# Core-collapse simulations of rapidly rotating progenitors by Boltzmann-radiation-hydrodynamics code

Akira Harada (ICRR)

Collaborators: Shoichi Yamada, Wakana Iwakami, Hirotada Okawa (Waseda), Hiroki Nagakura (Princeton), Kohsuke Sumiyoshi (Numazu), Shun Furusawa (Tokyo Sci.), Hideo Matsufuru (KEK)

## Abstract

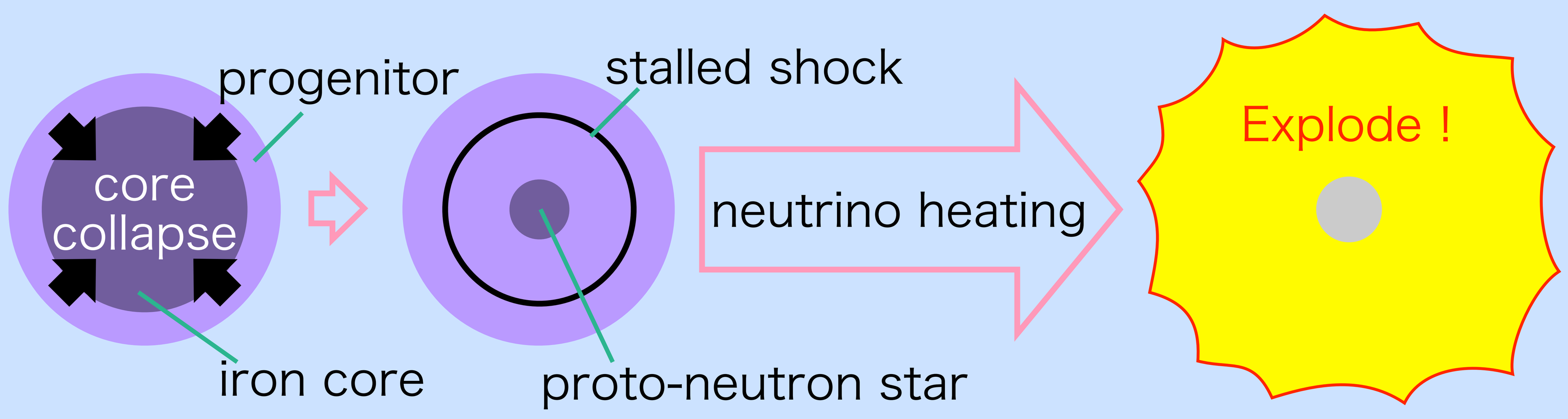
By using Boltzmann-radiation-hydrodynamics code, we are running the core-collapse simulations of the progenitor with 2 & 4 rad/s rotations. Shock dynamics is under investigation and unique data to analyze the collective neutrino oscillation is provided.

## 1. Introduction

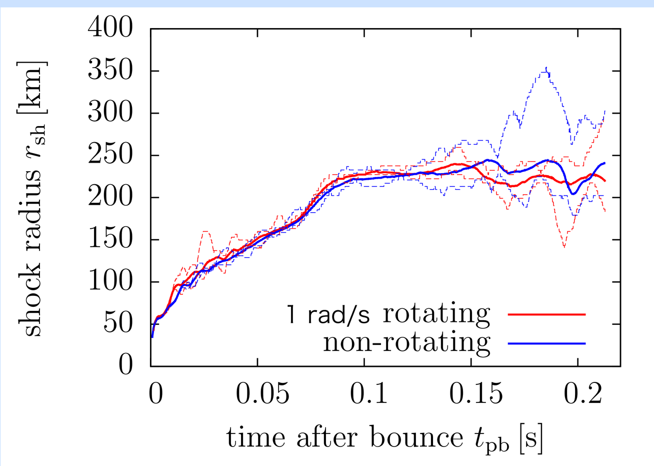
Core-collapse supernovae are explosive deaths of massive stars. Neutrino heating is promising candidate of the energy source. We developed 6D Boltzmann equation solver for neutrino transport to demonstrate this scenario.

