Compact star constraints on the high-density EoS

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Abstract

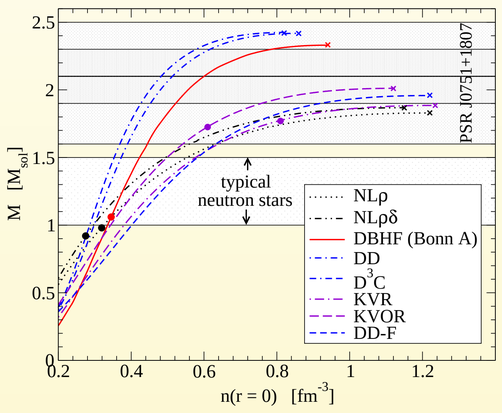
A new scheme for testing nuclear matter equations of state (EsoS) at high densities using constraints from neutron star phenomenology is suggested [1]. An acceptable EoS shall not allow the direct Urca (DU) process to occur in neutron stars with masses below $1.5\ M_\odot$ and not to be in conflict with the known Temperature-Age data of observed objects. Compact star constraints include the mass measurements of 2.1 ± 0.2 $M_\odot$ (1 σ level) for PSR J0751+1807 [2], of 2.0 ± 0.1 $M_\odot$ from the innermost stable circular orbit for 4U 1636-536 [3], the baryon mass - gravitational mass relationships from Pulsar B in J0737-3039 and the mass-radius relationships from quasiperiodic brightness oscillations in 4U 0614+09 [4] and from the thermal emission of RX J1856-3754[5]. The scheme also includes comparison with LogN-LogS data within a population synthesis approach [6]. It is applied to a set of relativistic EsoS constrained otherwise from nuclear matter saturation properties [1]. A possible transition to quark matter is discussed for a three-flavor NJL model [7], parametrized from the meson properties in vacuum [8].

Hadronic and Quark EoS

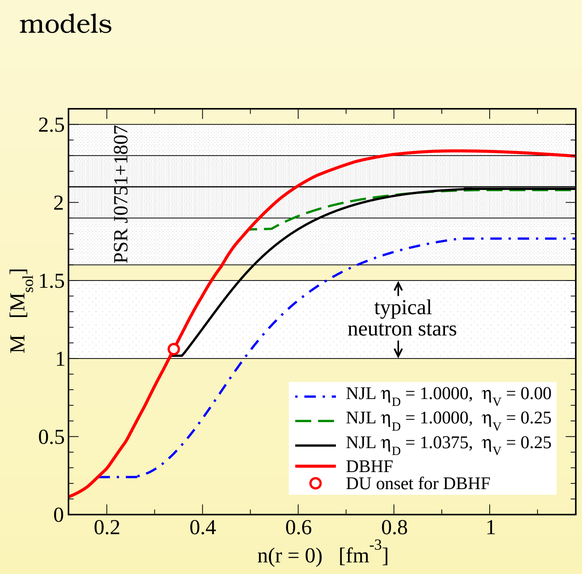
- Relativistic meanfield EsoS for *Hadronic matter* are contrasted to the microscopic Dirac-Brueckner-Hartree-Fock (DBHF) approach [9], where the nucleon self-energy Σ is based on the T-matrix for a Bonn A potential.
- The *Quark matter* EoS is derived for a three-flavor Chiral Quark Model (NJL) with coupling to scalar diquark (η_D) and vector meson (η_V) meanfields [7].

Maximum mass & DU constraint

- Stable configurations for different hadronic models [1]. Filled circles denote the DU threshold.



- Stable configurations for different hybrid models



- Hybrid stars can have a mass of $M \approx 2.1 M_\odot$ (η_V)
- Masses of 2.1 $M_\odot$ require the EoS to be rather stiff.

DU constraint

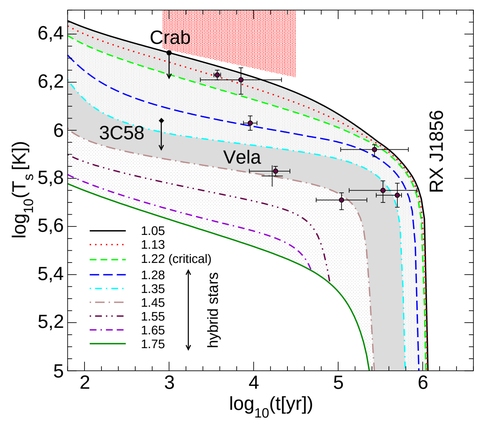
- **Direct Urca (DU) processes** - the β-decay, $n \to p + e^- + \bar{\nu}_e$, is the most effective mechanism cooling compact stars. Even under consideration of nucleon superfluidity it leads to an **unacceptable fast cooling** of NSs in disagreement with present observational soft X-ray data in the temperature - age diagram [10, 11]

- Avoiding DU-cooling requires a rather soft asymmetry energy in nuclear matter and all quarks to be gapped in quark matter.

