Realistic nucleon force and X-ray observations of neutron stars

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New perspectives on neutron star interiors
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The team

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Bottom line

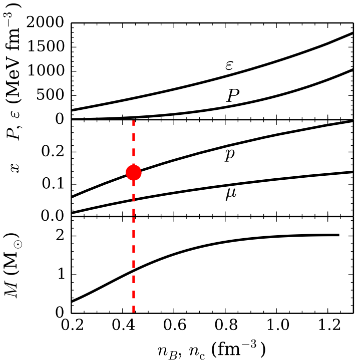
Using realistic NN+NNN obtain EOS for the NS crust and core, superfluid gaps Δ_n,Δ_p, effective masses m_n^*, m_p^*, neutrino emissivity Q_ν, heat capacity c_V.

Then add heat conductivity, and deep crustal heating ($Q_{\rm DCH}$) in accreting NS.

Calculate models of cooling isolated NS and thermal states of transiently accreting NS between accretion episodes. Compare fixed NS-mass curves with X-ray observations of isolated NS and NS in X-ray transients in quiescence and use this to constrain uncertainties in superfluid gaps.

Our EOS etc.

Realistic non-relativistic NN: v_{ij} - AV18, NNN: V_{ijk} - UIX



Normal nucleons - Brueckner-Hartree-Fock (BHF) with continuous U_j

Nuclear matter $n_{\rm b} = n_n + n_p$, $x_p = n_p/n_{\rm b}$

$v_{ij} \longrightarrow V_{ij} = v_{ij} + \widetilde{v}_{ij}$

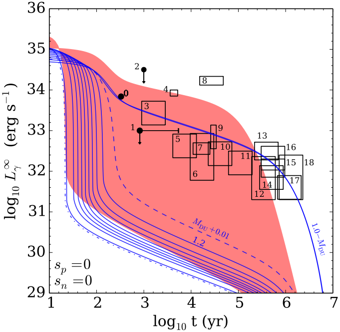
BHF with V_{ij} yields $E(n_n, n_p)$, U_n, U_p, $e_j = \epsilon_j + U_j$

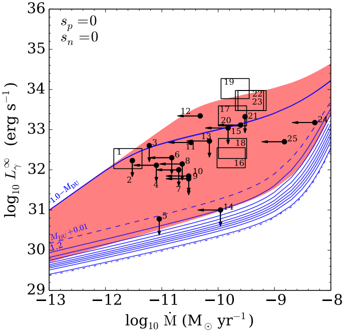
Saturation parameters: $n_{\rm s} = 0.16\ {\rm fm}^{-3}$, $E_{\rm s} = -16.0$ MeV, $E_{\rm sym} = 31.9$ MeV, $K_0 = 212$ MeV, $L = 52.9$ MeV

Results: EOS, also x_p, m_j^* - crucial for Q_ν. For $x_p > x_{\rm DU} = 0.136$ DUrca open; reached at $0.44\ {\rm fm}^{-3}$. DUrca proceeds in $M > M_{\rm DU} = 1.10\ {\rm M}_\odot$ - looks shocking. Catalyzed crust EOS based on the same interaction calculated using the Energy Density Functional method *Sharma et al. 2017*

No superfluidity: $s_n = s_p = 0$

red - fully accreted crust; blue - catalyzed (ground-state) crust. Pathological feature: nearly all sources have $M \simeq M_{\rm DU} = 1.10\ {\rm M}_\odot$ "DUrca problem"

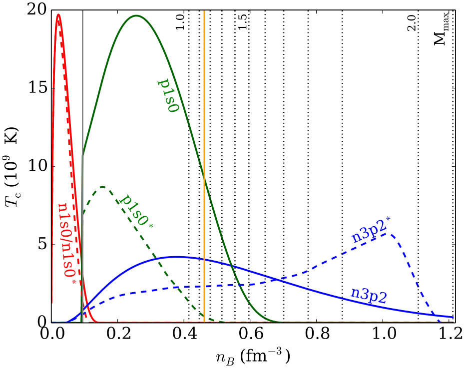




INS: 0 - CasA NS, 1 - PSR J0205+6449 (in 3C58), 2 - PSR B0531+21 (Crab), 3 - PSR J1119−6127, 4 - RX J0822−4300 (in PupA), 5 - PSR J1357−6429, 6 - PSR B1706−44, 7 - PSR B0833−45 (Vela), 8 - XMMU J1731−347, 9 - PSR J0538+2817, 10 - PSR B2334+61, 11 - PSR B0656+14, 12 - PSR B0633+1748 (Geminga), 13 - PSR J1741−2054, 14 - RX J1856.4−3754, 15 - PSR J0357+3205 (Morla), 16 - PSR B1055−52, 17 - PSR J2043+2740, 18 - RX J0720.4−3125

