The Rotating Core-Collapse Supernova Simulation with Full Boltzmann Neutrino Transport

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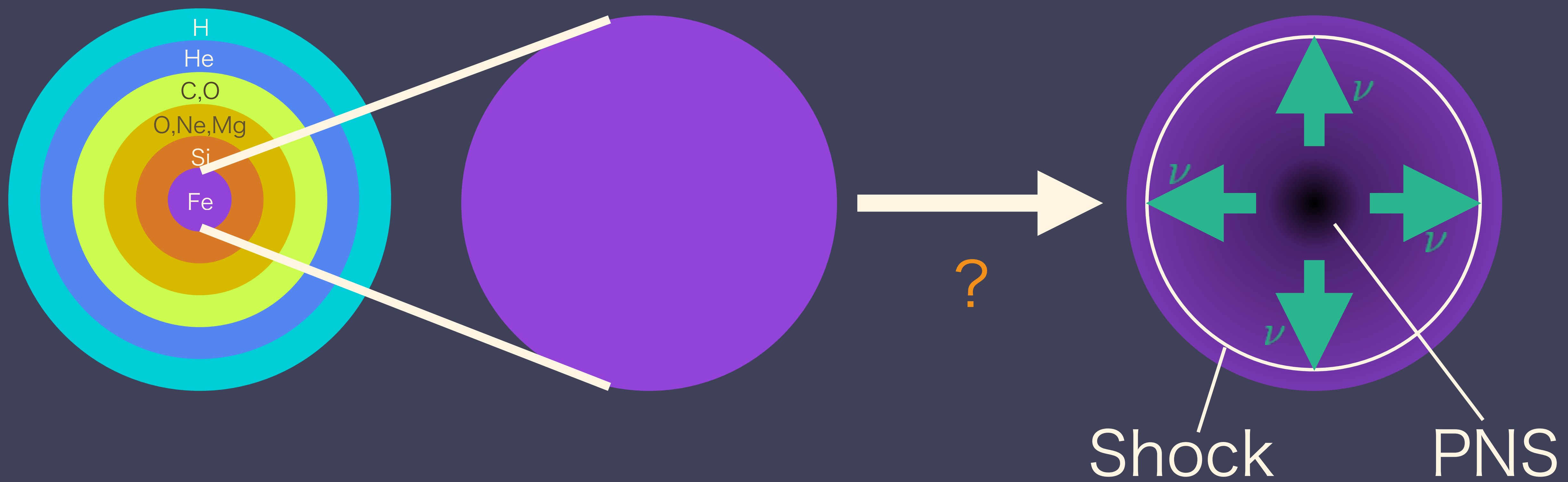
Core-collapse supernovae

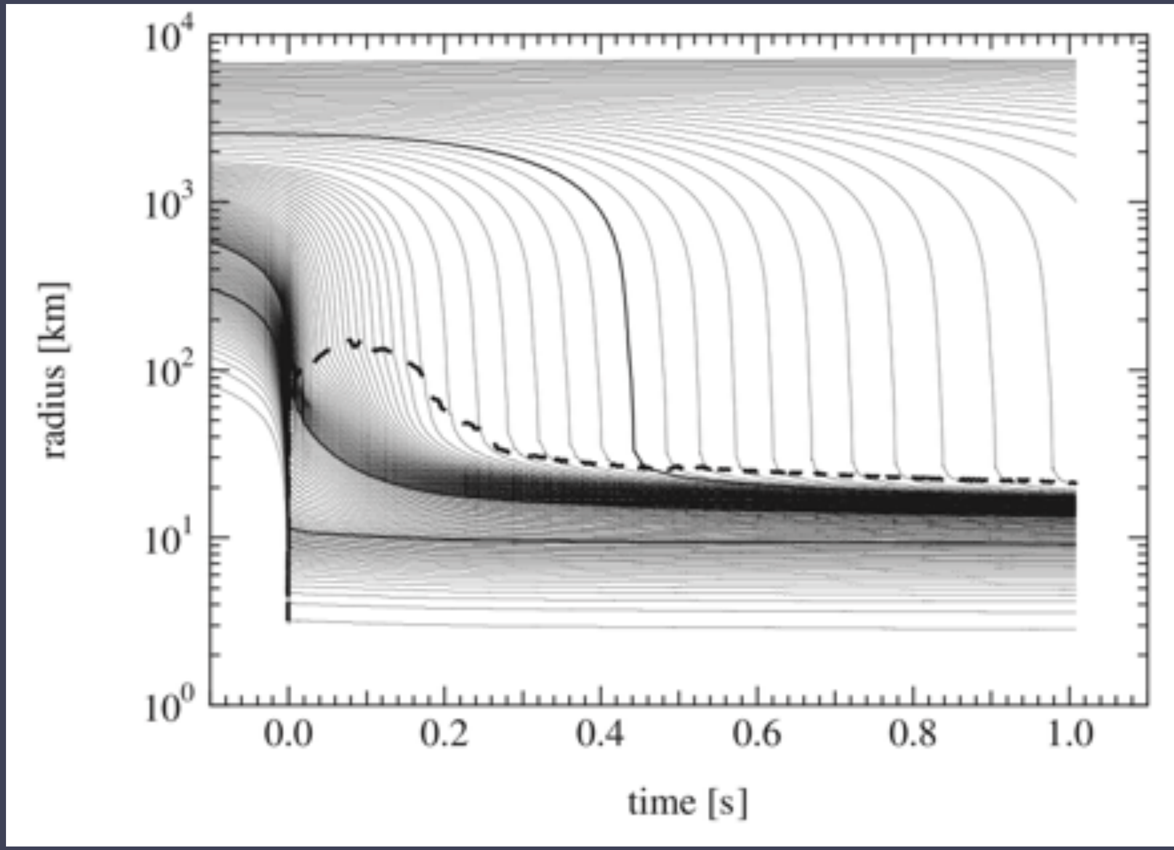


- The death of massive stars
- The neutrino heating mechanism?

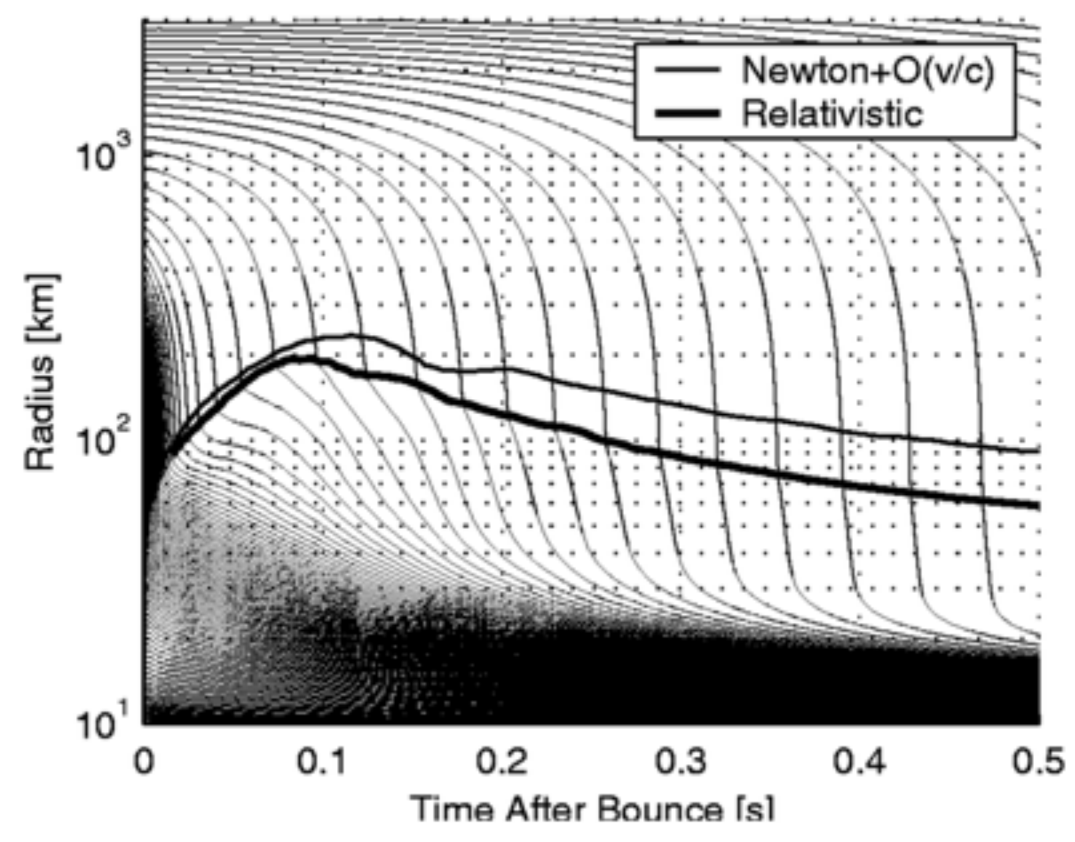
(The acoustic mechanism?
see Burrows+(2006, 2007), Harada+(2017))

