Study on the properties of a proto-neutron star with SU(6) symmetry

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Abstract

It is of great importance to study the properties of a proto-neutron star(PNS) because of its complex evolution into a cold NS. With the emergence of hyperons, the interaction between hyperon and hyperon needs to be considered. The coupling parameters of all vector mesons are determined by SU(6) symmetry. The research results are meaningful for understanding the properties of PNS.

Introduction

In PNS, the escape of a large number of neutrinos accelerates the cooling of the star and shortens its evolution process. As we all know, the emergence of hyperons will soften the equation of state(EOS), so the repulsion and attraction between hyperon and hyperon should be considered simultaneously. In addition, the hyperon-meson couplings satisfy SU(6) symmetry. In fact, the proportion and interaction force of hyperons in different cases are different, which ultimately leads to different EOS and properties of the star.The observation of gravitational redshift on the surface of a NS can accurately limit the ratio of the mass to radius, thereby constraining the EOS of NS [1].

Relativistic Mean Field Theory

Under the framework of relativistic mean field(RMF) theory [2] with octet of baryons, the interaction of baryons is achieved by exchanging the σ mesons which produce the medium range attraction and the ω mesons responsible for the short range repulsion, and the vector-isospin meson ρ describes the difference between neutron and proton. In addition, the interactions between hyperons can be described through the exchange of scalar meson σ^* and vector meson ϕ [3]. The vector meson coupling constants of ω, ρ and strange vector meson ϕ are determined from the SU(6) symmetry [4]

$$\begin{cases} \frac{1}{3}g_{\omega N} = \frac{1}{2}g_{\omega\Lambda} = \frac{1}{2}g_{\omega\Sigma} = g_{\omega\Xi}, \\ 2g_{\rho N} = g_{\rho\Sigma}, g_{\rho N} = g_{\rho\Xi}, g_{\rho\Lambda} = 0, \\ 2g_{\phi\Lambda} = 2g_{\phi\Sigma} = g_{\phi\Xi} = \frac{2\sqrt{2}}{3}g_{\omega N} \end{cases} \quad (1)$$

Conclusion

Under the framework of RMF theory, the coupling parameters of all vector mesons are determined by SU(6) symmetry. By considering entropy, temperature and neutrino, respectively, we investigate the properties of a PNS, and find that compared with entropy and temperature, neutrino has more obvious influence on the mass of PNS.

References

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Maximum Mass And Corresponding Properties Of (P)NS

Table 1 shows the calculated maximum masses and the corresponding radius and gravitational redshift in different cases. The results show that neutrinos have a significant impact on the mass of PNS. As the proportion of neutrinos increases, the maximum mass of PNS increases. It can be found that the maximum mass of cold NS is the smallest.

	T=0	S=1	S=2	T=10	T=15	T=20	Y=0.1	Y=0.2	Y=0.3
$M_{(max)}(M_\odot)$	1.657	1.664	1.697	1.737	1.744	1.755	1.677	1.770	1.850
R(km)	13.275	13.534	14.400	13.605	14.271	15.123	13.195	12.674	12.548
z	0.256	0.253	0.238	0.267	0.251	0.234	0.265	0.305	0.331

Table 1: Radius and gravitational redshift corresponding to maximum mass. z represents the gravitational redshift of (P)NS star.

EOS And Mass-Radius Relation

By choosing appropriate coupling parameters in RMF theory, the properties of cold NS($T = 0$) and PNS were studied. For PNS, the effects of entropy($S = 1, 2$), neutrinos($Y_L = 0.1, 0.2, 0.3, 0.4$) and temperature($T = 10, 15, 20, 25, 30MeV$) on the properties are considered separately.

