EOS dependence of the proto-neutron star evolution

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thanks to: NewCompStar

PHAROS meeting @ Coimbra
26 September 2018

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 $\simeq 40\,\mathrm{MeV}$
- HUGE amount of neutrinos released
- gravitational wave emission

A many-body EOS

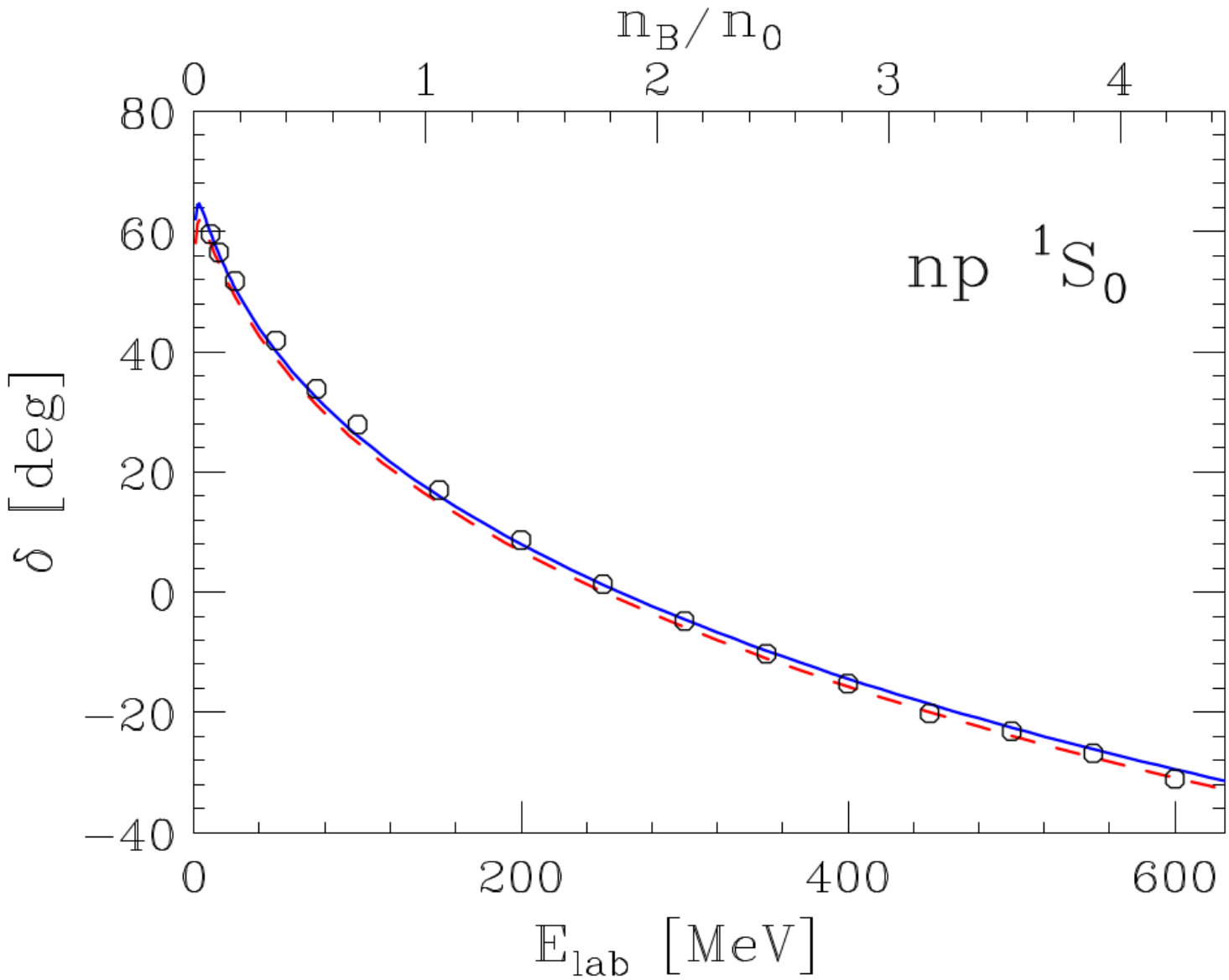
Zero temperature case discussed in Benhar and Lovato (2017):

- non relativistic
- Correlated Basis Function – Effective Interaction formalism
- 2-body potential: Argonne V6 $\rightarrow$ 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 $50\,\mathrm{MeV}$
- fits will be provided (see also Camelio+ 2017)

Scattering neutron-protron



How to include it in the simulation?