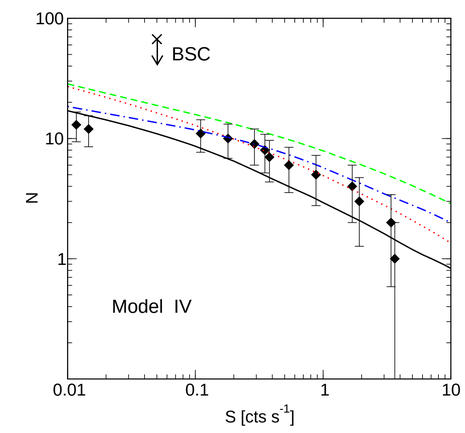
Temperature-Age & Log N–Log S

- Additionally to the explanation of the known Temperature-Age data cooling calculations shall not predict the existence of young and hot objects ($3 < log_{10}(t/yr) < 4.5$) with temperatures higher than the temperatures of already observed objects.

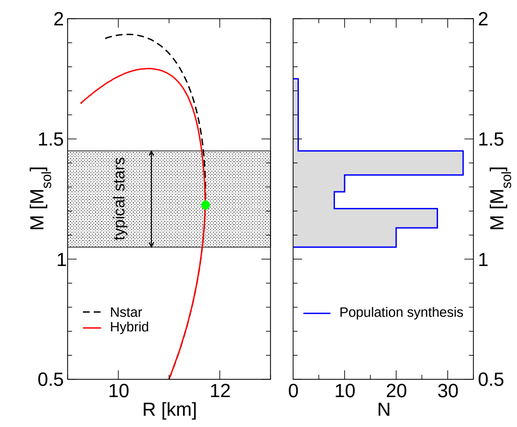
  → **Brightness Constraint**[12]



- LogN-LogS constraint emerges from results of NS cooling calculations and population synthesis models for young, nearby NSs [6].



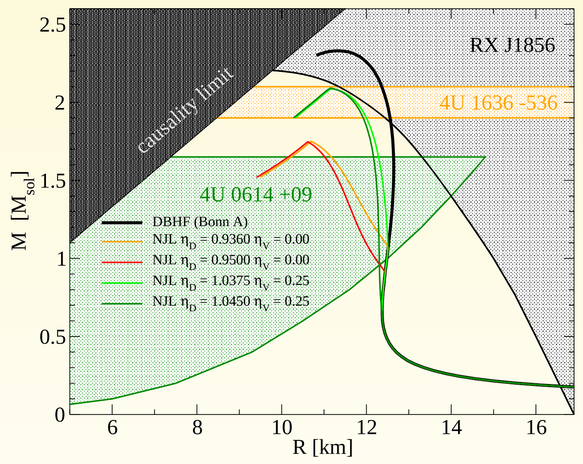
- Constraint requires a rather broad spectrum of masses for young nearby NSs.



- The Hybrid star cooling behavior fits these constraints assuming the existence of a 2SC phase with X-gaps.

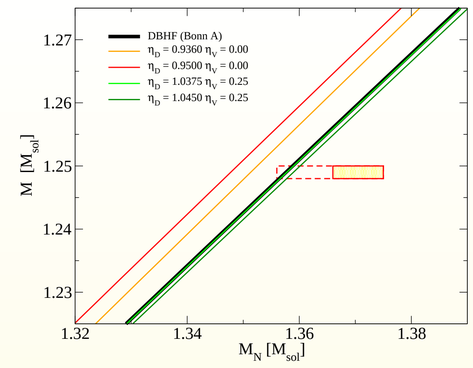
Mass-Radius constraints

- **An upper bound in the mass-radius plane** is derived from the quasiperiodic oscillations (QPOs) of the low-mass X-ray binary (LMXB) 4U 0614+09 [3].
- For some LMXB's there are measurements of the frequency corresponding to the innermost stable circular orbit $r_{ISCO} \approx 6M$. For the NS in the system 4U 1636-536 a **mass limit of** $2.0 \pm 0.1\ M_\odot$ has been obtained [4].



