Developing "1D+" simulation of Core-collapse supernovae

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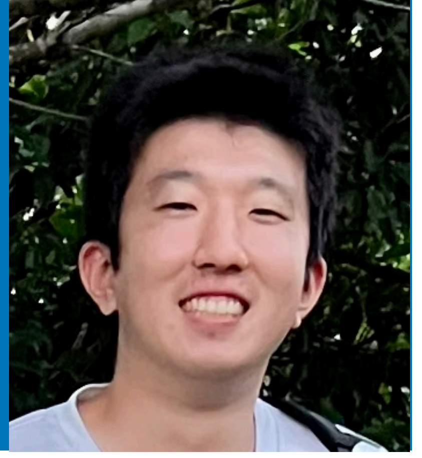
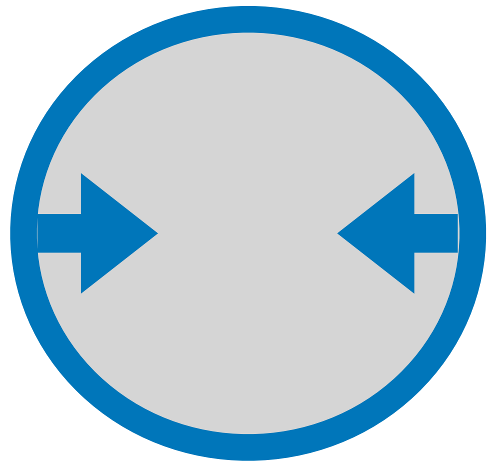
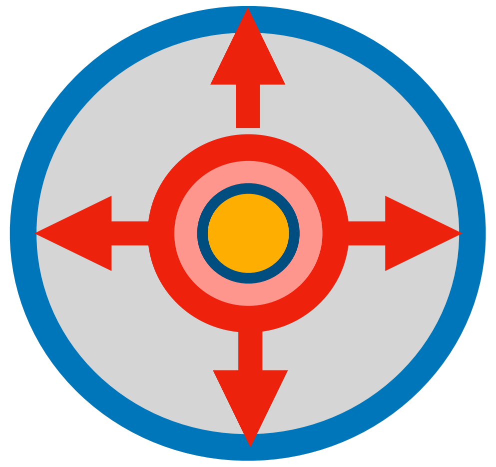
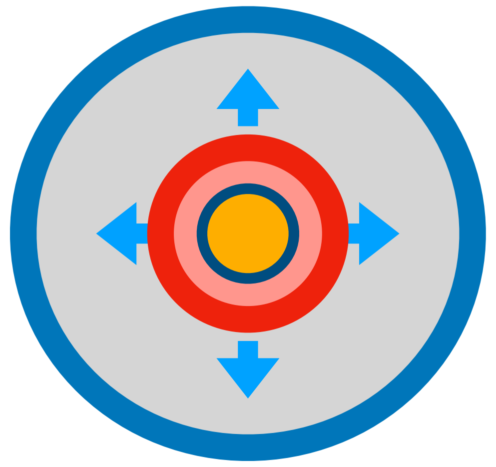