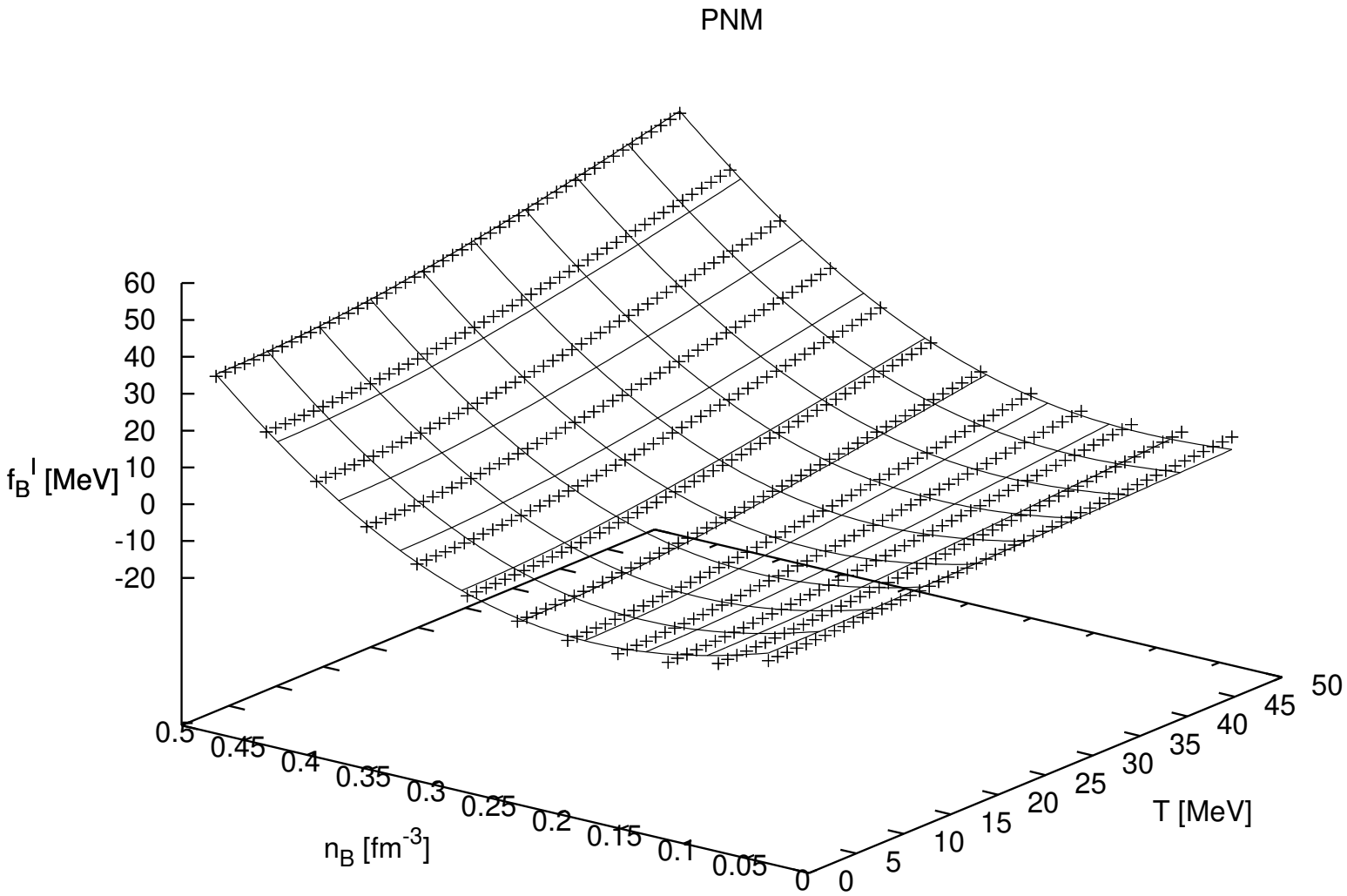
We choose to use a fit:

