Possible collective neutrino oscillation in a rotating supernova

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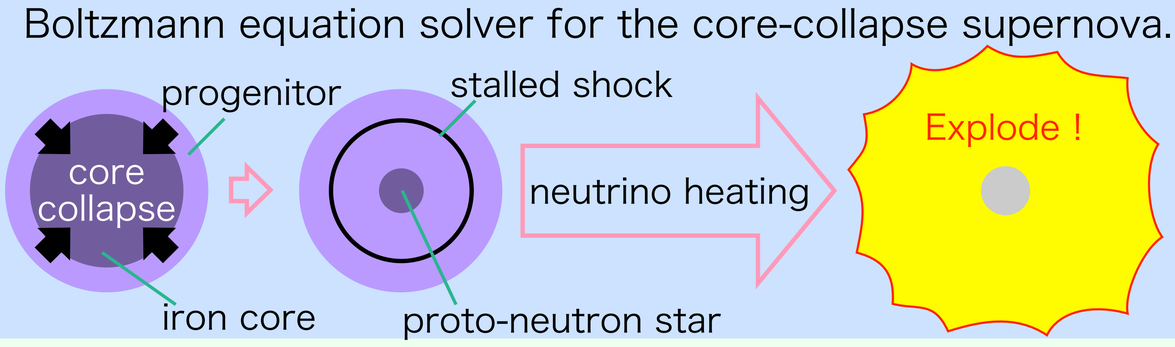
Abstract

With Boltzmann-radiation-hydrodynamics code, we are running the core-collapse simulations of the rotating progenitors. The deformation by the centrifugal force can induce collective neutrino oscillation, which may influence the nucleosynthesis.

1. Introduction

Core-collapse supernovae are explosive deaths of massive stars. Neutrino heating not only is a promising candidate of the energy source, but also changes the nucleosynthetic yields through the electron fraction. The collective neutrino oscillation, in which the neutrino de Broglie frequency is modified by the neutrino—neutrino interaction, can affect the neutrino flavor and hence the nucleosynthetic yields. Investigating the collective neutrino oscillation is very hard computational task, but we can assess the possibility of the occurrence of the collective neutrino oscillation by the Boltzmann equation solver for the core-collapse supernova.



2. Method

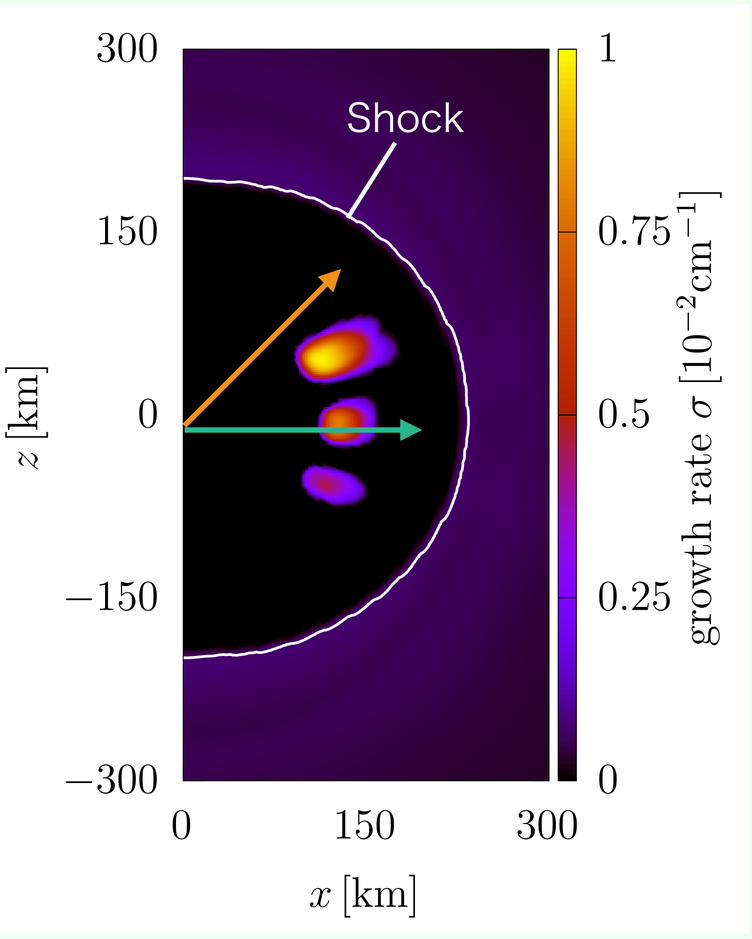
Code: Boltzmann-radiation-hydrodynamics code
Progenitor: 15 M⊙ (Woosley et al., 2002) $\Omega(r) = \frac{2 \text{ or } 4\,\text{rad/s}}{1 + (r/10^8\,\text{cm})^2}$
EOS: Furusawa-Togashi EOS (Furusawa et al. 2017)
Neutrino reactions: Bruenn's standard set
+ Electron capture by light and heavy nuclei, NN-Bremss