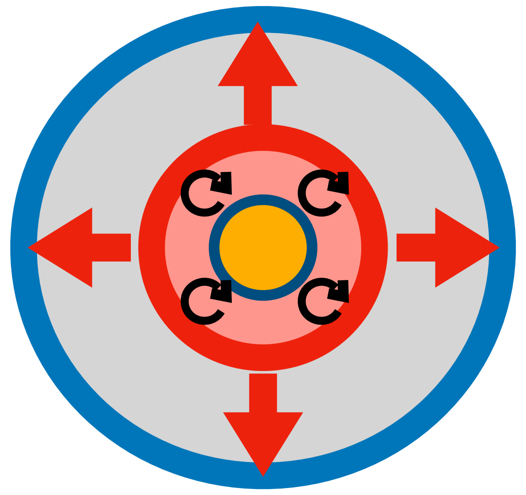
1: Core collapse



2: Core bounce



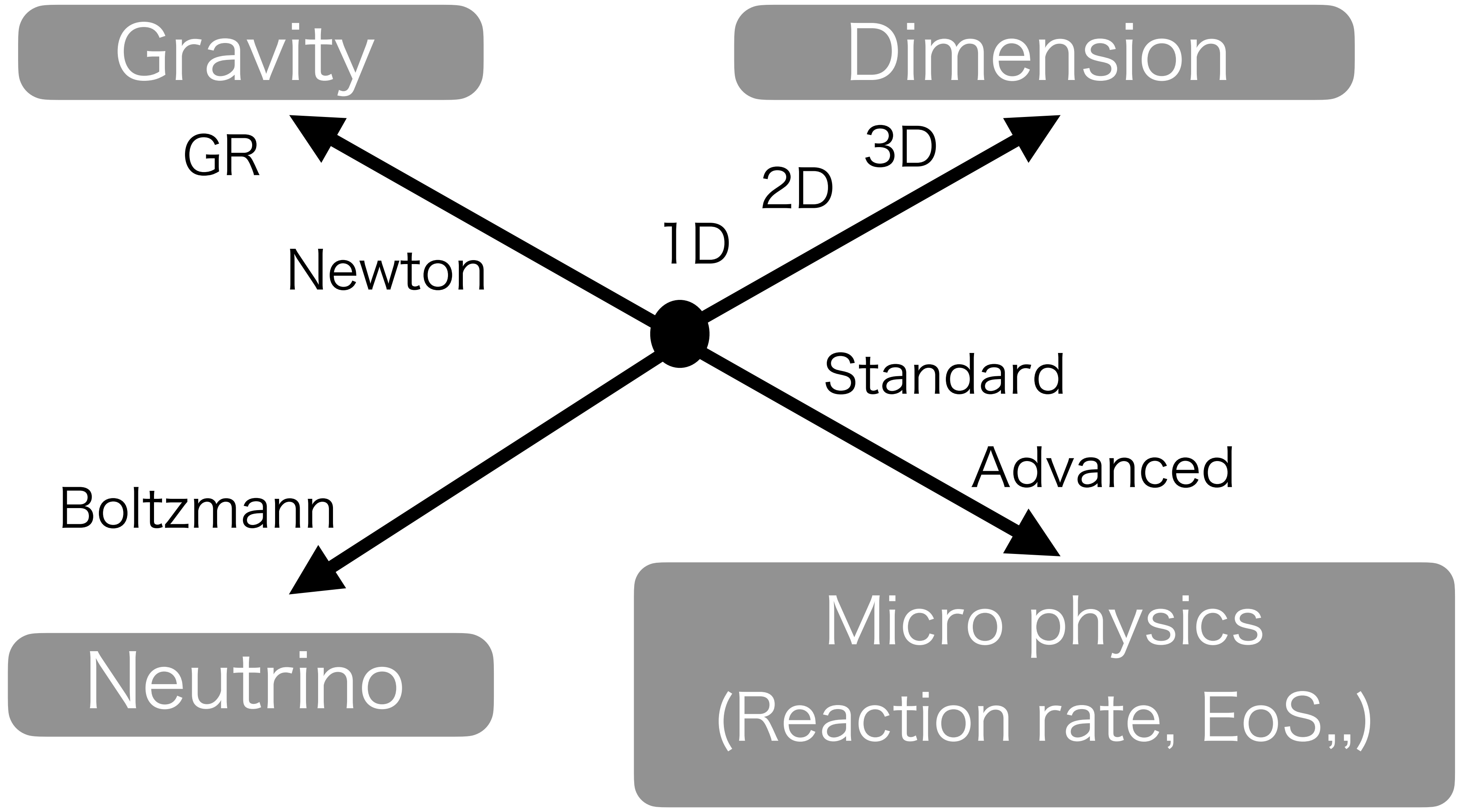
3: Shock stall



4: Shock revival

Shock evolution is important in core collapse supernova mechanism.