arXiv:1704.02984

Full Boltzmann Solver



Sumiyoshi+ (2005)



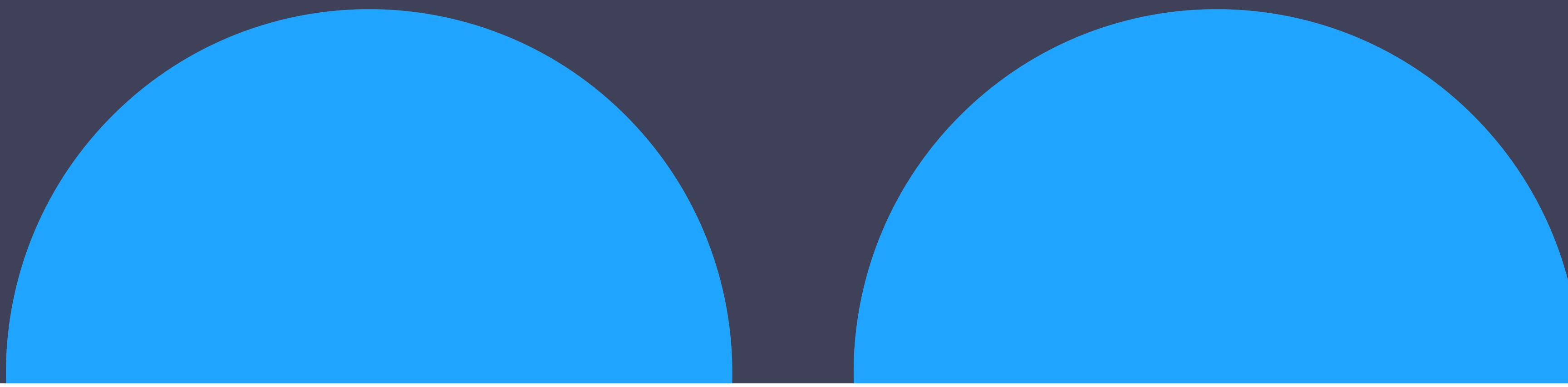
Liebendoerfer+ (2001)

- 1D simulation fails: concluded by Boltzmann solver
  →How about multi-D?
- Boltzmann solver is implemented.

Special Relativity in Boltzmann

Nagakura+ ApJS (2014)

Fluid rest frame | Laboratory frame



$$\frac{\partial f}{\partial t} + \frac{\mathrm{d}\boldsymbol{r}}{\mathrm{d}t} \cdot \frac{\partial f}{\partial \boldsymbol{r}} + \frac{\mathrm{d}p}{\mathrm{d}t} \cdot \frac{\partial f}{\partial \boldsymbol{p}} = \left(\frac{\delta f}{\delta t} \right)_{\mathrm{col}}$$

Simple in laboratory frame/Simple in fluid rest frame

- Special relativistic beaming effect is important in treating neutrino trapping.
- Usually, terms ~$O(v^2/c^2)$ is neglected.

Special Relativity in Boltzmann

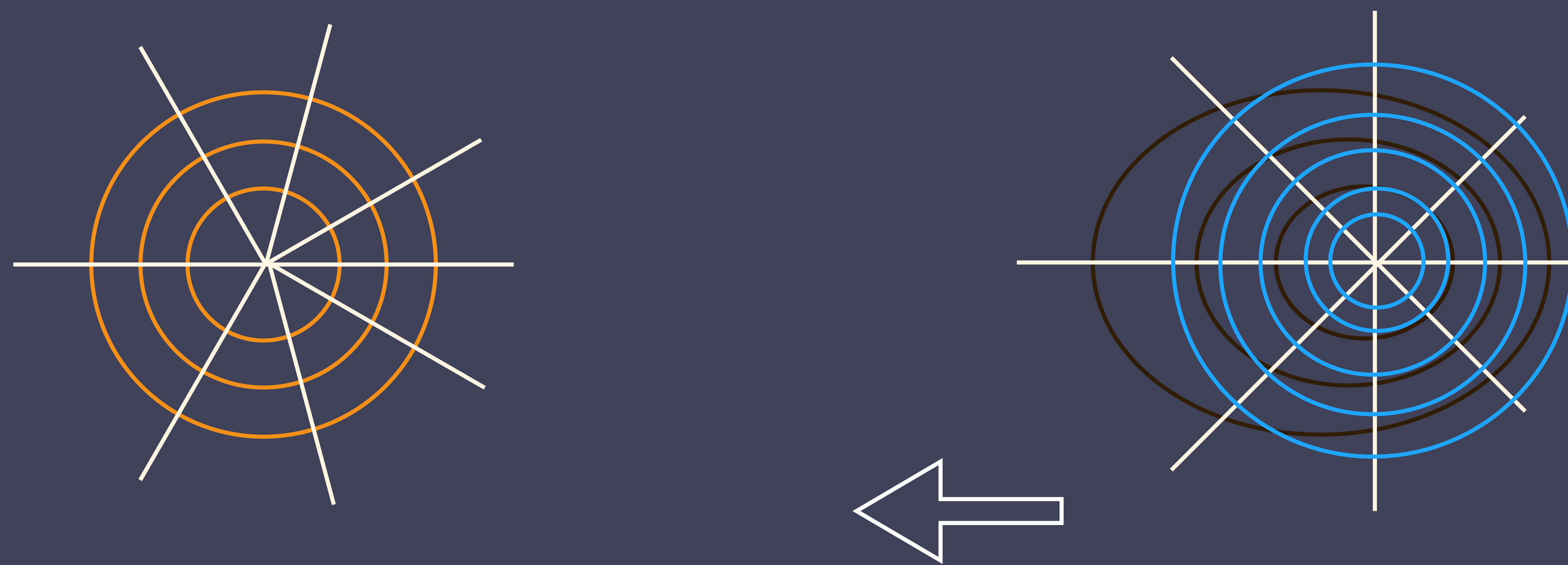
Nagakura+ ApJS (2014)

Lagrangian Remapping Grid

(Fluid rest frame)

(Laboratory frame)

