Core-Collpase Supernova Simulations by Boltzmann-Hydro Code

*Wakana Iwakami[1], Hirotada Okawa[1], Hiroki Nagakura[2], Akira Harada[3], Ryuichiro Akaho[1], Shun Furusawa[6], Hideo Matsufuru[5], Kosuke Sumiyoshi[4], Shoichi Yamada[1]

1. Waseda University, 2. Princeton University, 3. University of Tokyo, 4. Numazu College of Technology, 5. High Energy Accelerator Research Organization, 6. Tokyo University of Science

A core-collapse supernova is considered as an explosion of a massive star at the end of life. Its explosion mechanism has not been fully understood yet. An iron core is formed in a massive star whose mass is 10 times larger than the mass of the sun. At the core the photodisintegration reaction of iron nuclei or the electron capture reaction occur by increasing temperature and density due to the gravitational contraction. These endthermal reactions take away heat from the matter, and lead to the sudden decrease of the central pressure which prevent the fall of the matter toward the central region. Then the gravitational collapse starts, and the shock wave is launched after the core-bounce which occur when the central density reaches the nuclear density. The explosion succeeds if the shock wave reach the surface of the star, and is observed as a supernova on the earth.

Currently, the most promising explosion mechanism is the neutrino heating mechanism. Neutrinos, enclosed into the central part during gravitational collapse, diffuse out from the proto-neutron star formed at the central part after the core-bounce. The diffusing neutrinos can heat the matter in the gain region below the shock wave. However, explosions have not occurred in one-dimensional spherically symmetric simulations, except for the very low mass star. On the other hand, the hydrodynamical instabilities and turbulence grow in the gain region in the multi-dimensional simulations. This multi-dimensional effect plays an important rule for explosion, since it increases the dwell time of the falling matter in the gain region. The hydrodynamical instabilities grown in the gain region are mainly divided into the neutrino-driven convection and the standing accretion shock instability (SASI). The former is driven by the neutrino heating, and the various scale of the vorticies are developed. The latter is the aspherical deformation of the shock wave, and the large scale of the matter motion is induced. Depending on the neutrino luminosity and the mass accretion rate, one of them is dominant or both of them coexist. Therefore, we might obtain the information about the explosion mechanism or progenitor star if we can detect the signal of convection and SASI by the gravitational wave or neutrino observation.

In order to predict the signals of gravitational waves and neutrinos, the accurate neutrino transport is important for the gravitational core-collapse simulations. The basic equation of the neutrino transport is the Boltzmann equation. Since it is computationally expensive to solve the Boltzmann equation directly, the approximate methods are used for the neutrino transport of the core-collapse simulations. Such methods are constructed using the characteristics of the optically thin and thick limits. Hence, the accuracy of these methods should be validated in the transition region between two limits. Furthermore, the understanding of the neutrino transport in the transition region is important for clarifying the explosion mechanism, because the neutrino heating region corresponds to the transition regions. Recently, we have developed the Boltzmann-Hydro code for solving both Boltzmann equation for neutrino transport and Euler equations for hydrodynamics. This code can calculate correctly the neutrino heating rate and the radiation pressure if the resolution is high enough. In this poster, we introduce the results obtained from the Boltzmann-Hydro code in K and Fugaku computer systems. The neutrino transport is investigated in the situations of growing hydrodynamical instabilities.

Keywords: Core-collapse supernovae, Neutrino Radiation Transfer, Hydrodynamical Instability