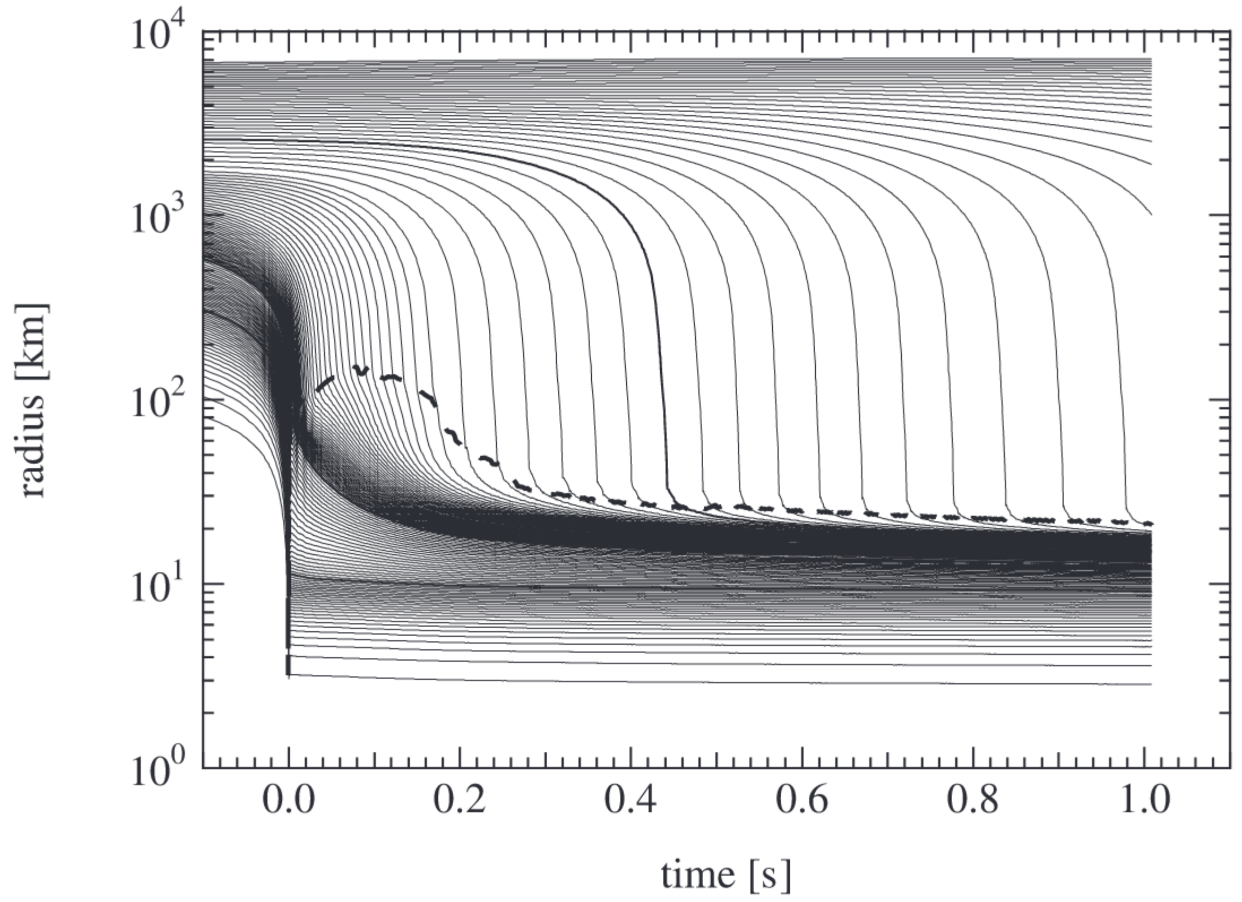
About core collapse supernova simulation