Laboratory Fixed Grid

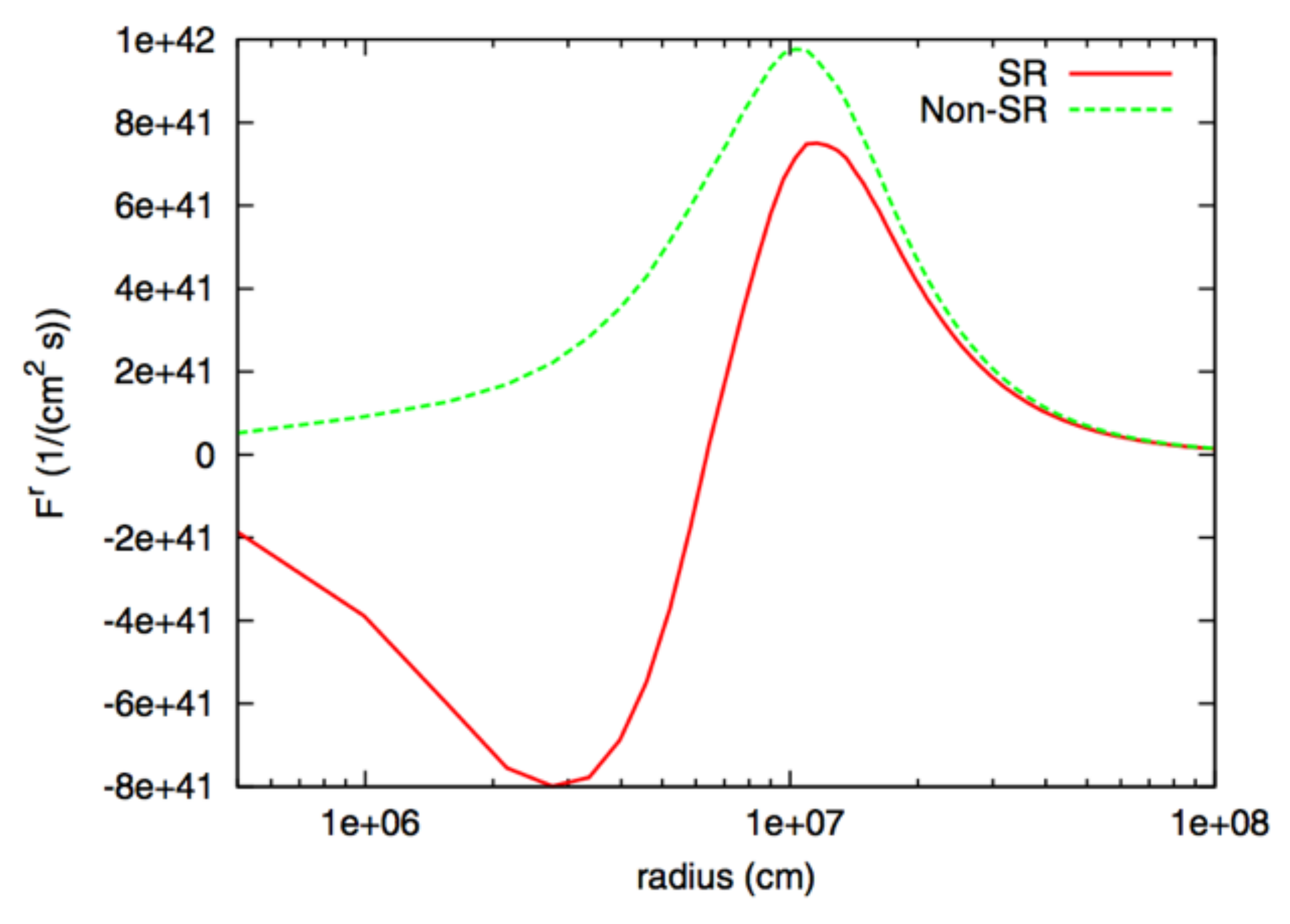


fluid velocity

- Two grid approach:
  Lagrangian Remapped Grid/Laboratory Fixed Grid

Special Relativity in Boltzmann

Nagakura+ ApJS (2014)

