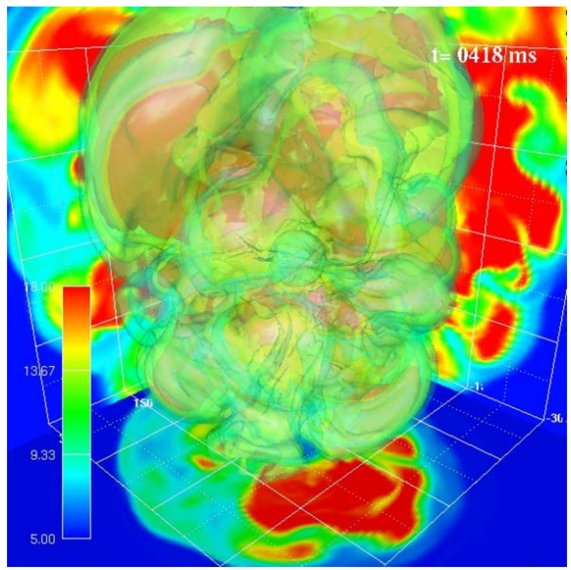
As a result 3D is good for explosion in this resolution.

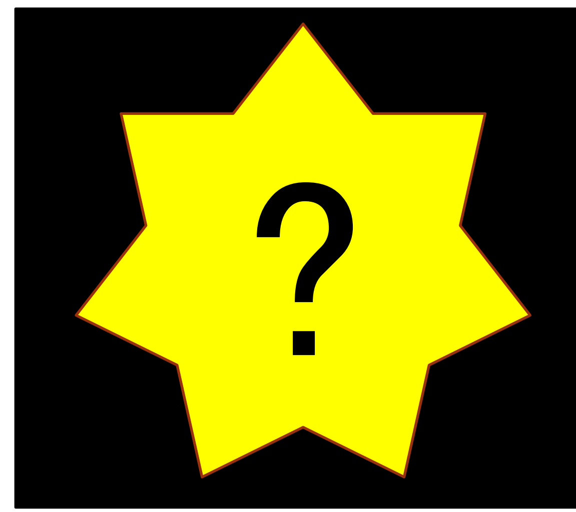
3D modeling of supernovae starts Young phase.

I wish this result (or tendency) is confirmed by models with higher resolution, that is computed by K computer.

Simulation with K computer







NAOJ-XT4

300x64x32

256 parallel

T2K-tukuba

320x64x128

4096 parallel

K computer

> 640x128x128

> 16,384 parallel