Massive hyperonic stars with the IUFSU parameter set

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Introduction

The recent discovery of massive neutron stars, such as PSR $J0348+0432$ [1] and PSR $J1614-2230$ [2], has raised questions about the existence of exotic matter such as hyperons in the neutron star core. Also the validity of many established equations of states (EoS's) like the GM1 and FSUGold are questioned. We investigate the existence of hyperonic matter in the central regions of massive neutron stars using Relativistic Mean Field (RMF) theory with the recently proposed Indiana University Florida State University (IUFSU) model. It is a new relativistic parameter set derived from FSUGold. Whether this new EoS can accommodate the hyperons inside compact stars, with the severe constraints imposed by the recent observations of $\sim 2M_\odot$ pulsars (Recently the radio timing measurements of the pulsar PSR $J0348+0432$ and its white dwarf companion have confirmed the mass of the pulsar to be in the range $1.97-2.05$ M$_\odot$ at 68.27% or $1.90-2.18$ M$_\odot$ at 99.73% confidence [1]), needs to be explored. In this work we plan to make a detailed study of such a possibility. For this purpose we have extended the IUFSU interaction to include the full baryon octet to construct a new equation of state and investigate the neutron star properties with hyperons.

IUFSU with hyperons: Equation of state

One of the possible approaches to describe neutron star matter is to adopt a RMF model subject to β equilibrium and charge neutrality. For our investigation of nucleons and hyperons in compact star matter we choose the full standard baryon octet as well as electrons and muons. Contribution from neutrinos are not taken into account assuming that they can escape freely from the system. In this model, baryon-baryon interaction is mediated by the exchange of scalar (σ), vector (ω), isovector (ρ) and the strange vector (ϕ) mesons. The Lagrangian density we considered is given in ref. [3].

The EoS gets softened due to the inclusion of hyperons whereas the inclusion of the ϕ meson makes the EoS stiffer.

Static and Rotating stars

In this section we are going to discuss the properties of static and axisymmetric rotating stars using the EoS which we have studied in the last section. The EoS without ϕ meson is softer compared to that with ϕ meson. So we do not discuss the EoS without ϕ as it results in lower maximum mass.

In this work we adopt the procedure of Komatsu *et al.* [4] to look into the observable properties of static and rotating stars. For this purpose the RNS code is used in this work. This code, developed by Stergoilas, is very efficient in calculating the rotating star observables [5]. For static stars with hyperonic core we get a maximum mass of $1.62M_\odot$. So IUFSU with hyperons can not reproduce the observed mass for static stars. However, as the observed $\sim 2M_\odot$ neutron stars are both pulsars, we compare the results in the rotating limit.

In Fig. 1 we plot the Mass-Radius curves for stars rotating with Keplerian velocities, for two cases. In Fig.1(a) we fix the cascade potential at $U_\Xi^{(N)} = +40$ MeV and vary $U_\Sigma^{(N)}$ between -40 MeV and $+40$ MeV. In Fig.1(b)

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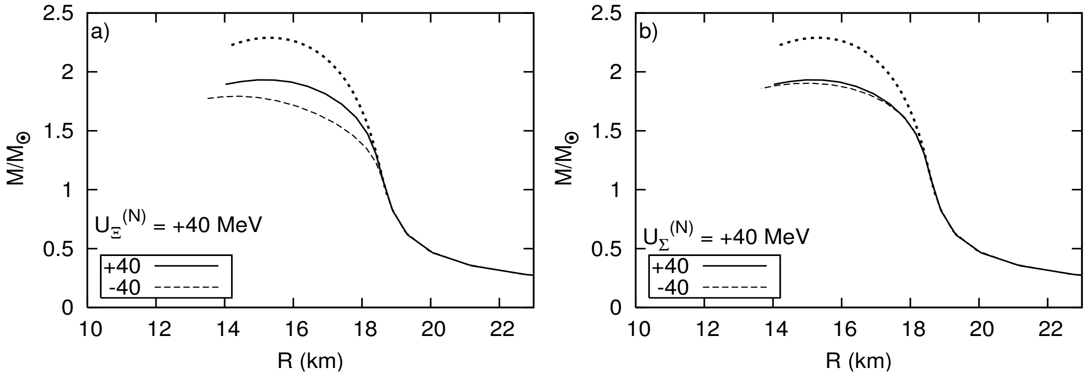

FIG. 1: Mass-Radius curves for rotating stars for two cases a) $U_{\Xi}^{(N)} = +40$ MeV and $-40MeV \leq U_{\Sigma}^{(N)} \leq +40$ MeV and b) $U_{\Sigma}^{(N)} = +40$ MeV and $-40MeV \leq U_{\Xi}^{(N)} \leq +40$ MeV. The uppermost curve in each case corresponds to the pure nuclear matter.

$U_{\Sigma}^{(N)}$ is fixed at +40 MeV and $U_{\Xi}^{(N)}$ is varied as before. The pure nuclear matter case is also shown in the uppermost curve. Maximum mass for the pure nucleonic star is $2.29M_{\odot}$ with a radius of 15.31 km. We see that the maximum mass obtained for a rotating star with hyperonic core is $1.93M_{\odot}$ with a radius of 14.7 km in the Keplerian limit with angular velocity $\Omega = 0.86 \times 10^{4} s^{-1}$, for $U_{\Sigma}^{(N)} = +40$ MeV and $U_{\Xi}^{(N)} \geq 0$. We see that the maximum mass for the rotating case increases with $U_{\Sigma}^{(N)}$ as we go towards more positive values of this potential. At $U_{\Sigma}^{(N)} = -40$ MeV we get a maximum mass of $1.79M_{\odot}$ whereas for $U_{\Sigma}^{(N)} = +40$ MeV the maximum mass is $1.93M_{\odot}$. The effect of $U_{\Xi}^{(N)}$ is much less significant on the maximum mass. From $U_{\Xi}^{(N)} = -40$ MeV to $U_{\Xi}^{(N)} = +40$ MeV mass changes only by $\triangle M = 0.03M_{\odot}$.

In the Keplerian limit we get a maximum mass of $1.93M_{\odot}$, which is within the 3σ limit of the mass of PSR $J0348+0432$ and 1σ limit of the earlier observation of PSR $J1614-2230$. We have looked at the particle densities inside the star having the maximum mass and found that a considerable amount of hyperons are present near the core. Therefore, our results are consistent with the recent observations of highly massive pulsars confirming the presence of hyperons in the core of such massive neutron stars.

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