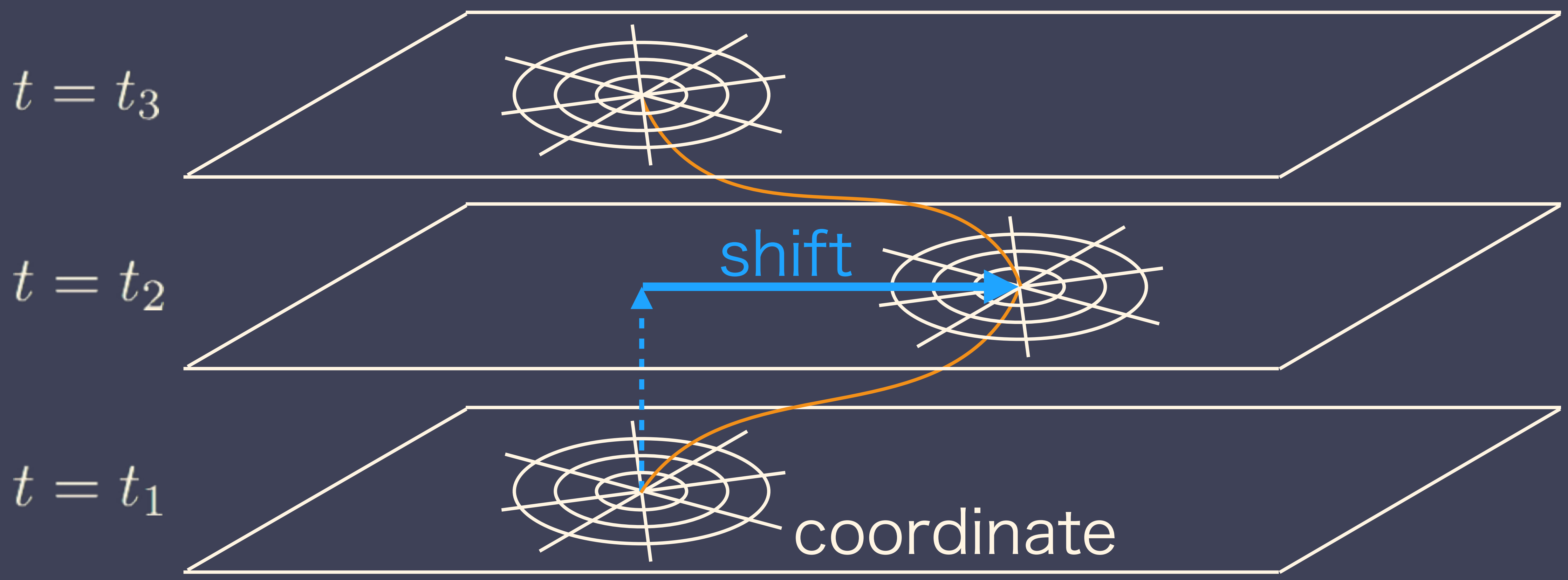


- Neutrino trapping is treated appropriately

“General Relativity” in Boltzmann

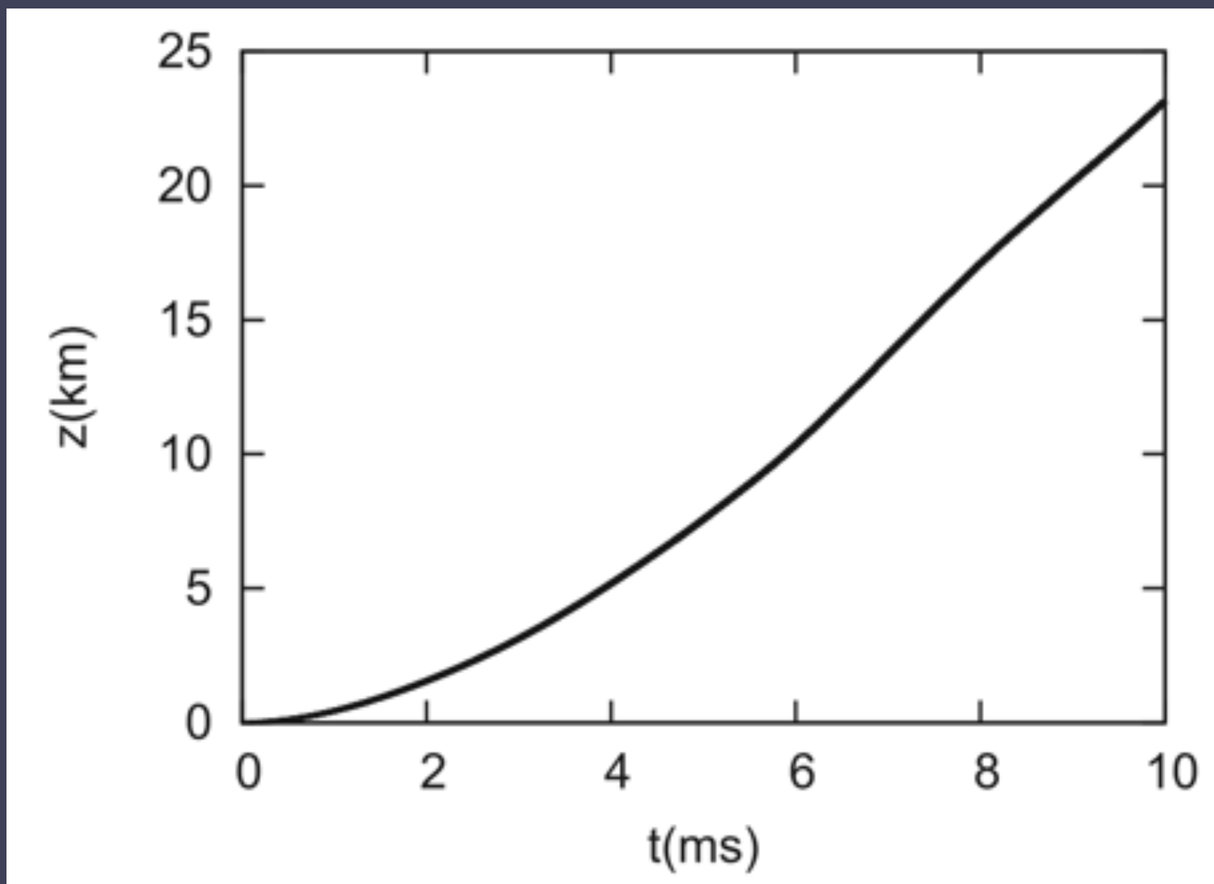
Nagakura+ ApJS (2017)

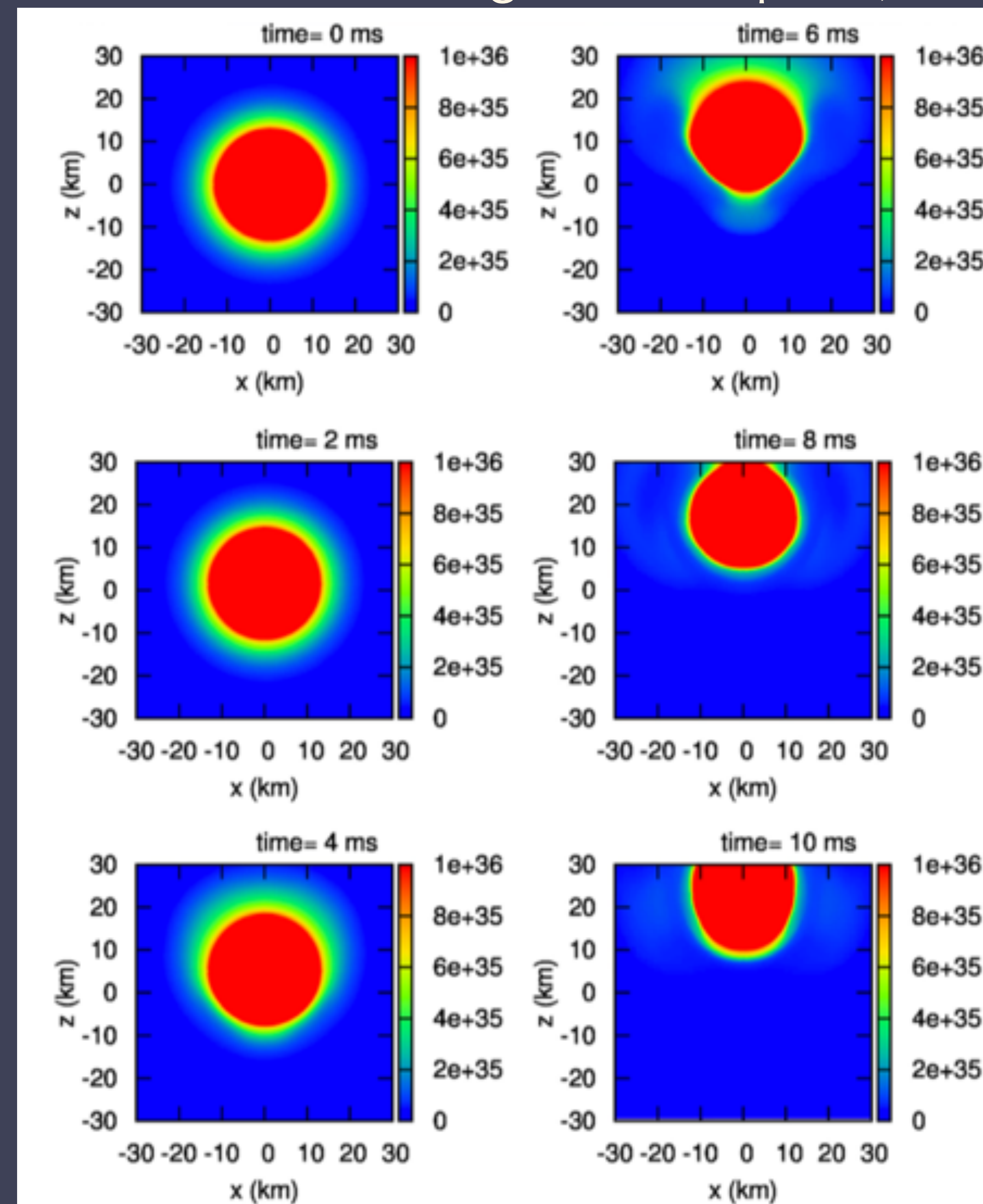
- PNS is kicked by atmosphere, then moves from the center of spherical coordinate.
- This leads to numerical difficulty.
  →acceleration frame



"General Relativity" in Boltzmann

Nagakura+ ApJS (2017)





- Shift of PNS is properly treated.
- Transfer in curved spacetime will be tested.

Setup

- 11.2 $M_\odot$ progenitor of Woosley+ (2002)
- Furusawa's multispiecies EOS based on RMF
- Bruenn's reaction set + updated e-capture, NN-bremss.