Harada et al. (2019) proved that the slow rotation (1 rad/s at center) of the progenitor hardly affects the shock revival.

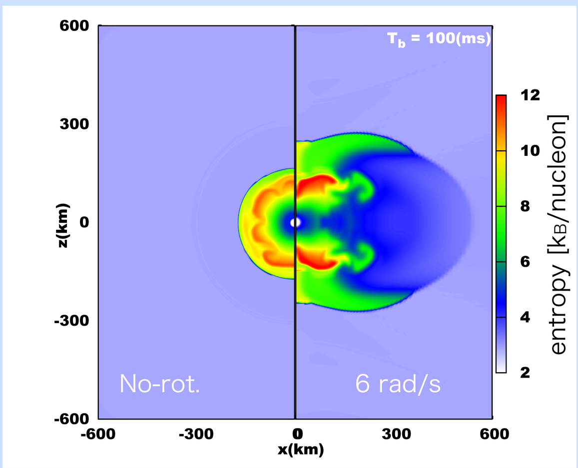
Nagakura et al. (in prep) showed that the extreamely fast rotation (6 rad/s) helps the shock revival. Here, influences of the rapid (2 and 4 rad/s at center) rotation is investigated.




Neutrino heating mechanism




Harada et al. (2019) shock evolution




Nagakura et al. (in prep) entropy distribution

## 2. Method

Code: Boltzmann-radiation-hydrodynamics code

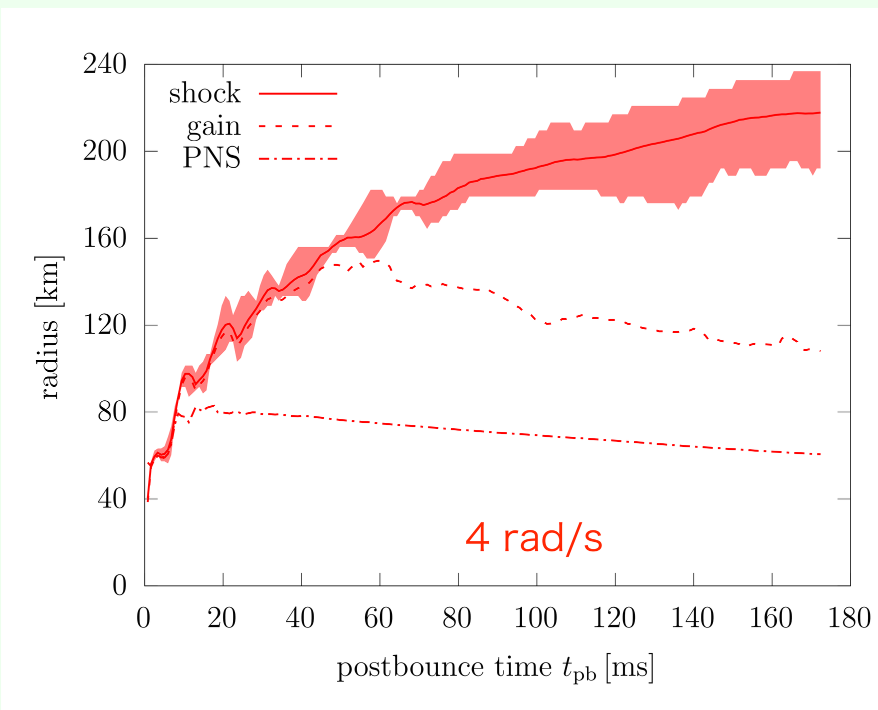
Progenitor: 15 M⊙ (Woosley et al., 2002) $\Omega(r) = \dfrac{2 \text{ or } 4\,\text{rad/s}}{1 + (r/10^8\,\text{cm})^2}$