The collective neutrino oscillation is governed by the density matrix equation. Here, we linearize the deviation from the neutrino-flavor eigenstate, whose density matrix is diagonal. The linear growth rate of this linearized problem (how much flavor mixes) is approximately evaluated by

$$\sigma = \sqrt{-\left(\int_{G(\Omega)>0} \frac{d\Omega}{4\pi} G(\Omega)\right)\left(\int_{G(\Omega)<0} \frac{d\Omega}{4\pi} G(\Omega)\right)}$$

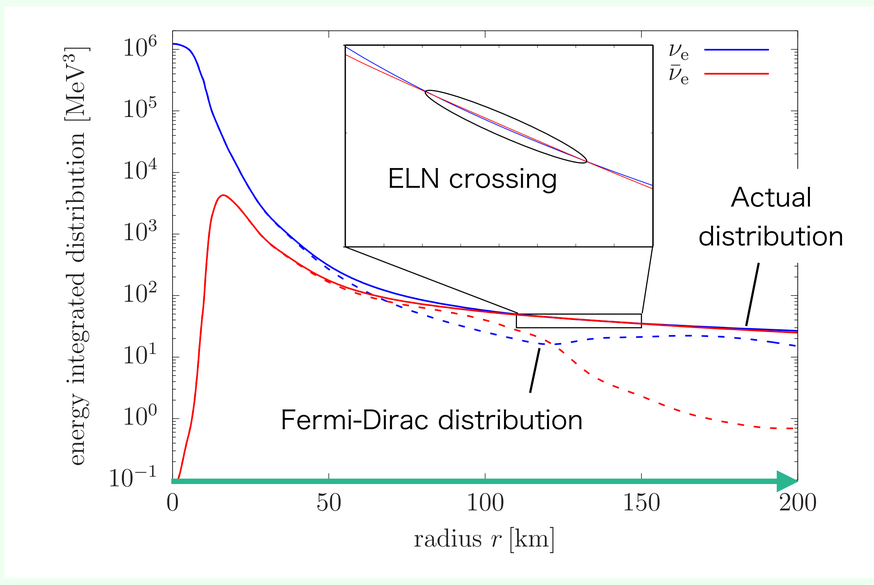
where G(Ω) is the electron lepton number defined by the difference between the energy integrated distribution function of electron neutrinos and antineutrinos.

3. Results

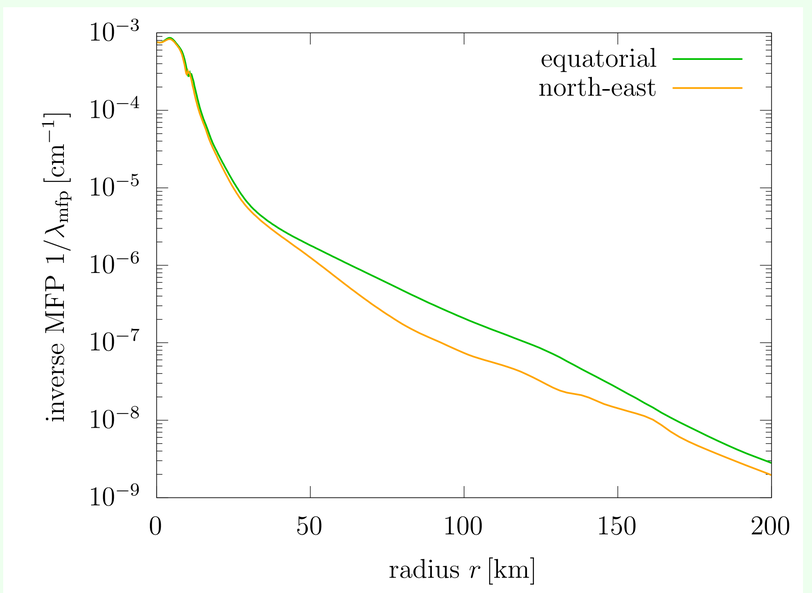


The linear growth rate of the collective neutrino oscillation for 4 rad/s model at 170 ms. This indicates that the collective neutrino oscillation possibly takes place inside the shock wave. Though how the oscillation affects the resultant nucleosynthetic yields is still hard to assess, consideration of the oscillation must be necessary in the future.

Occurrence of the collective neutrino oscillation means there are more antineutrino than neutrinos in some directions. Here, anitineutrinos dominates in the forward direction. This is because of the absorption reactions, whose strength is proportional to the difference from the Fermi—Dirac distribution; because the electron fraction there is small, the FD distribution for antineutrinos becomes larger than that for neutrinos.



Collective neutrino oscillation occurs in the vicinity of the equator. This is because of the equatorial extension of matter by the centrifugal force. In the north-east direction, for example, the absorptivity drops faster than in the equatorial direction, and the neutrino absorption is not enough for the oscillation to occur.



4. Summary

By using the Boltzmann-radiation-hydrodynamics code, we are running rapidly rotating stellar core collapse simulations. In the 4 rad/s model, we found a possible collective neutrino oscillation by evaluating the linear growth rate of the flavor mixing instability. We also found the origin is that there are more antineutrinos than neutrinos in the forward direction, and this is because more neutrinos are absorbed. We further discovered that the centrifugal force plays a role in extending matter equatorially and enhance the neutrino absorption. In the future, the collective neutrino oscillation must be taken account.