- 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

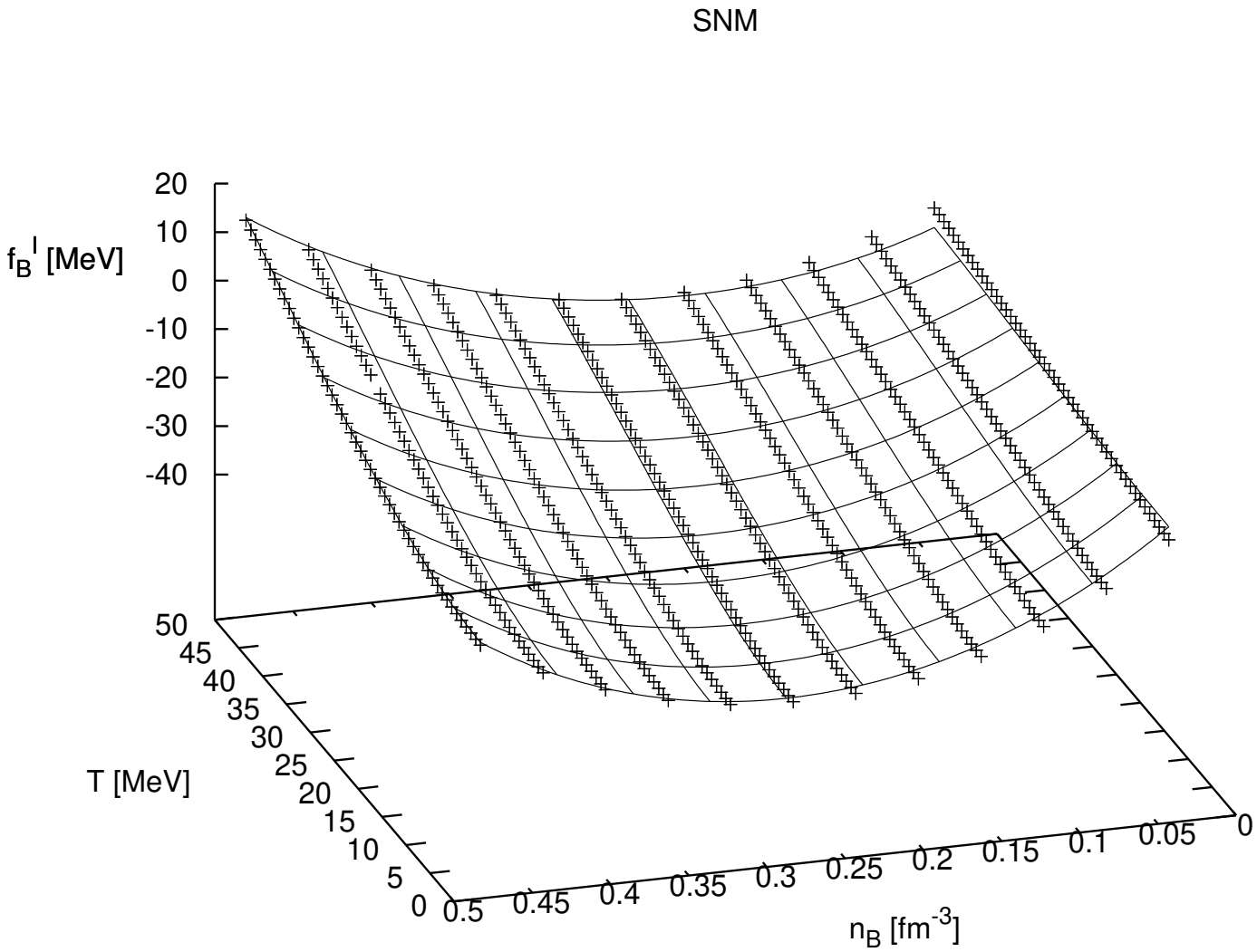
$$f_i(n, T, Y_p) = (1 - 2Y_p) f_{PNM}(n, T) + 4Y_p(1 - Y_p) f_{SNM}(n, T)$$

$$f_{*NM}(n, T) = a_1 n + a_2 n^2 + a_3 n^3 + a_4 n^4 + nT^2\left(a_5 + a_6 T + a_7 n + a_8 nT\right)$$

