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Composition and Structure of Massive Protoneutron Star of PSR J0348+0432† ⋆

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Abstract Considering the baryon octet in the framework of relativistic mean field (RMF) theory, and the entropy per baryon is selected to be 1 or 2, we investigate the entropy effect on the protostar properties of the massive neutron star PSR J0348+0432. One set of coupling constants GL85 in the RMF are selected to reproduce the mass of PSR J0348+0432 at zero temperature, and then the parameter set is extended to calculate the properties of the massive protoneutron star with the entropy per baryon S =1 or S =2. It is found that more hyperons will occur in the protoneutron star than that in the zero-temperature neutron star, the temperature in the protoneutron star increases with the increase of density from surface to interior, and the occurrence of hyperons will reduce the interior temperature. Meanwhile, the entropy causes the increase of the mass of massive protoneutron star, and this effect exceeds that of hyperons to decrease the mass of massive neutron star. The entropy also brings on the increase of the radius of protoneutron star. In other words, the cooling of protoneutron star is a contraction process of stellar object.

Key words astroparticle physics—dense matter—equation of state—stars: evolution—stars: massive—stars: neutron

1. INTRODUCTION

Neutron stars are known as the stellar objects with the smallest volume and highest density, they provide with the extreme physical conditions that cannot be realized in the terrestrial laboratories, they are always the research objects in the fields of astrophysics, nuclear physics, and particle physics. The mass of a typical neutron star is about 1.5 solar mass, and the radius is about 12 km[1]. There have been many studies on the mass, radius, and the

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equation of state of neutron stars[2−6]. In 2010, a massive neutron star of $(1.97\pm0.04)\,\mathrm{M}_\odot$[7] was observed, and catalogued as PSR J1614-2230, and in 2013 another massive neutron star PSR J0348+0432 of $(2.01\pm0.04)\,\mathrm{M}_\odot$ was observed. The discovery of this kind of massive neutron stars has strongly supported the hardening of the equation of state for the constituent matter of neutron stars, and aroused the interests of many researchers. Using the chiral quark-meson coupling model, Miyatsu et al. rebuilt the equation of state for the neutron stars at zero temperature, which includes the baryon octec, and calculated the maximum mass to be $1.95\,\mathrm{M}_\odot$, consistent with the mass of the observed PSR J1614-2230[9]. Weissenborn et al.[10] studied the effect of potential well depth of hyperon on the equation of state, and found that if taking account of the strange-meson repulsive interaction among hyperons, the properties of massive neutron star can be calculated. Zhao et al. tried to describe the massive neutron star PSR J1614-2230 by selecting a set of reasonable hyperon coupling parameters[11]. Neutron stars are all evolved from protoneutron stars, to study the properties of massive protoneutron star are quite important for understanding the properties and evolutionary process of massive neutron star, but sofar the studies on the protostar properties of massive neutron stars are relatively rare, especially the entropy effect of the massive neutron star PSR J0348+0432 observed in 2013 has not been reported yet.

In this paper, considering the baryon octec in the framework of relativistic mean field (RMF) theory, and selecting the entropy per baryon to be S =1 or S =2[12], we study the composition and structure of the protostar of the massive neutron star PSR J0348+0432, particularly the entropy effect of the neutron star.

2. RELATIVISTIC MEAN FIELD THEORY UNDER LIMITED TEMPERATURES

The RMF theory is an effective field theory to describe the hyperon interaction[13], in which the scalar meson σ, vector meson ω, and isospin meson ρ are used to describe the interaction among nucleons. σ provides the median-range attractive force, ω provides the short-range repulsive force, and ρ is used to describe the difference between protons and neutrons.

Protoneutron star is a thermodynamic system, for a giant canonical system, the partition function of the system is

$$Z = \mathrm{Tr}\{\exp[-(\hat{\boldsymbol{H}} - \mu\hat{\boldsymbol{N}})/T]\}\,, \tag{1}$$

in which, $\hat{\boldsymbol{H}}$ is the Hamiltonian operator of the system, $\hat{\boldsymbol{N}}$ is the particle number operator of the system, μ indicates the chemical potential, and T expresses the system temperature, from the partition function the energy density ε, particle number density n, pressure P of

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