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Stiffening baryonic equation of state with hyperons

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Study of the structure and properties of neutron stars (NS) has attracted ever increasing theoretical and observational efforts during the last few decades [1]. The baryonic equation of state (EOS) is an essential step towards creating an efficient and convenient model
for NS structure and composition [2-4]. Recent observations of two solar-mass NS, lead the EOS of theoretical models to a more stiff behavior until a value greater
than of this value for the maximum mass of NS is obtained. Due to rapid increase of the nucleon chemical potential with density, hyperons are expected to appear.
When strange matter is included in the structure, the EOS gets an
inevitable soft behavior. Having large rest mass of
hyperons, reduces of the kinetic energy density and lies these
particles at lower momentum states. Therefore the EOS with
hyperons needs to be stiffer. We can overcome to this softening mechanism
through a generalized interaction to reach finally the value upper than
$2M_\odot$ for maximum mass of NS. This generalized
interaction of Myers and Swiatecki (MS) type [2,3] with explicit density and momentum
dependent strength in phase space is:
$\mathrm{V}_{12} = -2\,G_{B1,B2}\,\rho_0^{-1} f(\frac{r_{12}}{a})\,\{\frac{1}{2}(1\mp\xi)\alpha - \frac{1}{2}(1\mp\zeta)\times[\beta(\frac{p_{12}}{p_b})^2 - \gamma(\frac{p_b}{|p_{12}|}) + \sigma(\frac{2\bar{\rho}}{\rho_0})^{\frac{2}{3}}]\} f(\frac{r_{12}}{a}) V_{12} = \frac{1}{4\pi a^3}\frac{exp(-\frac{r_{12}}{a})}{\frac{r_{12}}{a}}\bar{\rho}^{\frac{2}{3}} = \frac{1}{2}(\rho_1^{\frac{2}{3}} + \rho_2^{\frac{2}{3}})$.

The interaction between like and unlike particles can be distinguished by *l,u* where the minus and plus signs indicate to like and unlike particles respectively:

$$\alpha_{l,u} = \frac{1}{2}(1\mp\xi)\alpha\ ,\ \beta_{l,u} = \frac{\eta}{2}(1\mp\zeta)\beta\ ,\ \gamma_{l,u} = \frac{1}{2}(1\mp\zeta)\gamma\ ,\ \sigma_{l,u} = \frac{\eta}{2}(1\mp\zeta)\sigma,$$

where $\eta = 1$ as that of MS potential for nucleon-nucleon interaction and $\eta = (\frac{\rho_B}{\rho_0})^{\frac{2}{3}}$ for hyperon-baryon interaction. According to the available hypernuclei experimental data, the Λ hyperon gets the best known adjustable potential well $U_\Lambda^{(N)} \simeq -30(MeV)$ in normal nuclear matter. In contrary to the $\Lambda - N$ interaction, we can't firmly extract the other potential well depths $U_i^{(j)}$ known as potential felt by baryon i-th in saturation density of baryonic matter j-th. This because, related hypernuclear experimental data are scared and ambiguous. Finally, we can generally adopt the following values $U_\Sigma^{(N)} \cong +30(MeV)$, $U_\Xi^{(N)} \cong -18(MeV)$ and: $\mathrm{U}_\Xi^{(\Xi)} \cong U_\Sigma^{(\Xi)} \cong U_\Lambda^{(\Xi)} \cong U_\Sigma^{(\Sigma)} \cong U_\Xi^{(\Sigma)} \cong U_\Lambda^{(\Sigma)} \cong 2U_\Lambda^{(\Lambda)} \cong 2U_\Xi^{(\Lambda)} \cong 2U_\Sigma^{(\Lambda)} \cong -10(MeV). As a result, the baryon-baryon coupling constants \mathrm{G}_{B1,B2}$ can be adjusted to the above constrain values for potential depths. Our main focus has been dedicated to study the possibility of how much the baryon-baryon interaction can affect to the stiffness of the EOS to raise the maximum mass of NS in agreement with the resent observed mass. It was shown that the hyperon formation is very sensitive to the interactions furnished by the baryon-baryon coupling constants. Within our generalized interactions with hyperon degrees of freedom the maximum mass of NS is in the range $1.90 \sim 2.09M_\odot$ for different interactions whereas within MS interactions this value is in the range $1.16 \sim 1.26M_\odot$. Our findings about the stellar matter
properties with strangeness content show the capability
and the general applicability of our statistical model.

References:

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