The fit


PNM
f_B^I [MeV]
60
50
40
30
20
10
0
-10
-20
n_B [fm^{-3}]
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
T [MeV]
0
5
10
15
20
25
30
35
40
45
50

The fit


SNM
f_B^I [MeV]
20
10
0
-10
-20
-30
-40
T [MeV]
50
45
40
35
30
25
20
15
10
5
0
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
n_B [fm^{-3}]

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:
   $\mathcal{E}(k) = k^2/2m^* + U_0$
3. neutrino mean free path in interacting matter (mean field), see Reddy+ (1998)

Results

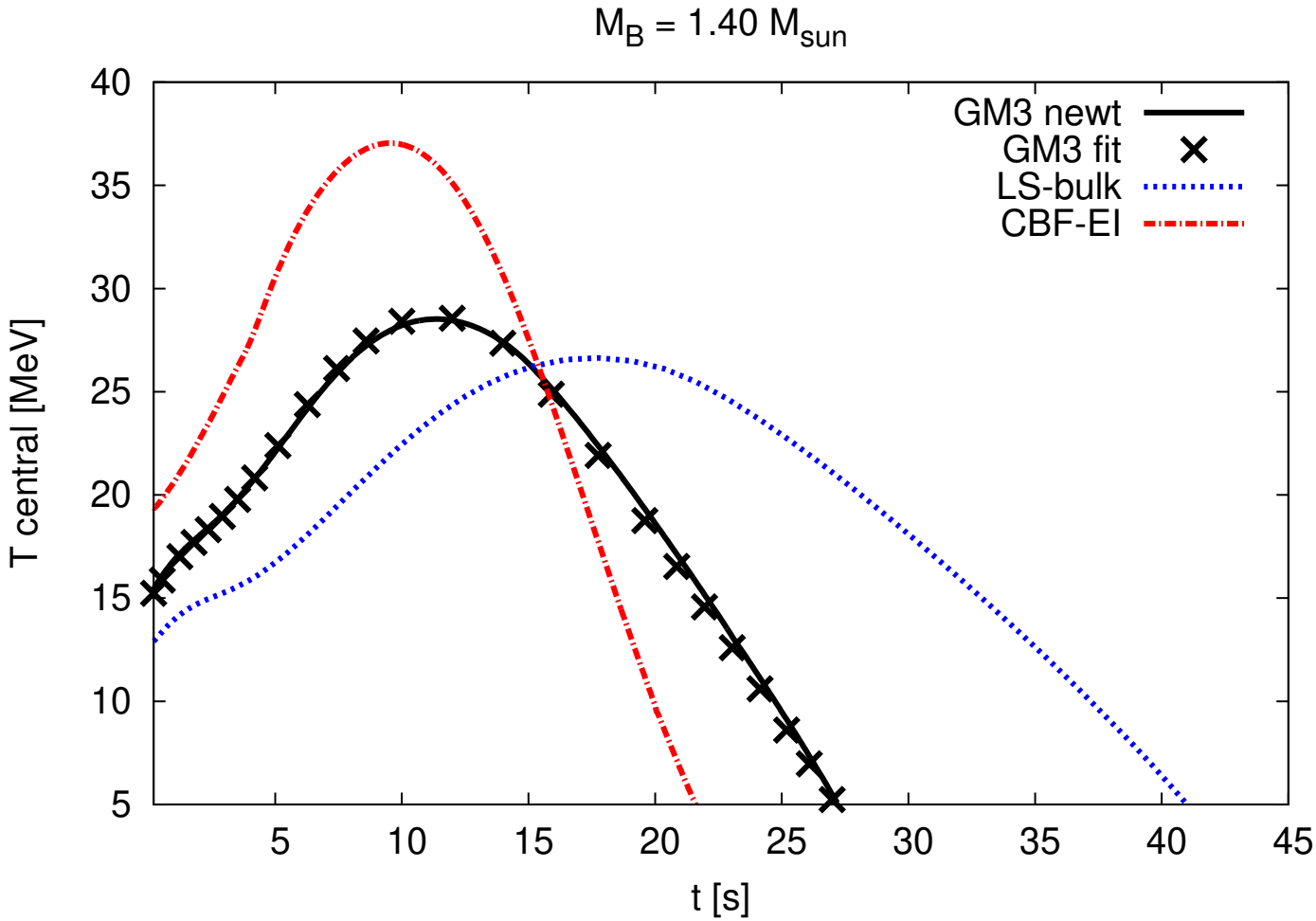


Figure: Camelio+ (2017)

