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Neutrino Leakage and Supernova Explosion† ⋆

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Abstract In the process of supernova explosion the leakage of neutrinos is very important. Adopting an one-dimensional spherically symmetrical model, and under the different neutrino leakage modes, the explosion processes of type II supernovae with masses of $12\,M_\odot$, $14\,M_\odot$, and $15\,M_\odot$ are simulated numerically. The results indicate that all these different neutrino leakage modes have influences on the supernova collapse, shock propagation, and supernova explosion. The best values of the related parameters which are propitious for the type II supernova explosion are given. In addition, the impacts of the equation of state and the compression modulus on the simulated results are discussed.

Key words supernovae—neutrinos—equation of state—shock waves

1. INTRODUCTION

Supernova is an explosive phenomenon occurred when a massive star has evolved to its late stage. The study of supernova explosion has become the important component of modern astrophysics. In observations, the luminosity during the supernova explosion can reach $10^7 \sim 10^{10}\ L_\odot$ ($L_\odot$ is the solar luminosity), it means that this star will brighten abruptly by a factor of almost a hundred million, hence the supernova explosion is considered to be the most violent and rare astronomical phenomenon in the universe. Internationally, on the basis of one-dimensional spherically symmetrical model, the numerical simulation of supernova explosion has been developed to the two-dimensional and three-dimensional spatial models, and for a few precursor stars with different masses the examples of successful explosion have been achieved under the 2-dimensional and 3-dimensional models. Although

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this is a great progress of numerical simulation, but for most precursor stars with different masses, the supernova explosion still can hardly be successfully simulated. Therefore, the improvement of the numerical simulation of supernova explosion under the one-dimensional spherically symmetrical model remains to be of important significance.

In the universe, the number of neutrinos is tremendous, they are mainly produced by through the weak interaction of matter in the process of nuclear reaction. Neutrinos bring with a great amount of energy, and the continuous nuclear reactions in the stellar interior are the main origin of neutrinos, hence in astrophysics, especially in the compact astrophysical process, neutrinos play important roles. For example, a new-born proto neutron star will produce and release a great number of neutrinos, which causes a part of the association energy of neutron star to disappear, and finally causes the temperature of neutron star to be increasingly reduced. Therefore, to discuss the neutrino effect in the process of supernova explosion has an important research value and significance for understanding in-depth the mechanism of supernova explosion.

In the collapse of a supernova, the electron capture of matter and the escape of neutrinos are the important processes of energy loss. The decrease of electron abundance on the one side causes the decline of electron pressure, on the other side will produce a large number of neutrinos, the neutrino leakage brings away a large amount of energy to cause the cooling of the core region, and therefore to accelerate the collapse of the core region. In the early stage of collapse, before the material density attains the neutrino trap density, the neutrinos leak directly and freely, and escape from the star; after the material density attains the neutrino trap density, the neutrino free path becomes very small, the neutrinos staying in the stellar core region can only slowly leak and escape away by through the process of diffusive transport, hence the neutrino trap density is an important characteristic parameter. This paper adopts the neutrino leakage equation provided by the Wang Yi-ren's group[1] to calculate the performance of neutrinos in the late stage of stellar evolution. For a given neutrino leakage mode, the trap density is dominated by the adjustable parameter b of optical depth and the characteristic parameter b_f. As for the valuation of the trap density, it has been taken as $1 \times 10^{11} \sim 5 \times 10^{11}$ g$\cdot$ cm^{-3}[2], afterwards, as the study goes deep into the theory of electron capture and the transport process, the more reasonable neutrino trap density obtained from the calculation of neutrino transport is about 1×10^{12} g$\cdot$ cm^{-3}[3]. The increase of neutrino trap density means the increase of neutrino leakage, consequently, the neutrino loss may increase, and the produced rebound shock will move inward, causing further the path of shock propagation to increase, and the increase of energy consumption, which has a very large influence on the supernova explosion.

The type II supernova explosion model can be divided into the instantaneous and delayed explosion models. What to be studied in this paper is the type II supernova instantaneous explosion model proposed successively by Baron, Wolff, and Arnett et al.[4−6]. They suggested that when a large-mass star evolves to the late stage, because of the β process,