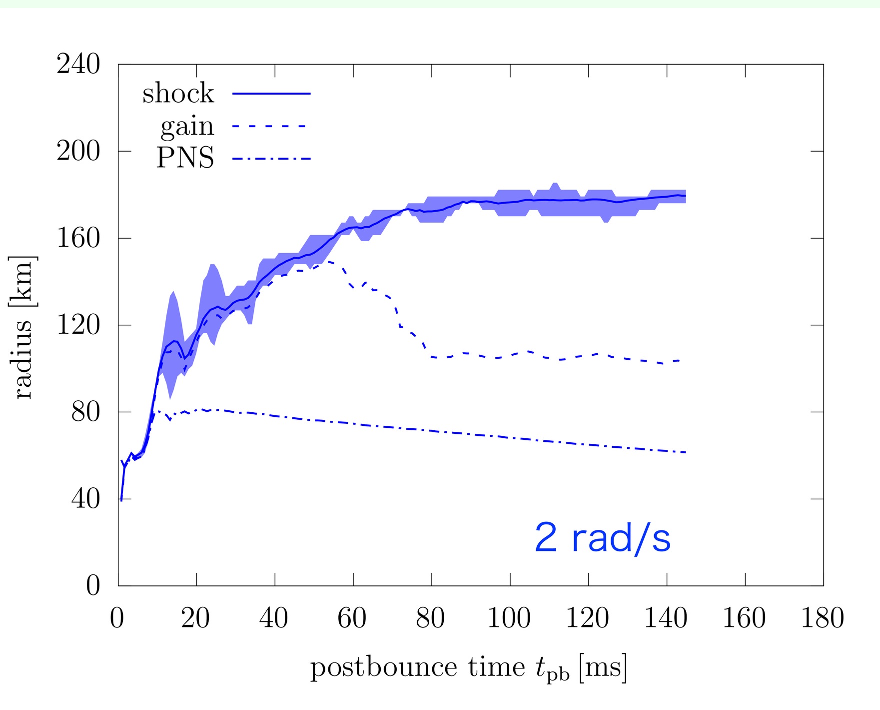
EOS: Furusawa-Togashi EOS (Furusawa et al. 2017)

Neutrino reactions: Bruenn's standard set

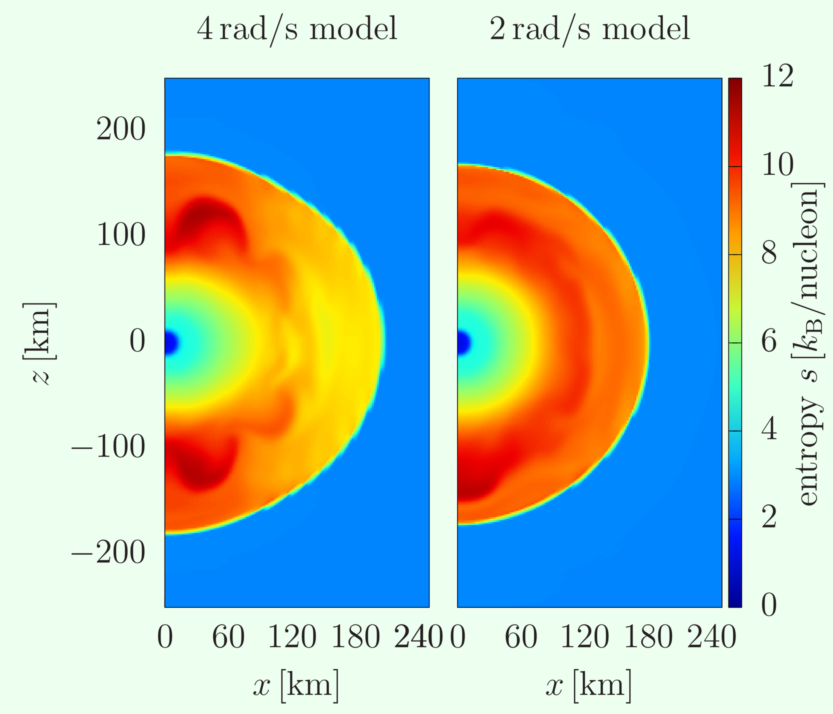
+ Electron capture by light and heavy nuclei, NN-Bremss