Results

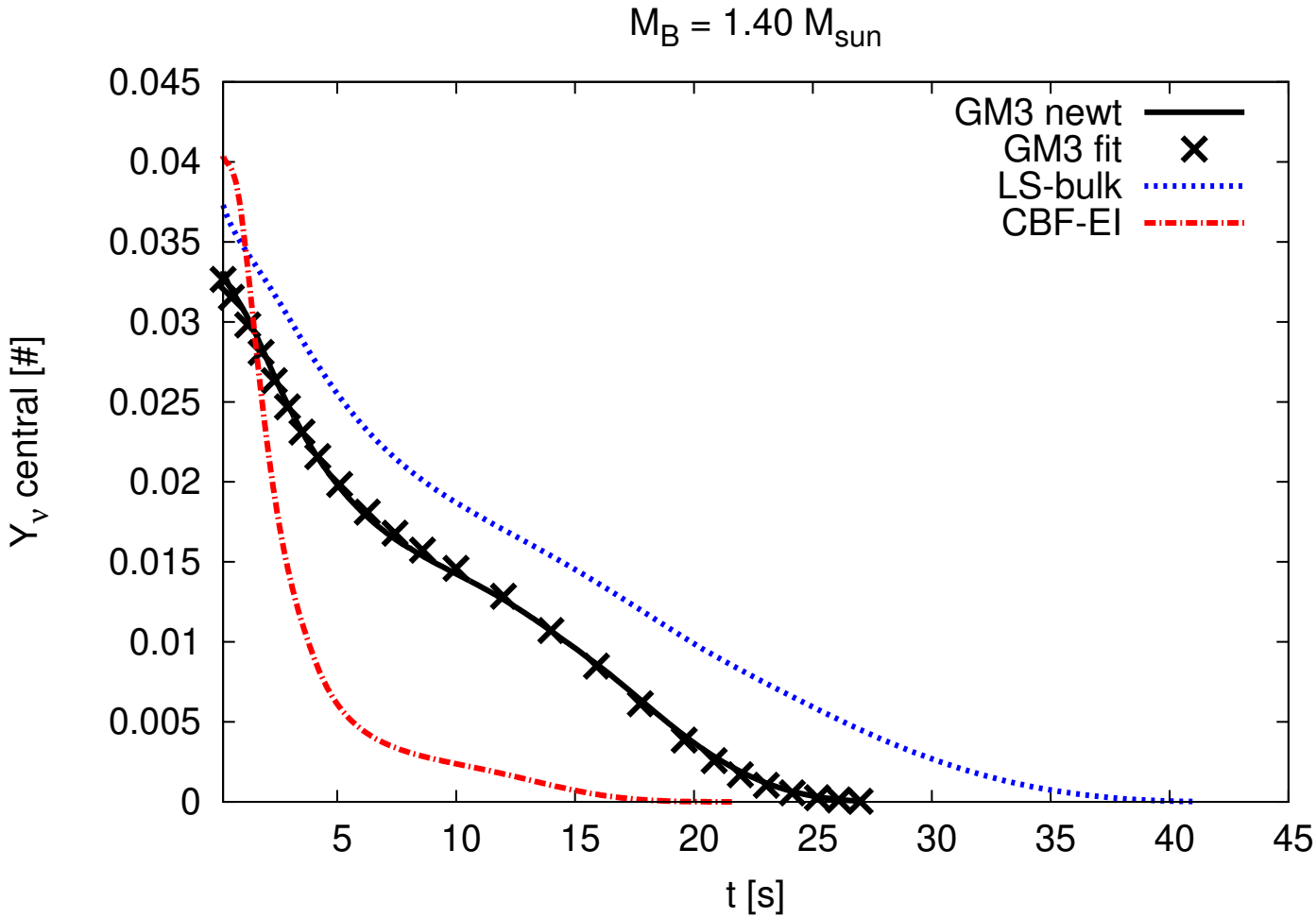


Figure: Camelio+ (2017)