Initial condition

- progenitor model
- Rotation
- Magnetic field
- Others

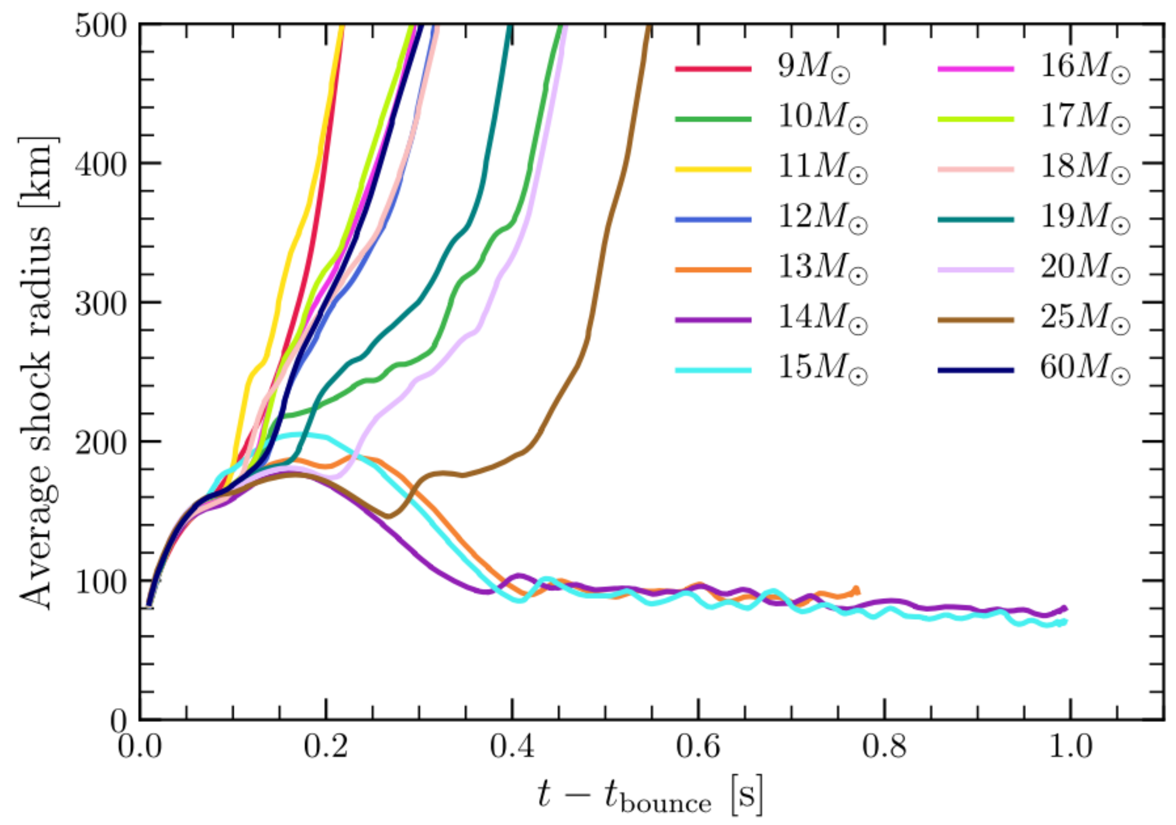
1D Simulation



Self consistent 1D simulation cannot get successful explosion result. (Sumiyoshi et al. 2005)

Latest 3D simulation can get successful explosion result. Multi dimensional turbulent effects is important for shock propagation