SXTq: 1 - IGR 00291+5934, 2 - XTE J1814−338, 3 - XTE J1751−305,4 - XTE J1807−294, 5 - SAX J1808−3658, 6 - SAX J18104−2609, 7 - XTE J0929−314, 8 - XTE 2123−058, 9 - NGC6440 X2, 10 - EXO 17474−214, 11 - Cen X−4, 12 - 4U1730−22, 13 - 2S1803−245, 14 - 1H 1905+000, 15 - Terzan 1, 16 - MXB 1659−29, 17 - RX J1709−2639, 18 - NGC 6440 X1, 19 - SAX J1750.8−2900, 20 - 1M 1716−315, 21 - Terzan 5, 22 - 4U 1608−522, 23 - Aql X−1, 24 - 4U 2129+47, 25 - KS 1731−260.

Superfluidity



Bardeen-Cooper-Schrieffer (BCS) with V_{ij}. Pairing gaps:

crust

n1s0 $(L = 0, S = 0)$

core

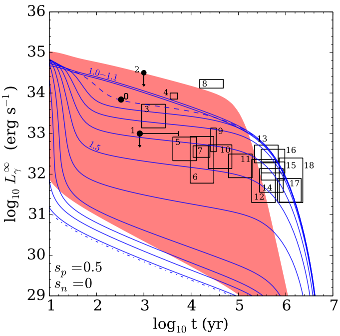
n3p2 $(J = 2, S = 1, L = 1, 3)$

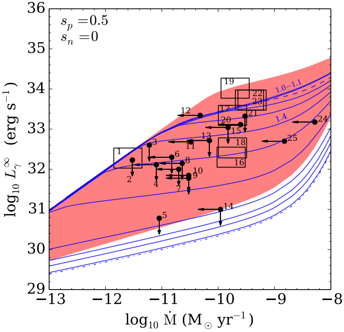
p1s0 $(S = 0, L = 0)$

The BCS values of Δ_n and Δ_p based on $V^{JS}_{LL'}$ do not contain contribution from nuclear matter polarization [*induced interaction*]

Superfluidity: $s_n \ll 1, s_p = 0.5$

Fast initial cooling of INS due to the Pair Braking and Formation $\nu\bar{\nu}$ emission when local T crosses $T_{\rm crit}$





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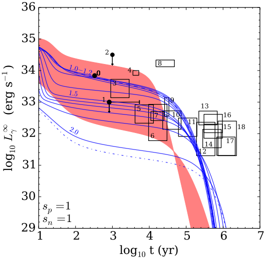
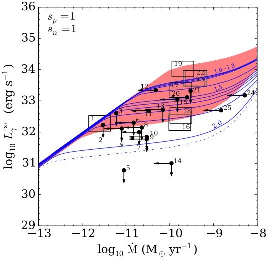
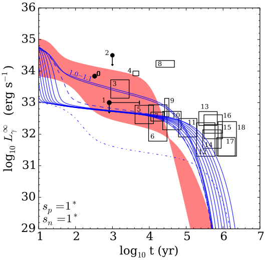
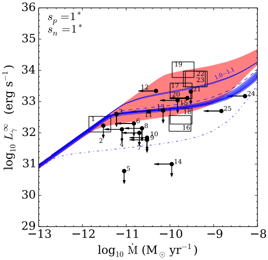
Superfluid failures - examples









Conclusions

- Durca cores are needed for two lowest luminosity SXTq (known)

- Mass distribution pathology due to sharp-Durca threshold is removed if p1s0 is strong enough (at maximum $T^p_{\rm crit} = 10^{10}$ K or more) and Durca threshold density is on the $T^p_{\rm crit}(n_{\rm b})$-curve descending side (known for INS)

- Strong sensitivity to m^*_j, more advanced calculations needed (known)

- $T^n_{\rm crit}$ in the core should be one - two orders smaller than $T^p_{\rm crit}$ (known). Not easy to get in the BCS approximation within $n_0 < n_{\rm b} < 5n_0$. We used not so fine-tuning imposing $s_n \ll 1$