→Kosuke Sumiyoshi's talk

- Sheller rotation

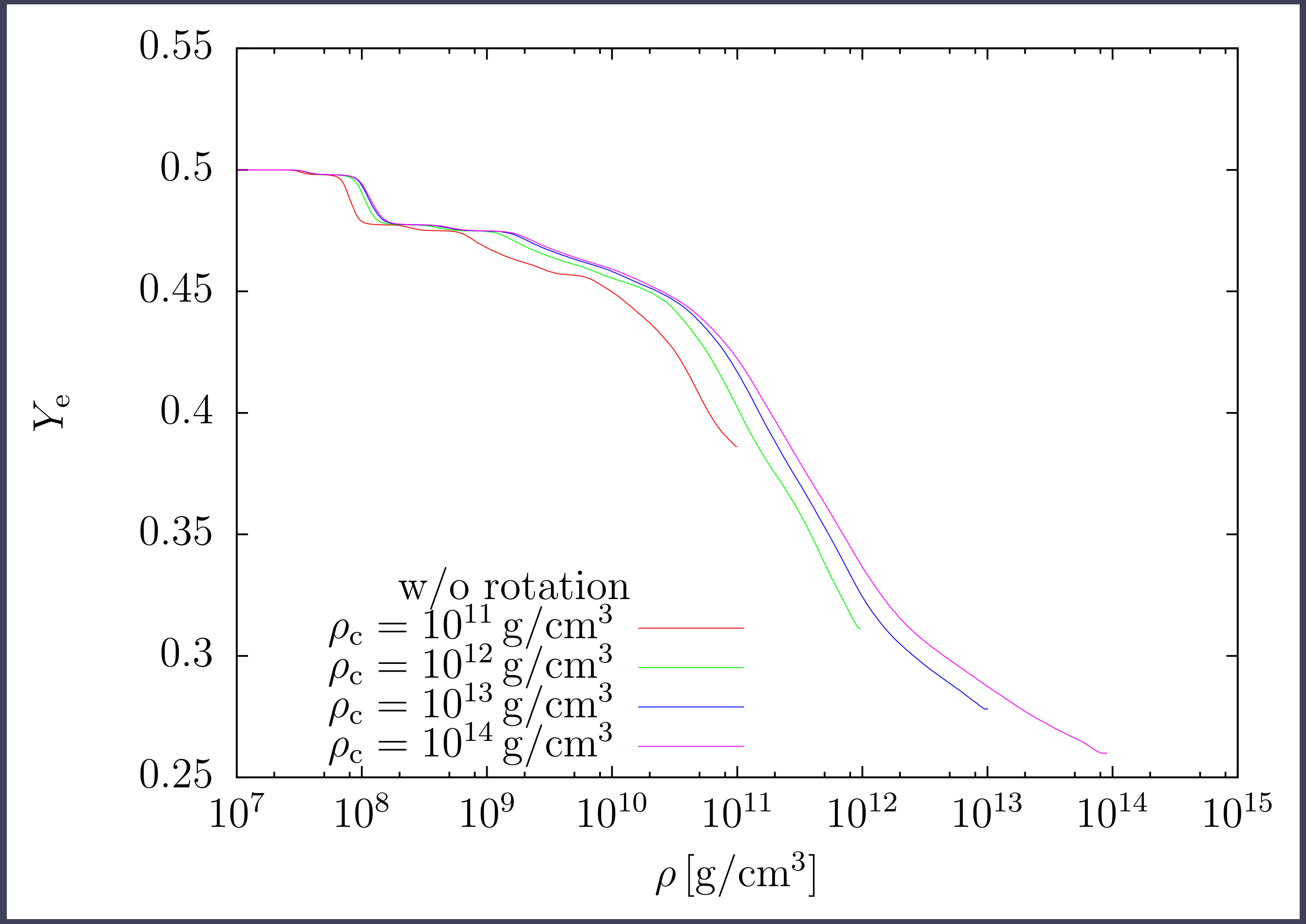
$$\Omega(r) = \frac{1\,\mathrm{rad/s}}{1 + (r/10^8\,\mathrm{cm})}$$

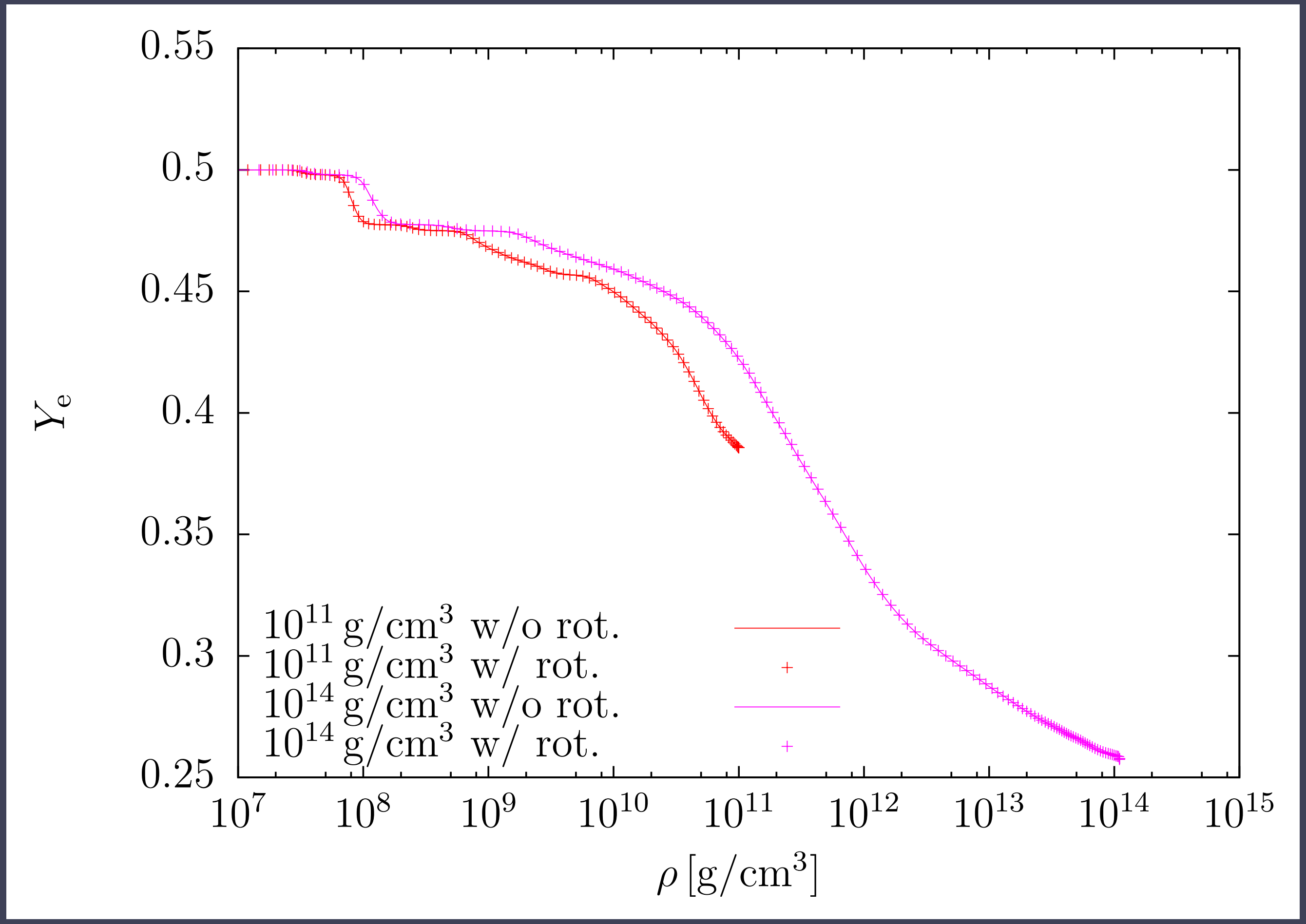
- Grid number is

$$(N_r, N_\theta, N_\phi, N_\nu, N_{\bar{\theta}}, N_{\bar{\phi}}) = (384, 64[128], 1, 20, 10, 6)$$

Rotation and Y_e prescription

- Electron fraction as a function of density (Liebendoerfer 2005), according to 1D Boltzmann solver.
- Effects of rotation is negligible.