Results

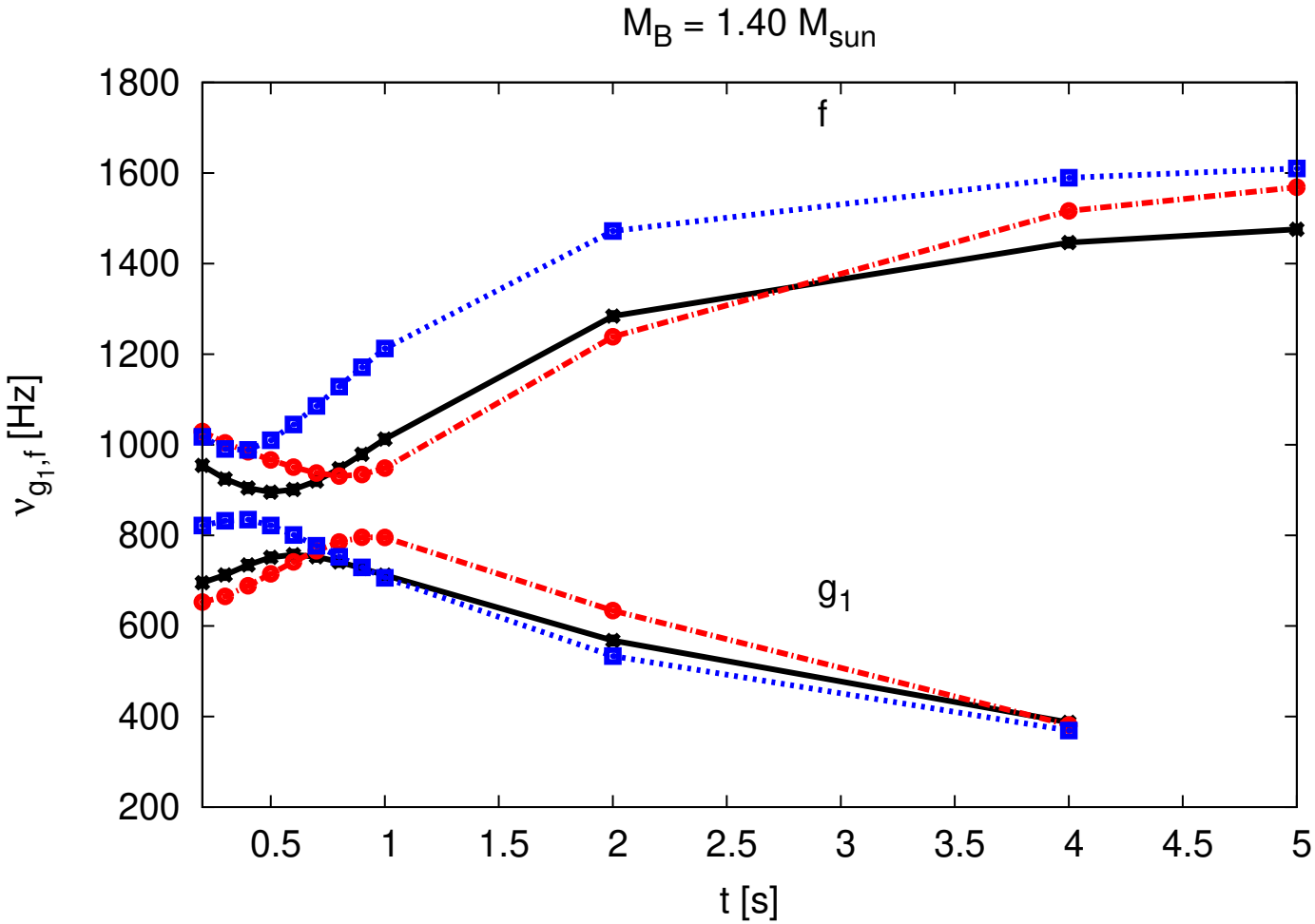


Figure: Camelio+ (2017)

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, λ_ν, ...

Thanks!