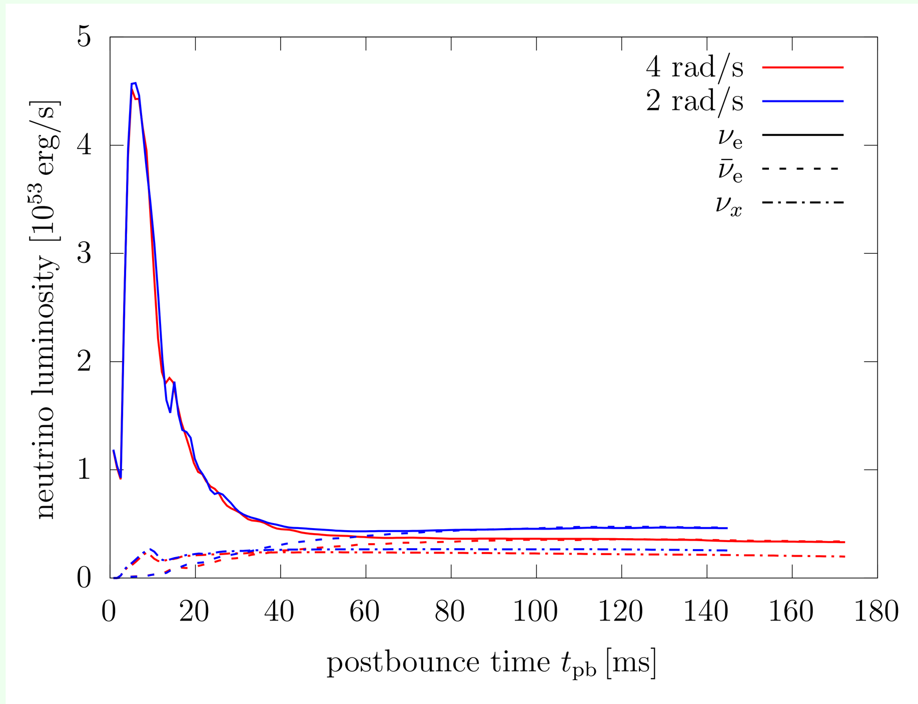
## 3. Results




Entropy distribution@$t_{pb}$=100 ms

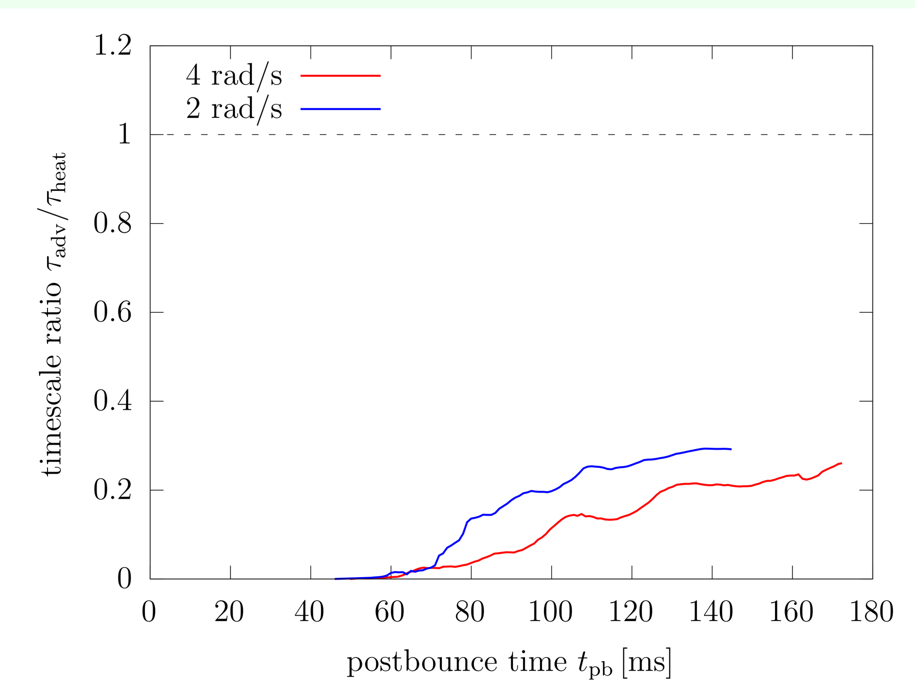



Shock radius for the 4 rad/s model is larger than that for the 2 rad/s model, though whether the shock revival succeed or not is yet to be determined. The shock radii and shock shape is clearly affected by the centrifugal force.

Gain radius (inner boundary of the neutrino heating region) is larger for the 4 rad/s model, implying that the heating rate is smaller. Indeed, the neutrino luminosity is lower for the 4 rad/s model. This is because the surface temperature of the proto-neutron star (PNS) is low owing to the slow contraction by the centrifugal force.

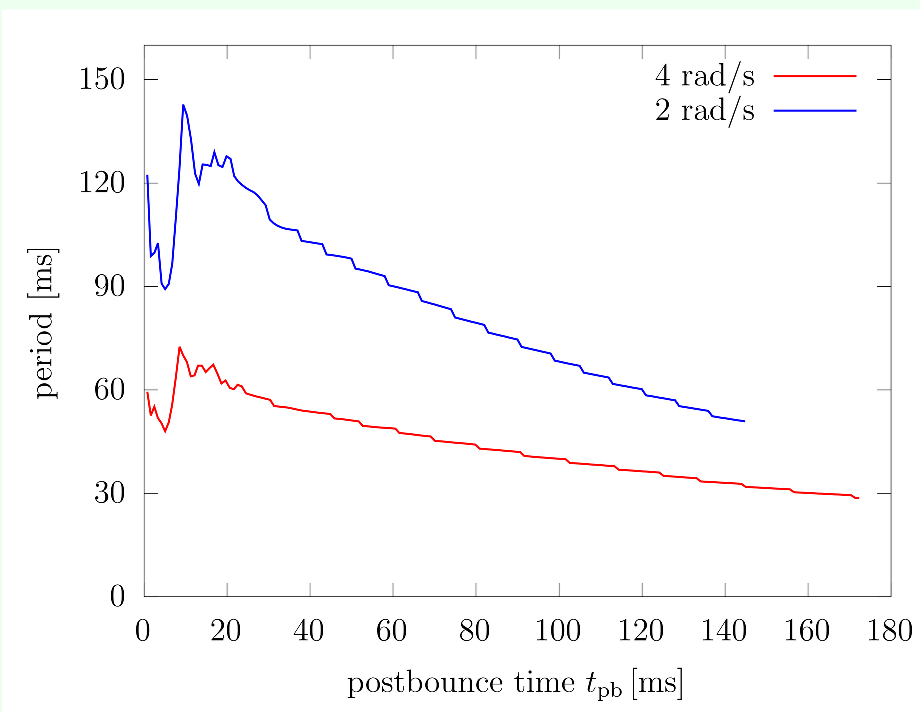
Whether the rotational model explodes or not depends on the competence between the extension of the shock and the slow contraction of the PNS.




$$\frac{\tau_{\rm adv}}{\tau_{\rm heat}} = \frac{\text{advection timescale}}{\text{heating timescale}}$$

Timescale ratio is a diagnostic of explosion: if the ratio exceeds unity, explosion is supposed to occur.

The ratio for both models is <1, but increasing.




Central proto-neutron stars are differentially rotating. The mean rotational periods are several tens to hundreds ms. Continual mass accretion provides angular momentum, and further simulations are required to obtain final rotational period.

## 4. Summary

By using the Boltzmann-radiation-hydrodynamics code, we are running two rapidly rotationg stellar core collapse simulations. Whether the shock revives or not is still uncertain, but the faster rotation model shows more extended shock. Furthermore, our Boltzmann solver provides unique data to investigate the collective neutrino oscillation.