A two meson exchange hyperonic TBF and consequences for neutron stars

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Outline

• NN and NY models
• Importance NNN TBF
• Hyperonic TBF and neutron stars
• Hyperonic TBF in hadronic matter
• Results
• Conclusions
NN and NY models

- Modern NN potentials ⇒ reproduce experimental scattering data up to 350 MeV in Lab! ⇒ very accurate!!

- Av18, CD-Bonn, Nijmegen 93...

- NY potentials (Nijmegen, Jülich...) ⇒ constrained by few (35) scattering data...less accurate!!

- Chiral potentials both for NN and NY forces recently built ⇒ very promising!
Importance of NNN forces

- Why do we need a NNN force?
- NN force not able to reproduce binding energies of finite nuclei ⇒ something missing...
- Saturation point of symmetric nuclear matter cannot be reproduced without a NNN force (at least using non-relativistic microscopic models)
- NNN TBF are important for nuclear physics!!
Hyperonic TBF forces

- NNY, NYY and YYY forces may play an important role in finite hypernuclei and infinite hadronic matter (Neutron stars) [Chalk, Gal, Usmani, Bodmer, Takatsuka, Loiseau, Nogami]

Recent measurement of a 2 solar mass pulsar!!

[Demorest et al. Nature 467, 1081 (2010)]

Microscopic models are in trouble

A possible solution ⇒

inclusion of hyperonic TBF

- Hyperonic TBF could provide the strength needed to reconcile theory and observations
  [T. Takatsuka et al. EPJ A 13, 213 (2002)]

- Preliminary study: I. Vidaña, D. Logoteta, C. Providencia, A. Polls and I. Bombaci
  EPL 94 11002 (2012) ⇒ \( M_{\text{max}} = 1.6 \) solar masses... now ...

- We built a NNY interaction based on two meson exchange mechanism ⇒ \( \pi, K, \sigma, \omega \)

- All vertices fixed at two body level

- Coupling constants and cut off consistent with the Jülich potential
Three baryon scattering amplitude

Two meson exchange approximation

\[ B_i = N, \Lambda, \Sigma \quad B = N, \Lambda, \Sigma, \Delta, \bar{N}, \bar{\Lambda}, \bar{\Sigma}, \Sigma^* \]
The BHF approach

\[ G(\omega)_{B_1B_2B_3B_4} = V_{B_1B_2B_3B_4} + \sum_{B_iB_j} V_{B_1B_2B_iB_j} \times \frac{Q_{B_iB_j}}{\omega - E_{B_i} - E_{B_j} + i\eta} G(\omega)_{B_iB_jB_3B_4} \]

\[ U_{B_i}(\vec{k}) = \sum_{B_j} \sum_{\vec{k}'} n_{B_j}(|\vec{k}'|) \times \langle \vec{k} \vec{k}' | G(E_{B_i}(\vec{k}) + E_{B_j}(\vec{k}'))_{B_iB_jB_iB_j} | \vec{k} \vec{k}' \rangle_A \]

\[ E_{B_i}(\vec{k}) = M_{B_i} + \frac{\hbar^2 k^2}{2M_{B_i}} + \text{Re}[U_{B_i}(\vec{k})] \]

\[ \epsilon_{BHF} = \frac{1}{V} \sum_{B_i} \sum_{k \leq k_{F_i}} \left[ M_{B_i} + \frac{\hbar^2 k^2}{2M_{B_i}} + \frac{1}{2} U_{B_i}(\vec{k}) \right] \]

In our calculation: \textit{Av18 NN potential} + NNN + 
+ \textit{Jülich04 NY potential} + NNY force

We neglected the YY interaction
NNY in hadronic matter

Effective potentials

Averaging over $N \Rightarrow$ effective $NY$ force:

$$\tilde{W}_{NY}(1, 2) = \frac{1}{(2S_N + 1)(2T_N + 1)} Tr_{(\tau_3, \sigma_3^N)} \int d\mathbf{r}_3^N W_{NNY}(1, 3, 2) n(1, 3, 2)$$

Averaging over $Y \Rightarrow$ effective $NN$ force:

$$\tilde{W}_{NN}(1, 2) = \frac{1}{(2S_Y + 1)(2T_Y + 1)} Tr_{(T_3, \sigma_3^Y)} \int d\mathbf{r}_3^Y W_{NNY}(1, 3, 2) \tilde{n}(1, 3, 2)$$
$U(k=0)$ for $\Lambda$ and $\Sigma^-$
\[ \beta = 0.75; Y = 0.1, 0.3; \alpha = 1 \]

\[
\rho = \rho_n + \rho_p + \rho_\Lambda + \rho_\Sigma^- \\
\beta = (\rho_n - \rho_p)/(\rho_n + \rho_p) \\
Y = (\rho_{\Sigma^-} + \rho_\Lambda)/\rho \\
\alpha = (\rho_{\Sigma^-} - \rho_\Lambda)/(\rho_{\Sigma^-} + \rho_\Lambda)
\]
\[ \beta = 0.75; \ Y = 0.1, \ 0.3; \ \alpha = 0 \]

\[
\rho = \rho_n + \rho_p + \rho_\Lambda + \rho_{\Sigma^-} \\
\beta = (\rho_n - \rho_p)/(\rho_n + \rho_p) \\
Y = (\rho_{\Sigma^-} + \rho_\Lambda)/\rho \\
\alpha = (\rho_{\Sigma^-} - \rho_\Lambda)/(\rho_{\Sigma^-} + \rho_\Lambda)
\]
Conclusions

• We constructed a two meson exchange NNY potential

• All vertices fixed at two body level by Jülich NY potential

• Z-diagram produces strong repulsion increasing the density as in the NNN case

• Important consequences for neutron star physics ⇒ work in progress!

• β-stable EoS ⇒ NS Maximum mass
Future work

• Include $\rho$ and $\kappa^*$ meson exchange

• Develop a NNY interaction consistent with the NY Nijmegen potentials

• Calculate a NYY potential

• Confront with hyperonic TBF based on Chiral perturbation theory...
Thank you!!