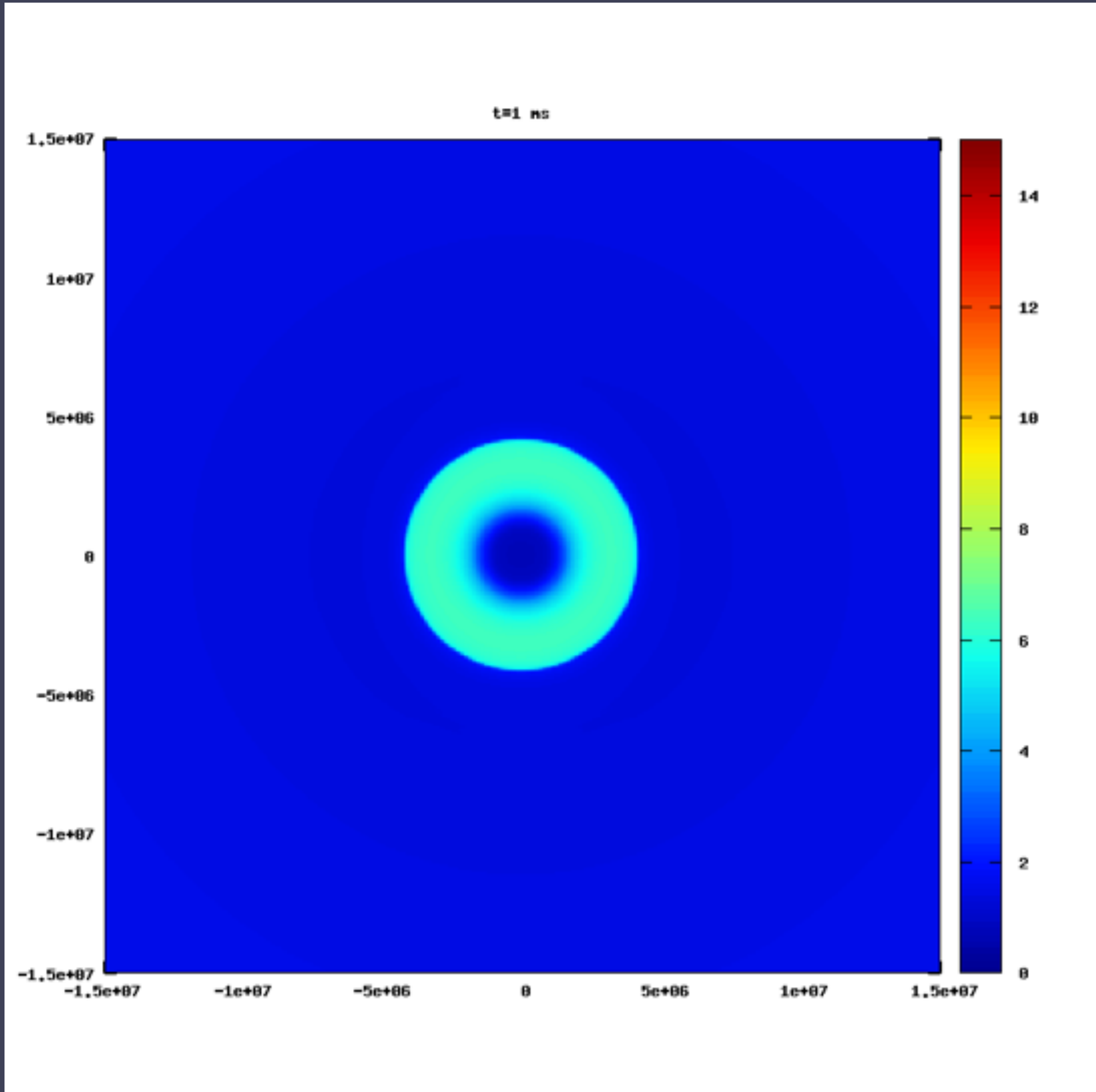




Current status of simulation

- Postbounce evolution until ~150 ms

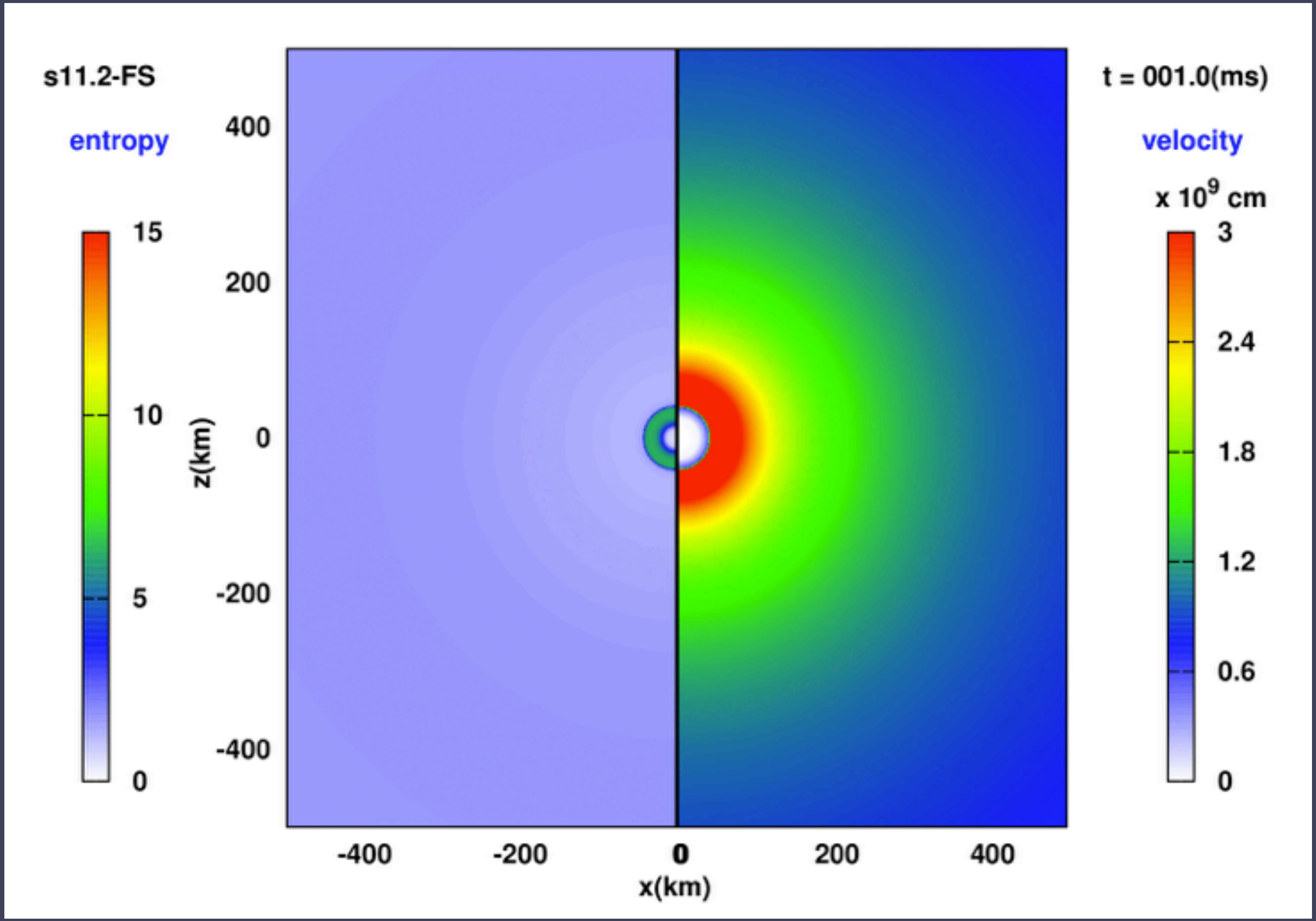
Rotating



