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

Akira Harada (Department of Physics, University of Tokyo)
Collaborator: W. Iwakami, H. Okawa, S. Yamada (Waseda Univ.), H. Nagakura (Caltech), K. Sumiyoshi (Numazu Col. of Tech.), H. Matsufuji (KEK), A. Imakura (Tsukuba Univ.)
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

- 1D simulation fails: concluded by Boltzmann solver
  \[\rightarrow\] How about multi-D?
- Boltzmann solver is implemented.
Special Relativity in Boltzmann

Fluid rest frame

\[ \frac{\partial f}{\partial t} + \frac{d \mathbf{r}}{dt} \cdot \frac{\partial f}{\partial \mathbf{r}} + \frac{d \mathbf{p}}{dt} \cdot \frac{\partial f}{\partial \mathbf{p}} = \left( \frac{\partial f}{\partial t} \right)_{\text{col}} \]

Laboratory frame

Simple in laboratory frame/Simple in fluid rest frame

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

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


- Neutrino trapping is treated appropriately
“General Relativity” in Boltzmann

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

in Boltzmann

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

- 11.2 M⊙ progenitor of Woosley+ (2002)
- Furusawa’s multispieceies EOS based on RMF
- Bruenn’s reaction set + updated e-capture, NN-bremss.

→ Kosuke Sumiyoshi’s talk

- Sheller rotation

\[ \Omega(r) = \frac{1 \text{ rad/s}}{1 + (r/10^8 \text{ cm})} \]

- 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
Current status of simulation

- Postbounce evolution until ~150 ms
- Non-rotating
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.