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- Reddy, Prakash & Lattimer, "Neutrino interactions in hot and dense matter", PRD **58**:013009 (1998).
- Pons et al., "Evolution of PNSs", ApJ **513**:780 (1999).
- Camelio et al., "Evolution of a PNS with a nuclear many-body EOS: Neutrino luminosity and GW frequencies", PRD **96**:043015 (2017).
- Benhar & Lovato, "Perturbation theory of nuclear matter with a microscopic effective interaction", PRC **96**:054301 (2017).
- Benhar, Lovato & Camelio, "Modeling NS matter in the age of GW astronomy", in preparation.

Backup: neutrino signal on Earth detectors

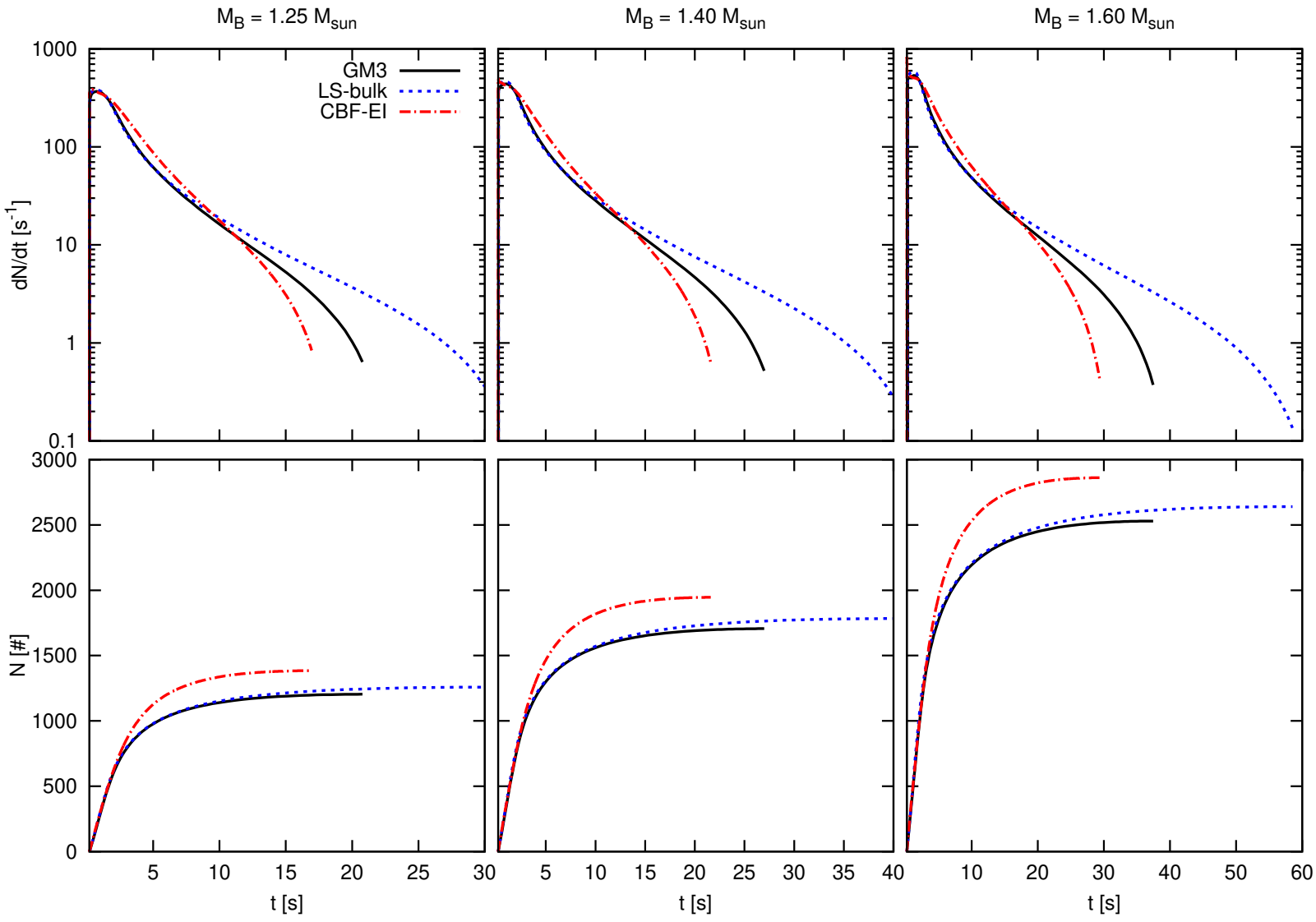

Figure: Camelio+ (2017)