Current status of simulation

- Postbounce evolution until ~150 ms

Non-rotating

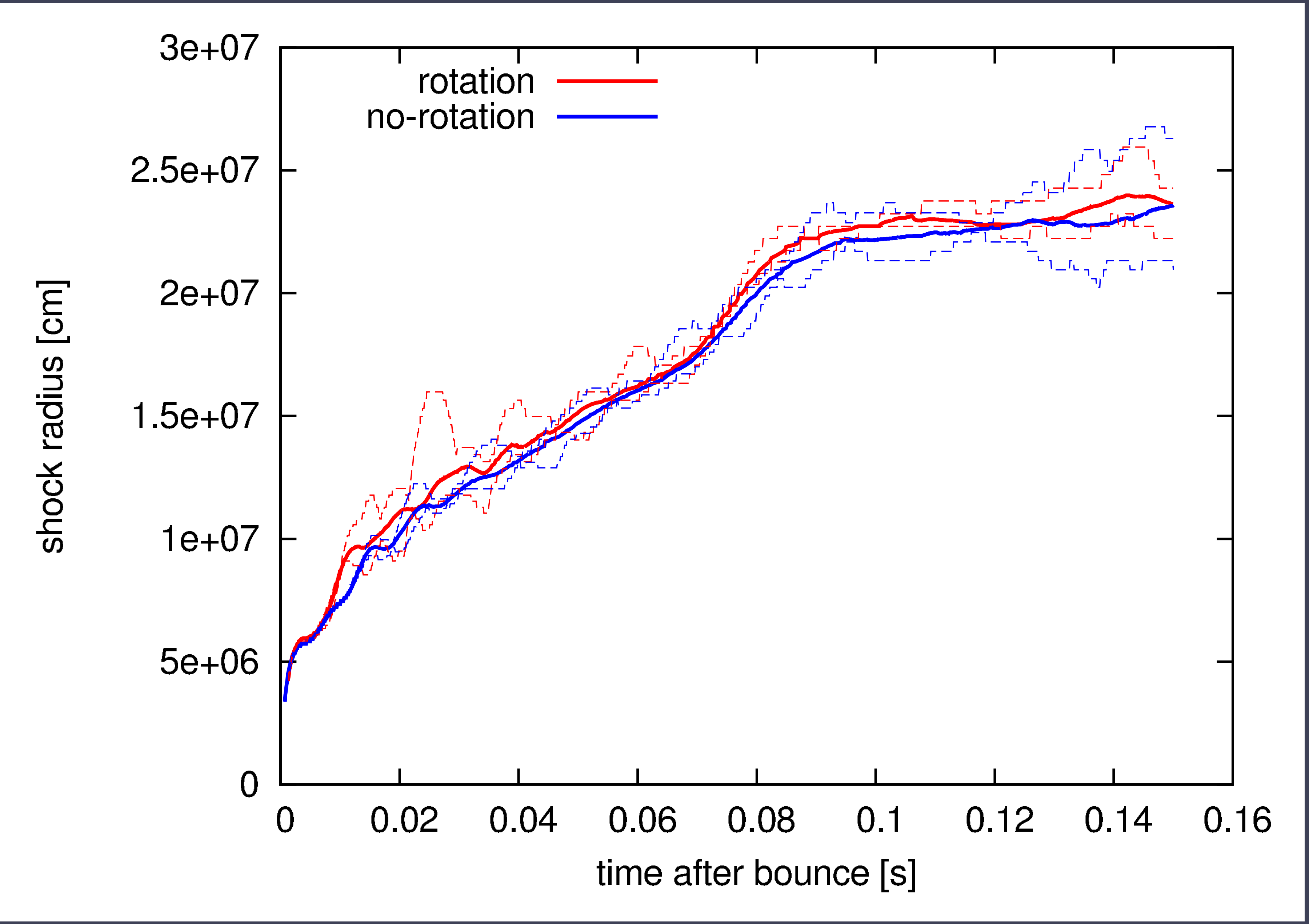


→Kosuke Sumiyoshi's talk

Nagakura+ (2017)

