nature astronomy

SUPPLEMENTARY INFORMATION

https://doi.org/10.1038/s41550-018-0583-0

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Quark deconfinement as a supernova explosion engine for massive blue supergiant stars

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Quark deconfinement as supernova explosion engine for massive blue-supergiant star

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Supplementary Material

In the Supplementary Figure 1, we provide the sequences of neutron star configurations based on the newly developed SF EOS parametrisation (black lines), in comparison to the hadronic reference EOS (red dash-dotted lines)[1]. It contains the neutron star mass-radius relations in graph (a) as well as the corresponding neutron star matter EOS, pressure and sound speed with respect to the energy density in graph (b) – only shown for the SF EOS. The tidal deformabilities are displayed in graphs (c) and (d). The latter are compared with the data obtained by the LIGO/Virgo collaboration[2] from the first observation of a binary neutron star merger GW170817. The employed low-mass prior neutron star masses, $m_1 = 1.36 - 1.60$ M$_\odot$ and $m_2 = 1.16 - 1.36$ M$_\odot$, corresponding to the tidal deformabilities Λ_1 and Λ_2 respectively, which are shown in graph (c).

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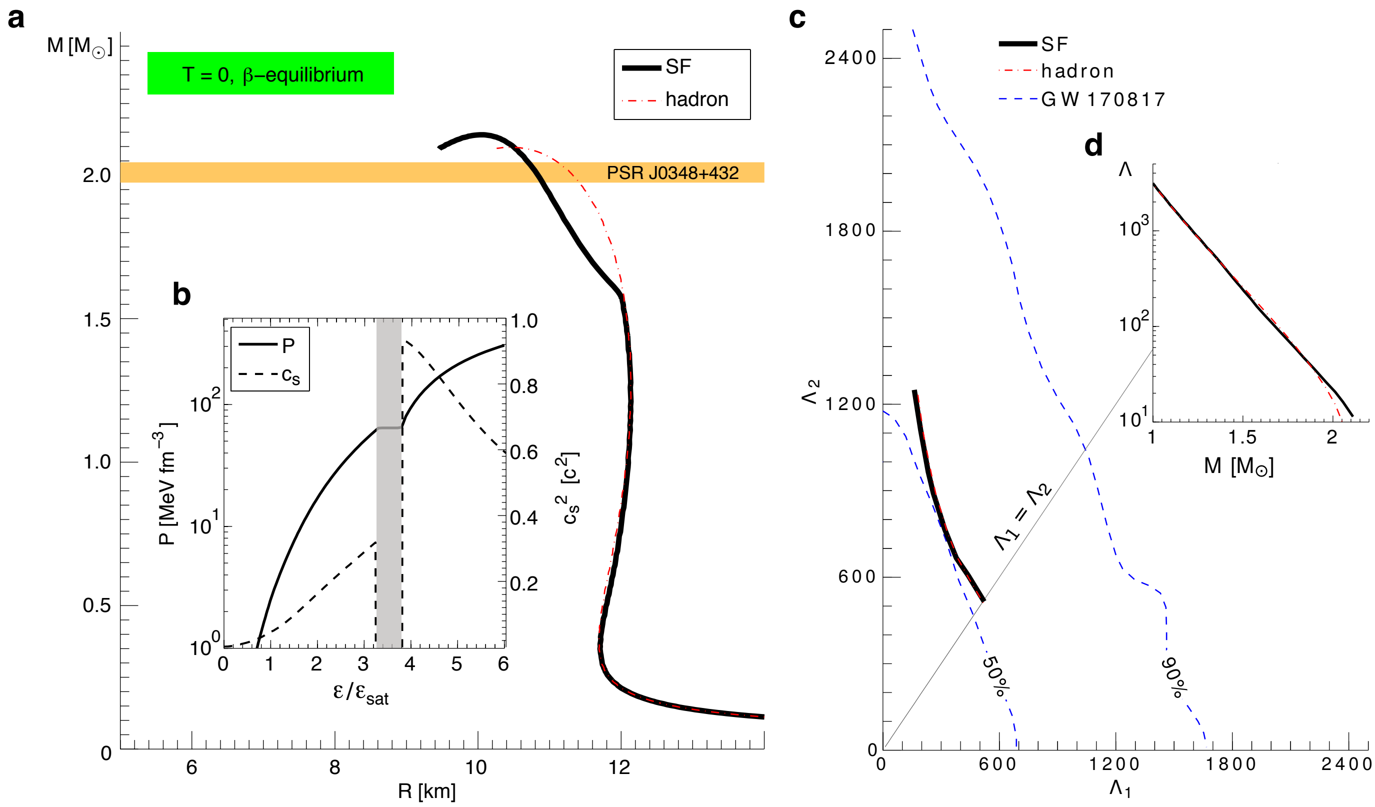
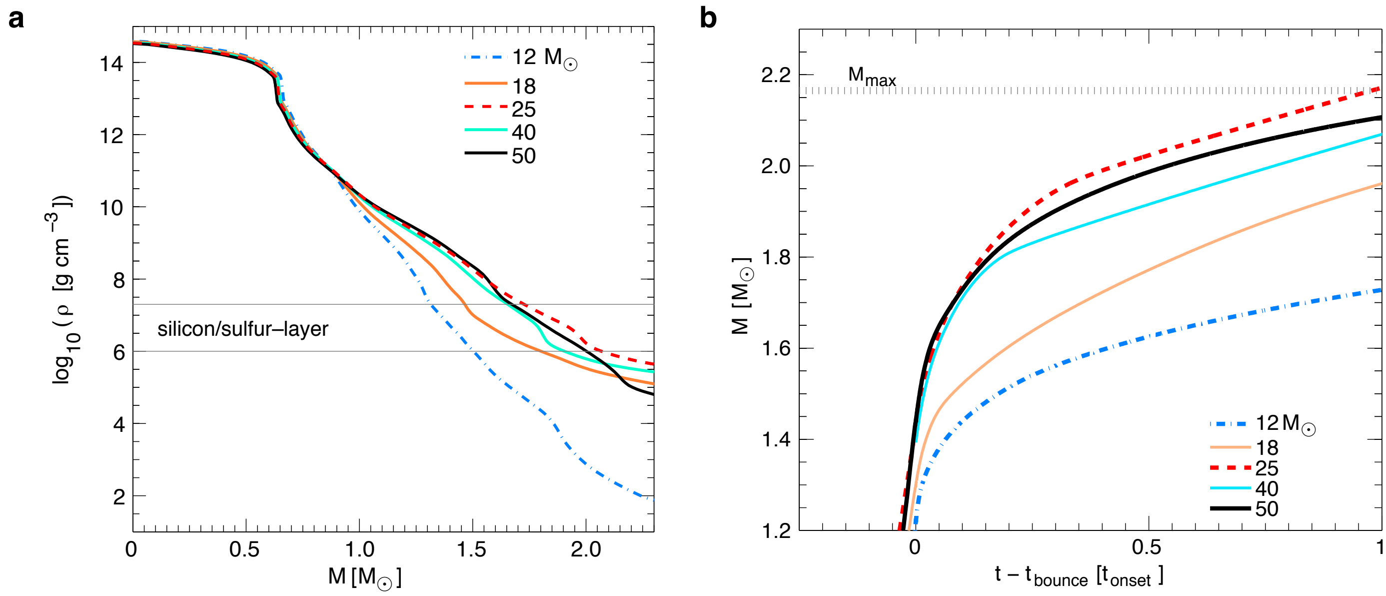