3D Simulation



Burrows et al. 2020

Motivation

Goal: collaboration with other field

Huge computational cost:
a few month/1model

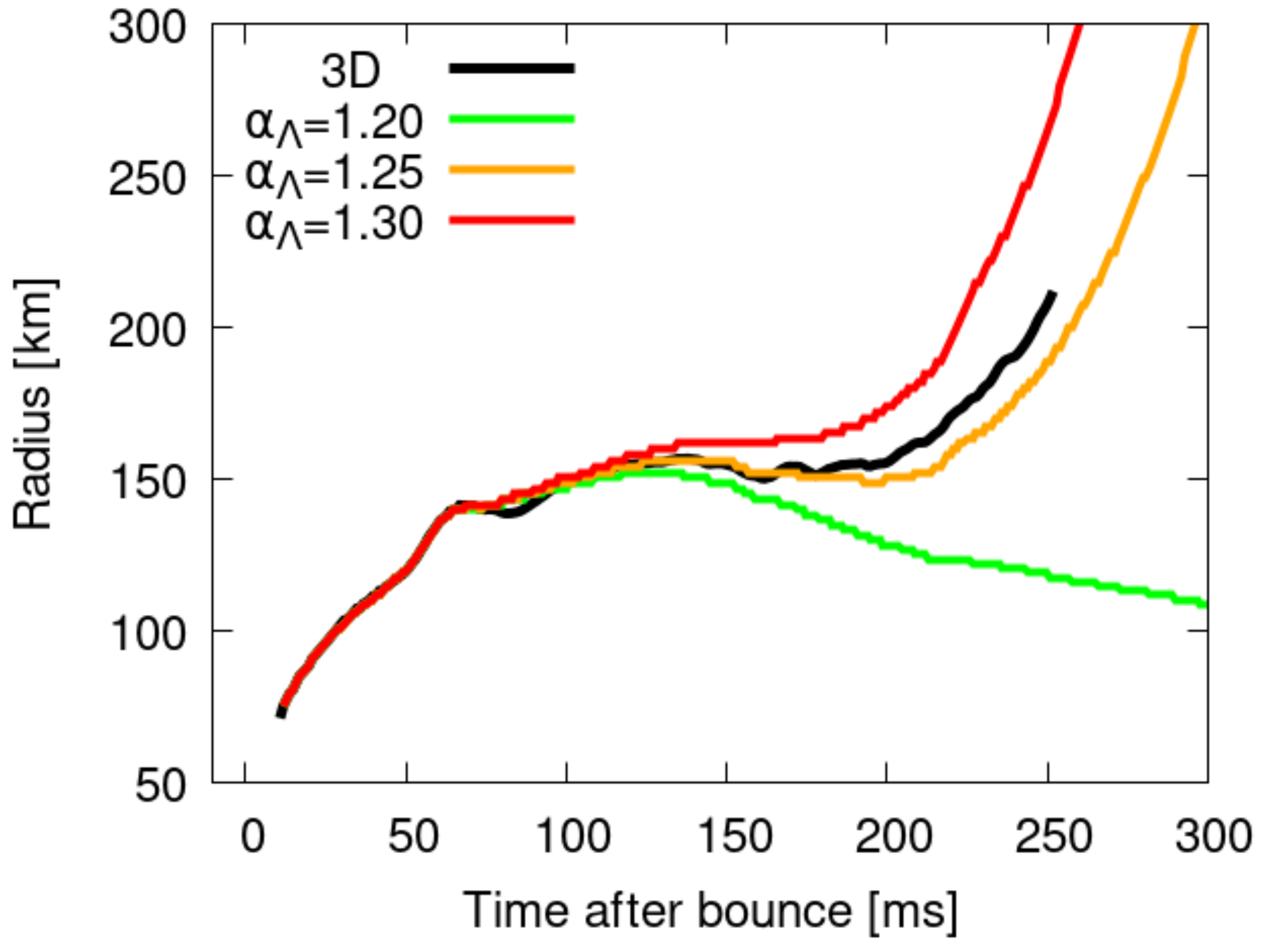
Low computational cost:
a week/1model

1D+

3D

Including 3D turbulent effects

Results



We need to set turbulent parameters to mimic 3D simulation.

Our 1D+ model with $\alpha_\Lambda = 1.25$ can mimic the evolution of shock .

Now we try to develop more realistic 1D+ simulation
e.g. progenitor dependence, magnetic field, rotation and so on.

Governing equation of 1D+ (hydro eq.)

$$\frac{\partial \rho}{\partial t} + \frac{1}{r^2}\frac{\partial}{\partial r} r^2[\rho v_r] = 0$$ Mass conservation

$$\frac{\partial \rho v_r}{\partial t} + \frac{1}{r^2}\frac{\partial}{\partial r}[r^2(\rho v_r^2 + P + P_{\rm turb})] = \frac{2\hat{P} + cP_{\rm turb}}{r} - \rho g + S_\nu$$ Euler equation

$$\frac{\partial (\rho e)}{\partial t} + \frac{1}{r^2}\frac{\partial}{\partial r}\left[r^2 v_r(\rho e + P + P_{\rm turb}) - r^2 \rho D_\epsilon \left(\frac{\partial \epsilon}{\partial r} + P\frac{\partial}{\partial r}\left(\frac{1}{\rho}\right)\right) - r^2 \rho D_K \nabla v_{\rm turb}^2\right] = -\rho v_r g + \rho v_{\rm turb} \omega_{\rm BV}^2 \Lambda_{\rm mix} + Q_\nu$$ Energy conservation

$$\partial_t e_{\rm turb} + \frac{1}{r^2}\frac{\partial}{\partial r}\left[e_{\rm turb} v_r - r^2 \rho D_K \nabla v_{\rm turb}^2\right] = \rho v_{\rm turb} \omega_{\rm BV}^2 \Lambda_{\rm mix} - \rho \frac{v_{\rm turb}^3}{\Lambda_{\rm mix}}$$ Turbulent energy conservation

We use mixing length theory in order to include 3D turbulent effects into 1D