EOS dependence of the proto-neutron star evolution

Giovanni Camelio
with Alessandro Lovato, Omar Benhar
Jose A. Pons, Leonardo Gualtieri & Valeria Ferrari
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Motivation

What is the Equation Of State at high density and temperature?

Proto-Neutron Stars (PNSs) are the ideal playground:

- result of a core-collapse supernova
- lifetime $\sim$ minutes
- first phase of life of the neutron star
- supranuclear densities
- temperatures $\sim 40$ MeV
- HUGE amount of neutrinos released
- gravitational wave emission
A many-body EOS

Zero temperature case discussed in Benhar and Lovato (2017):

- non relativistic
- Correlated Basis Function – Effective Interaction formalism
- 2-body potential: Argonne V6 → charge symmetry
- 3-body potential: Urbana IX
- \( \sim 2.3 \, M_\odot \) max mass

Finite temperature extension will be presented in Benhar, Lovato & Camelio (in preparation):

- temperatures up to 50 MeV
- fits will be provided (see also Camelio+ 2017)
Scattering neutron-proton

\[ \delta \, [\text{deg}] \]

\[ \frac{n_B}{n_0} \]

np \, ^1S_0

\[ E_{\text{lab}} \, [\text{MeV}] \]
How to include it in the simulation?

We choose to use a fit:

- thermodynamical consistency is easy (derivatives)
- physical limiting behaviour (no singularities!)
- polytropic fit of the interacting free energy $f_i(n, T, Y_p)$
- all quantities have been fitted at the same time

\[
\begin{align*}
    f_i(n, T, Y_p) &= (1 - 2Y_p)f_{PNM}(n, T) + 4Y_p(1 - Y_p)f_{SNM}(n, T) \\
    f_{*NM}(n, T) &= a_1n + a_2n^2 + a_3n^3 + a_4n^4 \\
    &\quad\quad + nT^2(a_5 + a_6T + a_7n + a_8nT)
\end{align*}
\]
The fit
The fit
Neutrino diffusion

1. single particle effective spectrum from the many-body calculations
2. effective mass $m^*$ and single particle potential $U_0$ from a fit of the single particle spectrum:
   \[ \mathcal{E}(k) = \frac{k^2}{2m^*} + U_0 \]
3. neutrino mean free path in interacting matter (mean field), see Reddy+ (1998)
Results

$M_B = 1.40 \, M_{\text{sun}}$

Figure: Camelio+ (2017)
Results

$M_B = 1.40 \, M_{\text{sun}}$

Figure: Camelio+ (2017)
Results

\[ M_B = 1.40 \ M_{\text{sun}} \]

\[ f \]

\[ \nu \]

\[ g_{1,f} \ [\text{Hz}] \]

\[ t \ [\text{s}] \]

**Figure:** Camelio+ (2017)
Conclusions

- new non relativistic many-body EOS at finite temperature
- new finite temperature EOS fit
- PNS evolution with self-consistent neutrino mean free paths
- neutrino and gravitational wave signals on Earth detectors

To be used in simulations, the EOS should be equipped with microphysical details: $m^*$, $U_0$, $\lambda_\nu$, …
Thanks!

contact: giovanni.camelio@astro.su.se

Backup: neutrino signal on Earth detectors

Figure: Camelio+ (2017)
Backup: mass-radius diagram

Figure: Camelio+ (2017)