- The thermal radiation of the isolated pulsar RX J1856 determines a **lower bound** for its mass-radius relation [5].
- The M-R constraint implies a stiff EoS.

Gravitational mass- Baryon mass



- Pulsar B in the double pulsar system J0737–3039 has a mass $M = 1.249 \pm 0.001\ M_\odot$ [13]. Assuming mass conservation during the progenitors collapse its baryon mass is $1.366\ M_\odot \leq M_N \leq 1.375\ M_\odot$ [3].
- This requires a rather strong binding of the compact star.

Flow constraint from HIC

- The analysis of the elliptic flow in heavy ion collisions within a kinetic theory constrains an allowed region in the pressure-density diagram of symmetric nuclear matter [14]

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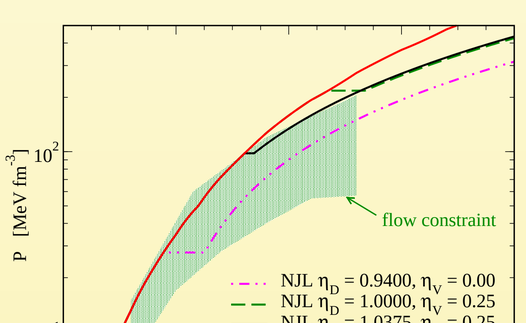
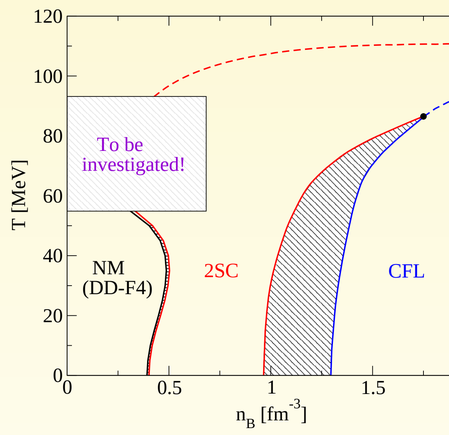


- The flow constraint rules out very stiff EsoS.

Phase diagram for HI

- The phase diagram shows a very we order (almost cross-over) phase trans quark matter. At low temperatures matter and quark matter with color conductivity are rather similar, there phase transition is not strong.



References

[1] T. Klähn *et al.*, arXiv:nucl-th/060203

[2] D.J. Nice, E.M. Splaver, I.H. Stairs, O A. Jessner, M. Kramer, and J.M. Co trophys. J. **634**, 1242 (2005)

[3] P. Podsiadlowski, J. D. M. Dewi, P J. C. Miller, W. G. Newton and J. Mon. Not. Roy. Astron. Soc. **361**, 124

[4] D. Barret, J. F. Olive and M. C. Mi Not. Roy. Astron. Soc. **361** (2005) 85

[5] J. E. Trümper, V. Burwitz, F. Ha V. E. Zavlin, Nucl. Phys. Proc. Su (2004) 560

[6] S. Popov, H. Grigorian, R. Tu D. Blaschke, Astron. & Astrophys. (2006)

[7] D. Blaschke, S. Fredriksson, H. A. M. Öztas and F. Sandin, Phys. (2005) 065020

[8] H. Grigorian, arXiv:hep-ph/0602238

[9] E.N.E. van Dalen, C. Fuchs, and A. Phys. Rev. Lett. **95**, 022302 (2005).

[10] D. Blaschke, H. Grigorian, and D. V sky, Astron.& Astrophys. **424**, 979 (

[11] H. Grigorian, D. Blaschke and D. V sky, Phys. Rev. C **71** (2005) 045801

[12] H. Grigorian, arXiv:astro-ph/050705

[13] M. Kramer *et al.*, eConf **C041213**, 00

[14] P. Danielewicz, R. Lacey and W. G. L ence **298**, 1592 (2002)

Summary

- A test scheme for the high densit EoS by the present phenomenology matter in compact stars and heavy lisions is developed.
- The application of this scheme for E deconfinement phase transition all identify the most of compact objects brid stars.
- The phase transition to quark ma be a solution for those nucleon which otherwise would not satis constraints for the high-density b ($n > 3\ n_0$).

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