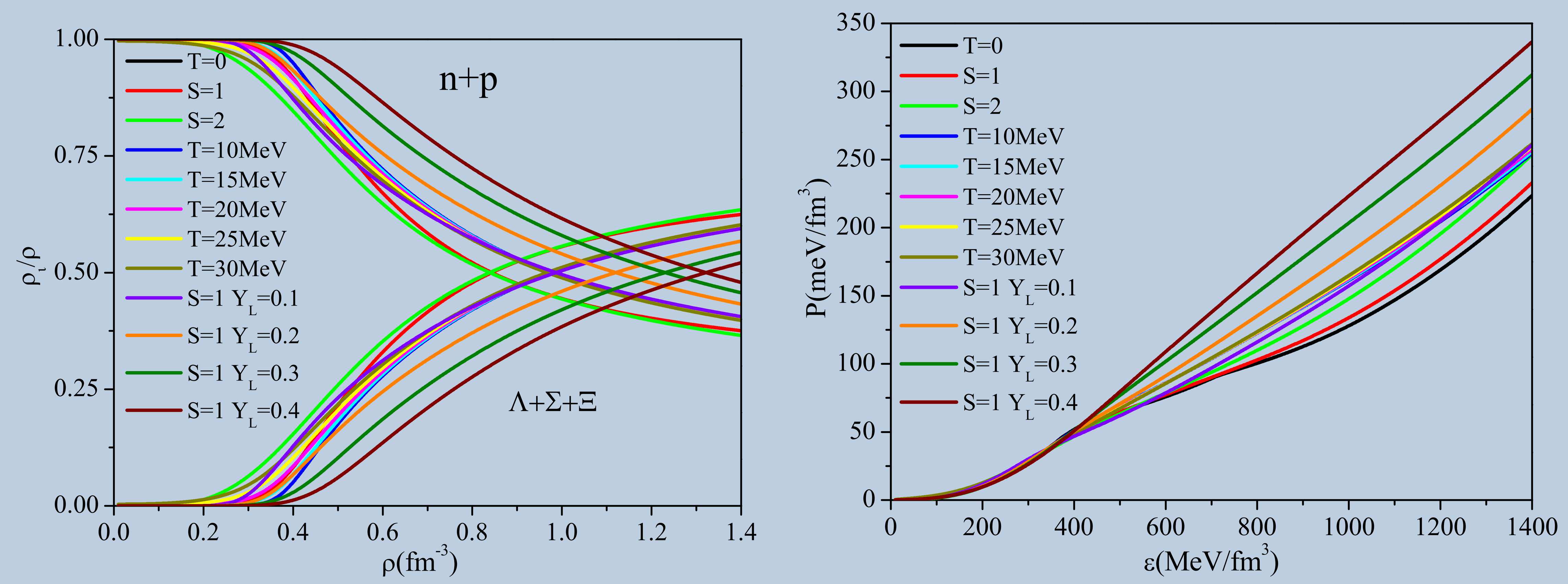

Figure 1: Relative populations of nucleons and hyperons(left); Equation of state(right)

Figure 1 shows the relative populations of nucleons and hyperons as functions of baryon density and the EOS respectively. When the density exceeds a certain value, the proportion of hyperons exceeds that of nucleons. It can be seen that when the proportion of neutrinos is the largest($Y_L = 0.4$), the proportion of hyperons is the smallest, so the obtained EOS is the hardest.

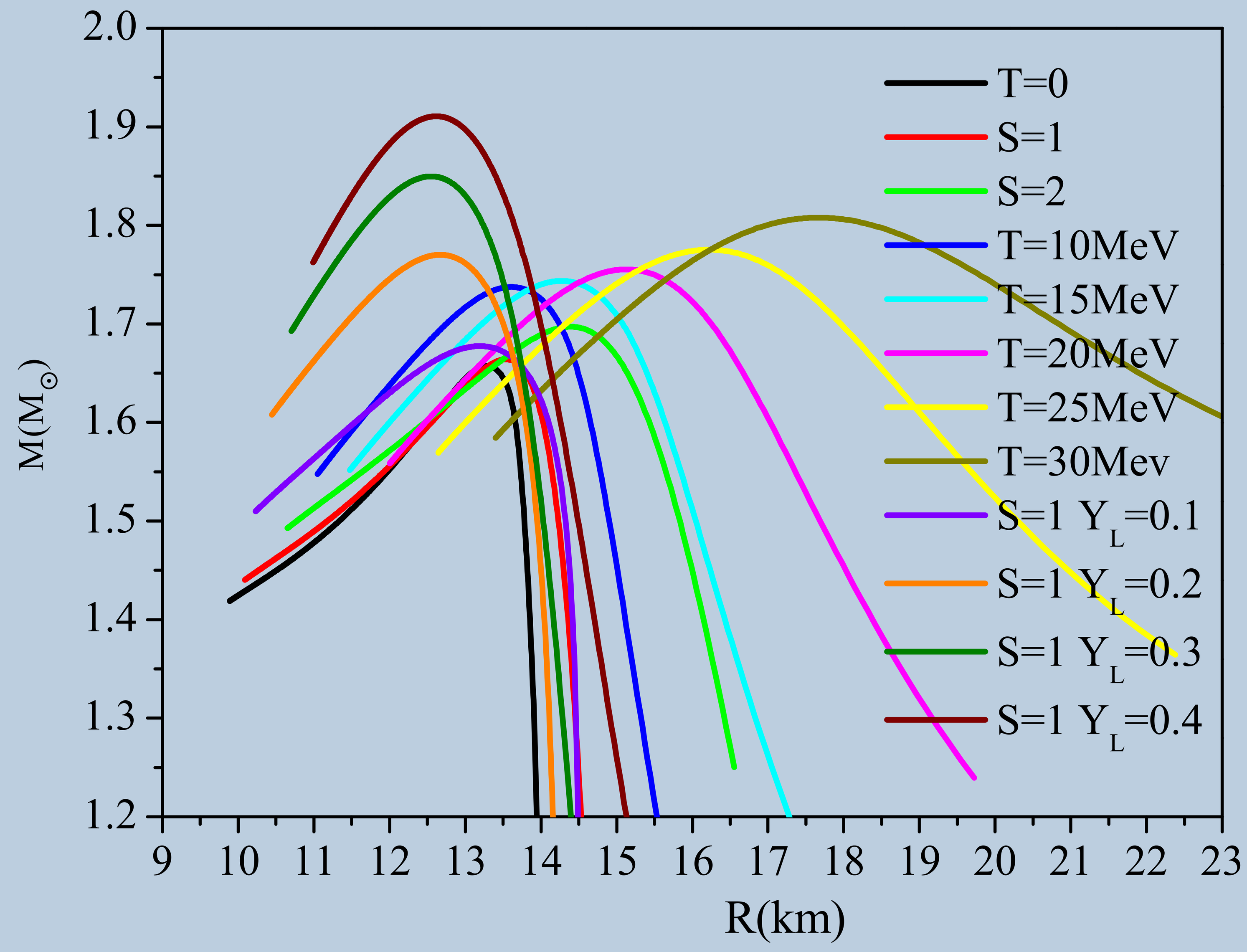

Figure 2: The relationship between mass and radius

Finally, the mass and radius of the (P)NS are calculated, and the result is shown in the Figure 2. Corresponding to the cases of EOS, when $Y_L = 0.4$, the calculated mass is the largest because of the hardest EOS. As the temperature increases, so does the mass and radius. It can be found that compared with entropy and temperature, neutrino has more obvious influence on the mass. In addition, as the temperature decreases and the proportion of neutrinos increases, the gravitational redshift increases. By analyzing the interaction forces between hyperons, it is helpful to understand the results. For example, the attraction between hyperons reduces the mass of a PNS, while repulsion is the opposite.