Supplementary Figure 1 | Neutron star configurations comparing the SF EOS (black lines) and the underlying hadronic EOS[1] (red dash-dotted line). **a** pressure P (solid line) and square of the sound speed c_s in units of the speed of light c (dashed line) of the SF EOS only, with respect of the energy density ε expressed in units of the value at saturation density, $\varepsilon_{\rm sat} \simeq 142$ MeV fm^{-3} in β-equilibrium at zero temperature. The grey-shaded region marks the hadron-quark mixed phase. **b.** mass-radius relations. The horizontal dark-yellow band marks the maximum neutron star mass constraint deduced from the pulsar observation PSR J0348+432[3]. **c.** Λ_1–Λ_2 tidal deformability relation as constrained from GW170817 (blue dashed lines show the 50% and 90% confidence levels) corresponding to the low-mass prior neutron star masses[2], and **d.** tidal deformability dependence on the neutron star mass.

Note that the maximum hybrid star mass, $M_{\max} = 2.17$ M$_\odot$, predicted by the SF EOS not only satisfies the lower limit of 2.01 M$_\odot$ (see graph (b) in the Supplementary Figure 1), but also fulfills the upper limit of ~ 2.2 M$_\odot$, recently deduced from the multi-messenger observation of GW170817[4–6].

The behaviour of the speed of sound is largely unknown between the maximum (energy) density of about twice the saturation value – up to which ab-initio nuclear matter calculations might at best be extrapolated, e.g., chiral effective field theories – and the maximal densities attained in the core of neutron stars, which are still well below the asymptotics of the conformal limit case $c_s^2 = 1/3$. In a recent work[7] different cases have been discussed that would fulfill the observational constraints for the compactness and the maximum mass of compact stars but that do not cover the case of a first-order phase transition which is provided by our hadron-quark hybrid star EOS. This work suggests that any hadron-quark hybrid EOS which satisfies both the current nuclear physics constraint at $\rho < 2 \times \rho_{\rm sat}$ and the lower bound on the maximum mass of 2.01 $M_\odot$, would have a region where the sound speed exceeds the conformal limit. We note here that an EOS construction which switches from a well constrained nuclear EOS directly to an asymptotic EOS, that obeys the conformal limit with $c_s^2 = 1/3$, would fulfill the 2 $M_\odot$ constraint on the maximum mass, provided the transition occurs at low enough densities not exceeding $2 \times \rho_{\rm sat}$[8]. A detailed discussion of this statement and a variety of model ansaetze for c_s^2 can be found in the recent literature[7]. In our SF EOS that features a first-order phase transition, which was not considered previously[7], the value of the sound speed right after the phase-transition exceeds this limit but gradually approaches it at large energy density.



Supplementary Figure 2 | Supernova simulation summary of all stellar models considered, ZAMS masses of 12–40 $M_\odot$[9] and 50 $M_\odot$[10], where the quark-hadron phase transition was taken into account based on the SF EOS. **a** restmass density profile at the moment of core bounce, $t_{\rm bounce}$. The horizontal band approximately marks the region of the silicon/sulfur layer, which determines the mass accretion onto the central proto-neutron star during the post-bounce evolution. **b** post-bounce evolution of the baryon mass enclosed inside the PNS, relative the onset times, $t_{\rm onset}$, when the hadron-quark phase boundary is reached (the corresponding conditions are given in Table 1 of the manuscript). The medium-modified SF EOS maximum mass is approximated by the horizontal band denoted as $M_{\rm max}$.

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