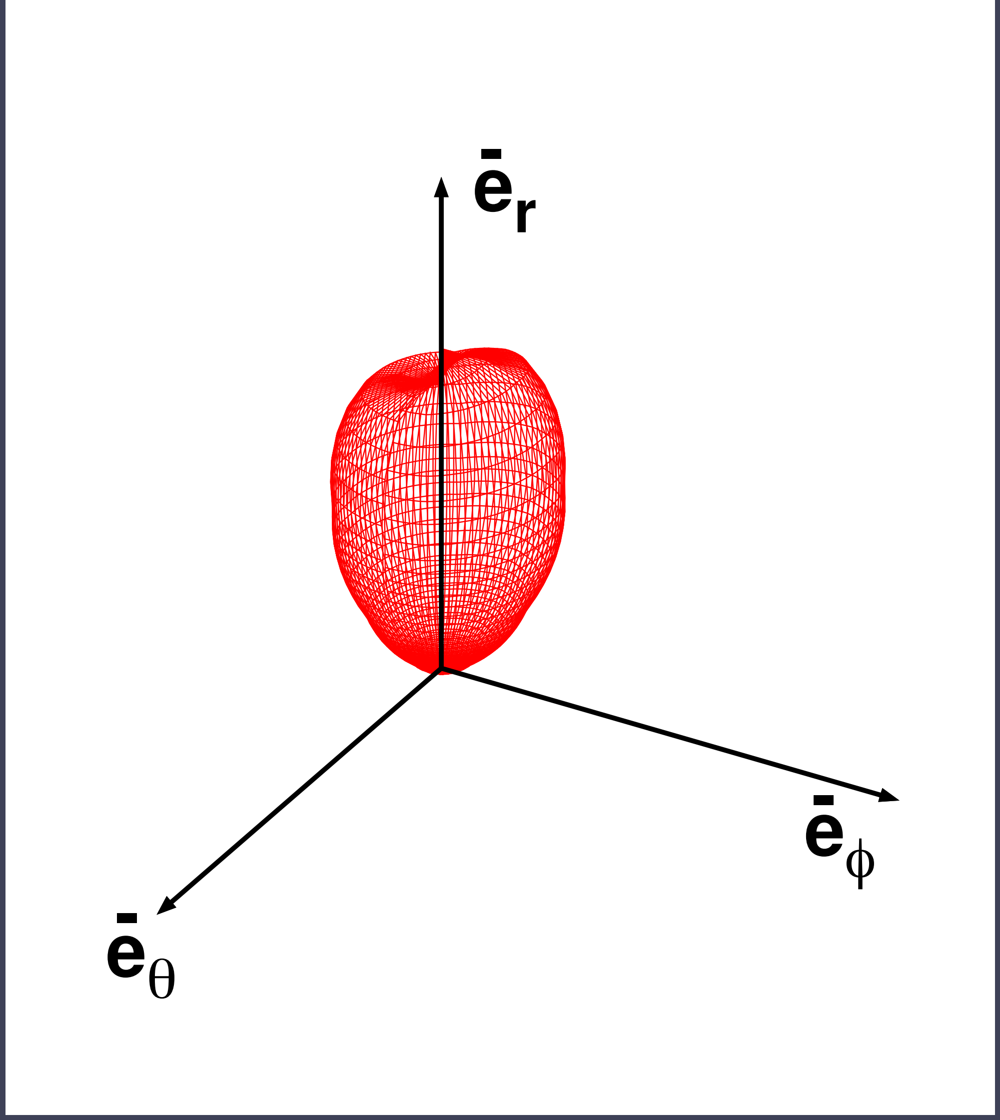
Current status of simulation

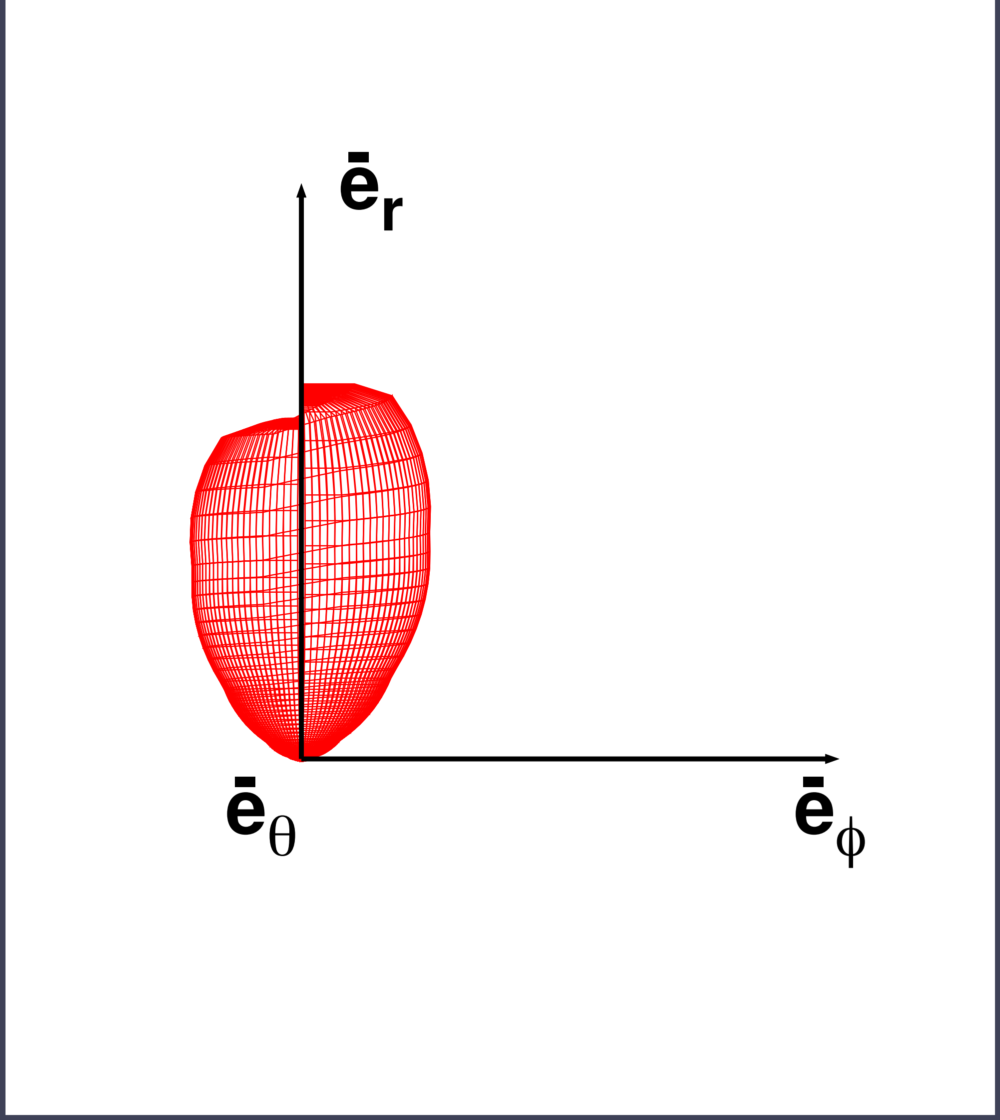
- Postbounce evolution until ~150 ms
- The difference between rotating & non-rotating model



Current status of simulation

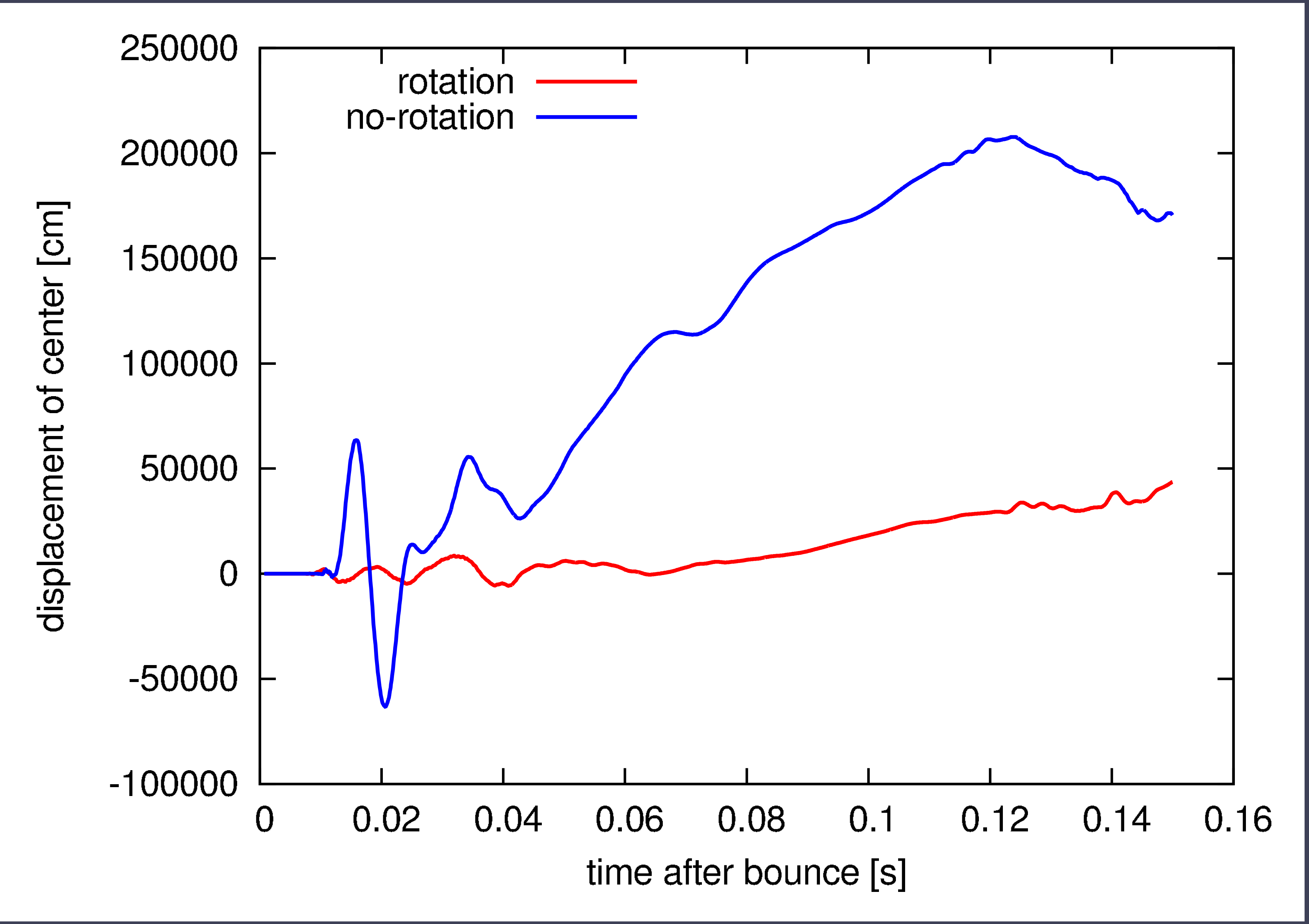
- Postbounce evolution until ~150 ms
- Neutrino distribution function just outside the gain radius.





Current status of simulation

- Postbounce evolution until ~150 ms
- The difference between rotating & non-rotating model



Summary

- Boltzmann-Radiation-Hydro code is developed.
- To include special relativistic effects, two grid approach is developed.
- To track the PNS kick, Boltzmann equation in 3+1 decomposed spacetime is implemented.
- Rotating supernova simulation is now running.