Interplay between hyperons and antikaons in E-RMF description of neutron stars

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I. INTRODUCTION

In the core of Neutron star (NS), the density is generally considered as high as several times the nuclear saturation density. At such high density, the conventional view of the NS, composed of nucleons and leptons, is insufficient and more realistic approaches are needed [1]. With increasing density, the chemical potential of baryon and electric charge increases rapidly and they provide energy for the production of low energy hyperons and kaons. This effects in softening the EoS and hence reduce the maximum mass of NS. Hyperons can also influence transport properties and thermal evolution of the stars. The onset of kaon condensation could send neutron stars into low-mass black holes and hence it is very interesting issue to investigate the stability of NS with the inclusion of kaon condensation.

Considering the fact that K^- meson is more favoured at lower density than other kaon species, we take only K^- into account here. With a similar reason, we choose Λ hyperon. With the inclusion of both K^- and Λ we study the properties of NS matter.

II. FORMALISM

As elaborated in our previous article [2], a recent version of RMF model [3] is adopted to describe the NS matter with the K^-. Here we extend it with the inclusion of Λ hyperon. The Λ hyperon (strangeness $S = -1$, isospin $I = 0$, and spin parity $J^P = \frac{1}{2}^+$), participate only in the interaction propagated by the isoscalars, i.e. σ and ω mesons. These interactions can be described by the Lagrangian density,

$$\mathcal{L}_\lambda = \bar{\psi}_\Lambda(i\gamma^\mu\partial_\mu - M_\Lambda - g_{\sigma\Lambda}\sigma - g_{\omega\Lambda}\gamma^\mu\omega_\mu)\psi_\Lambda. \quad (1)$$

In the effective Langragian approach adopted here, knowledge of three distinct sets of coupling constants, parametrizing — nucleon-meson, kaon-meson, hyperon-meson are required. The detailed list of parameters for nucleon-meson and kaon-meson are explained in our previous work [2]. Here the hyperon-meson coupling constants are taken from the SU(6) quark model, with $g_{\omega\Lambda} = 2g_{\omega N}/3$, $g_{\rho\Lambda} = 0$. The scalar meson-hyperon coupling constant is adjusted to the potential depths U_Λ felt by a Λ hyperon in the bath of nucleons at saturation, following the relation,

$$U_\Lambda = -g_{\sigma\Lambda}\sigma(\rho_0) + g_{\omega\Lambda}\omega(\rho_0), \quad (2)$$

where $U_\Lambda = -30$ MeV [4].

III. RESULTS

We start our investigation with the conventional view of the NS and extend it with inclusion of K^-, Λ and K^- Λ and compare these results. The onset of kaon condensation determined by the interplay between kaon energy and electron chemical potential and similarly the onset of Λ hyperon is depend on the interplay of neutron chemical potential and Λ hyperon chemical potential. These quantities depend on the EoS and hence the model. In our calculations presented here, we consider the G2 parameter set.

In fig. 1(a) we have plotted the pressure as a function of energy density with and without the inclusion of exotic particles. Inclusion of exotic particles soften the EoS and the softness depend on the onset of the exotic particle. The onset of Λ hyperon is earlier than K^- and hence Λ hyperon softens the EoS more. With the inclusion of both exotic particles the onset of K^- is delayed and hence the effect of K^-

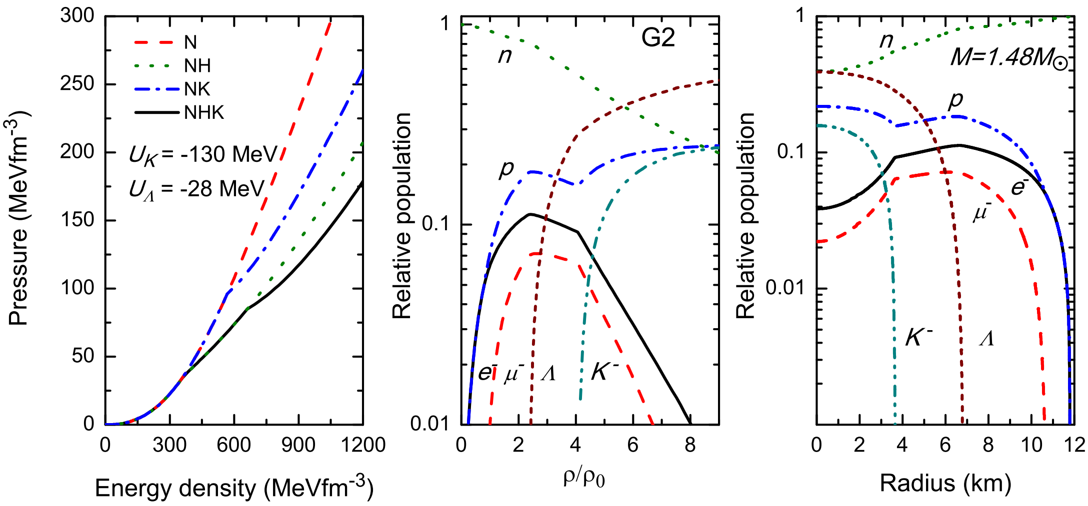

FIG. 1: (a)The EoS for a pure nucleon (N), nucleon-kaon (NK), nucleon-Λ hyperon (NΛ), nucleon-kaon-Λ hyperon (NKΛ) phases with G2 parameter set. (b)The relative population of hadron and lepton in NS as a function of baryon density calculated with G2 parameter set. (c)The composition of maximum mass of NS as a function of radial distance calculated using G2 parameter set.

Composition	Mass ($M_\odot$)	Radius (km)
N	1.95	11.21
NK	1.76	11.56
NΛ	1.53	11.31
NΛK	1.48	11.96

TABLE I: The mass- radius relation for a pure nucleon (N), nucleon-kaon (NK), nucleon-Λ hyperon (NΛ), nucleon-kaon-Λ hyperon (NKΛ) phases with G2 parameter set, for $U_K = -130$ MeV and $U_\Lambda = -30$ MeV.

on the EoS is lesser. These effects should naturally be seen in the calculation of maximum mass and radius of NS.

Our results for maximum mass and corresponding radius of NS are given in Table I for different compositions. Mass with G2 parameter set decreases with the inclusion of exotic particles while the radius increases. There is a significant reduction of mass in the presence of K^- and Λ hyperon and it marginally changes with the inclusion of kaon in the NΛ phase. Figures 2(b) and 2(c) represent the NS structure as a function of baryon density and radial distance. We observe that the Λ and K^- are strongly populated in the inner core as much as neutrons and protons, respectively.

In this work, we quantitatively compare the N, NΛ, NK, NΛK interactions in NS matter and show that the hyperons and antikaons can strongly influence the properties of NS, even in the presence of higher order couplings. We are studying the inclusion of hyperon-hyperon and antikaon-antikaon interactions, which could change this scenario.

References

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