New Table of Supernova Equation of State Using a Variational Method and Its Application to Astrophysical Compact Objects

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We have constructed a new equation of state (EOS) for dense nuclear matter based on a variational many-body theory. For the homogeneous phase, the free energy is calculated by the cluster variational method with the realistic nuclear Hamiltonian composed of the Argonne v18 two-nucleon and Urbana IX three-nucleon potentials. For the inhomogeneous phase, the Thomas-Fermi approximation is adopted so as to construct the EOS of non-uniform matter which is consistent with that of uniform phase. It is found that the obtained EOS shows the higher critical temperature and larger mass numbers of nuclides in neutron-rich nuclear matter, as compared with the Shen EOS. We tabulate the present EOS in wade ranges of the temperature, proton fraction, and baryon density. Using the resultant EOS table, we finally perform the calculation of protoneutron star structures and the simple supernova simulation to investigate the properties of our EOS.

KEYWORDS: Nuclear matter, Nuclear EOS, Variational method, Neutron stars, Supernovae

1. Introduction

The equation of state (EOS) for dense nuclear matter is an essential ingredient in many astrophysical simulations, such as core-collapse supernovae, cooling of protoneutron stars, black hole formations, and binary neutron star mergers. However, constructing a nuclear EOS suitable for the astrophysical simulations is a difficult task, because an EOS table must contain various thermodynamic quantities in wide ranges of the temperature, particle fractions, and total baryon density. In fact, only a limited number of EOSs are currently available for the simulations [1]. Since those EOSs are based on phenomenological models for uniform matter, it is desirable that nuclear EOSs calculated within the microscopic many-body theories are applied to astrophysical simulations. Under these circumstances, we have recently constructed a new nuclear EOS table based on the realistic nuclear forces with the variational many-body theory. For uniform matter, the EOS is calculated with the cluster variational method [2, 3], while the Thomas-Fermi method is adopted for non-uniform phase [4, 5]. In this paper, we report on the properties of our nuclear EOS and its applications to protoneutron stars and spherically symmetric core-collapse supernovae.