Backup: mass-radius diagram

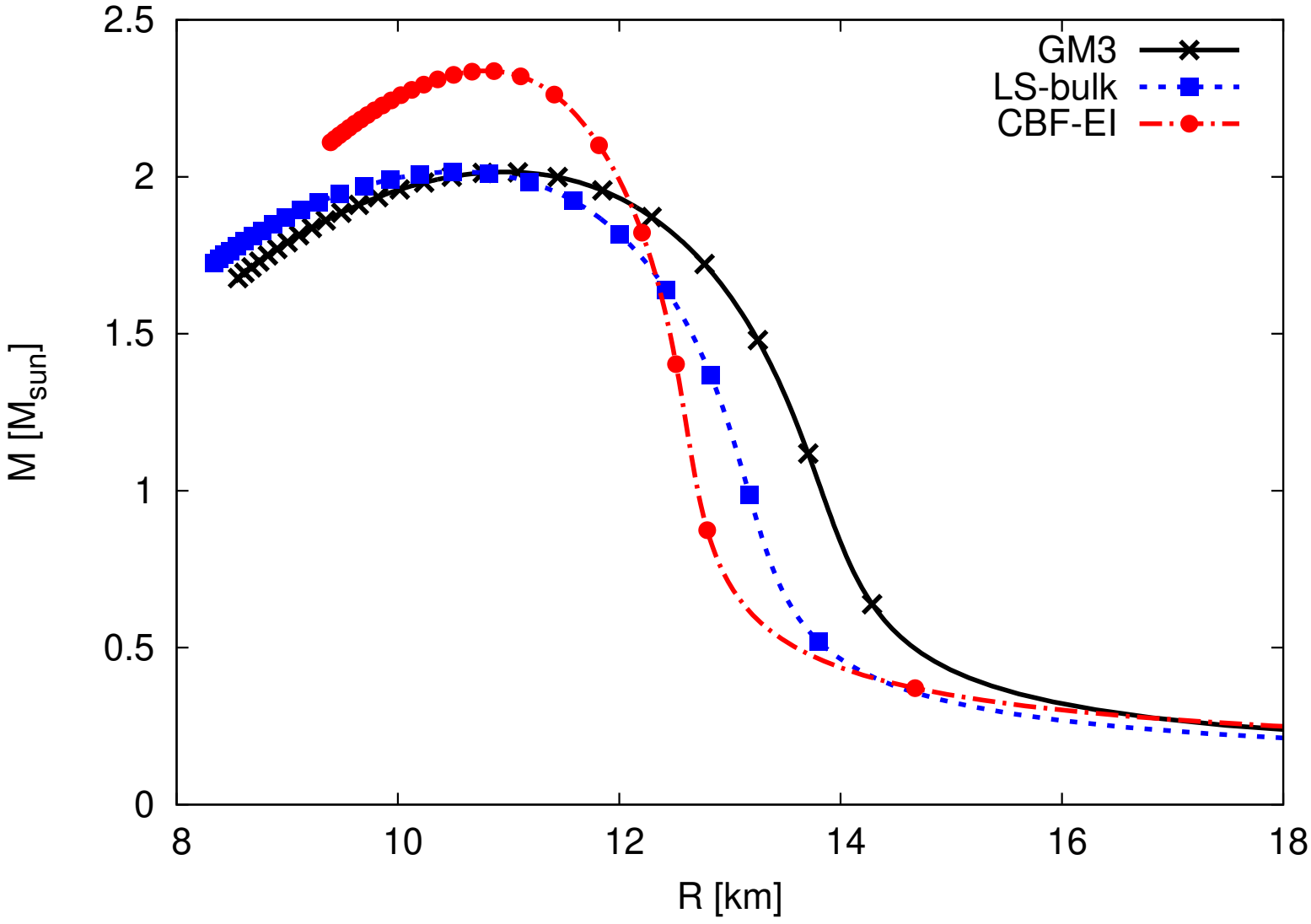

Figure: Camelio+ (2017)