Stability and instability of strange dwarfs

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Abstract

More than 20 years ago, Glendenning, Kettner and Weber [1,2] proposed the existence of stable white dwarfs with **a core of strange quark matter**. More recently, by studying radial modes, Alford, Harris and Sachdeva [3] concluded instead that those objects are unstable. We investigate the stability of these objects by looking again at their radial oscillations, while incorporating boundary conditions at the quark-hadron interface which correspond either to a rapid or to a slow conversion of hadrons into quarks. Our analysis shows **that objects of this type are stable if the star is not strongly perturbed**, and ordinary matter cannot transform into strange quark matter because of the Coulomb barrier separating the two components. On the other hand, ordinary matter can be transformed into strange quark matter if the star undergoes a violent process, as in the preliminary stages of a type Ia supernova, and this causes the system to become unstable and to collapse into a strange quark star.

Structure of a strange dwarf

A white dwarf can collect nuggets of strange matter during its lifetime (**strangelets**). These extremely dense nuggets would form a **tiny core** which can play a decisive role in the white dwarf evolution. A white dwarf having a strange core is called **strange dwarf** (SD).

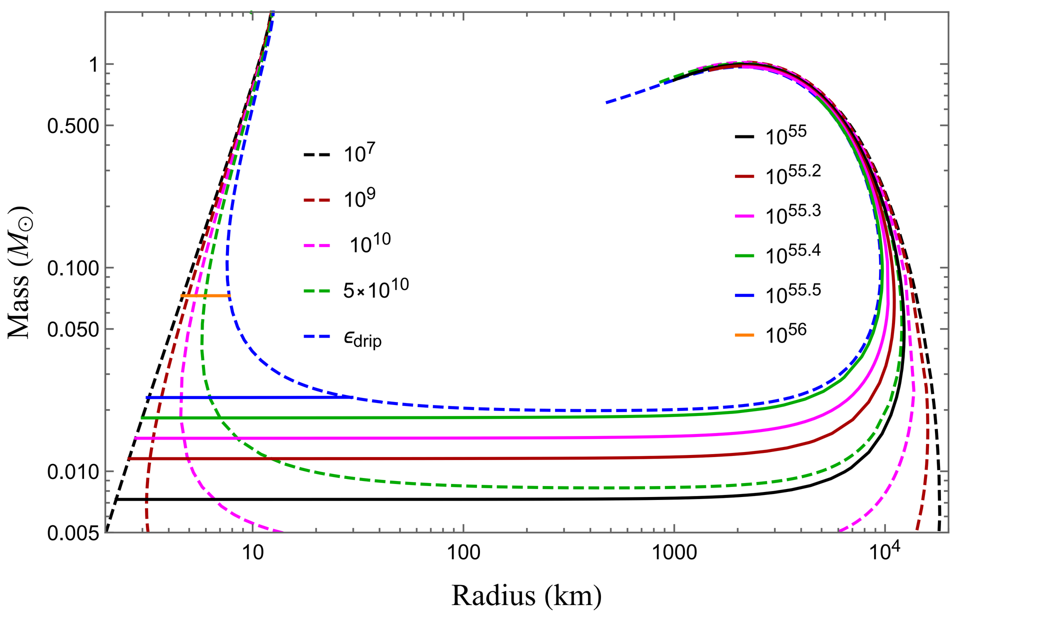


Figure 1: MR sequences. Dashed: configurations in which P_t is constant. Increasing P_0 (and therefore also the number of baryons of the core B_{core}) the curves are followed clockwise. The legend indicates εt in g/cm³. Solid: configurations in which B_{core} is constant. Here, increasing P_0 (and therefore also P_t) the curves are followed counter-clockwise. The legend indicates the value of B_{core}.

Each stellar configuration depends on the parameter pair (P_0, P_t), the central pressure P_0 and the transition pressure P_t, i.e., the pressure of the nuclear matter at the interface with the strange core.

$$\varepsilon(P) = \begin{cases} \varepsilon_{\mathrm{WD}}(P) & P \le P_{\mathrm{t}} \\ \varepsilon_{\mathrm{quark}}(P) & P > P_{\mathrm{t}} \end{cases}$$

If the interface energy density $\varepsilon_t \le \varepsilon_{drip} \sim 4 \times 10^{11}$ g/cm³ then the nuclear matter is separated from the strange core by a **Coulomb barrier**, meaning that the nuclear and the quark matter don't mix spontaneously. Therefore, to build a mass-radius sequence one has to consider the pair (P_0, B_{core}) instead of (P_0, P_t), namely one must **fix the quark content of the core** instead of the transition pressure.

The stability issue: radial oscillations

The most straightforward way to check for the stability of a stellar configuration is to study **radial oscillations**, by solving the equation:

$$(H\xi')' = -(\omega^2 W + Q)\xi$$

Where *H, W, Q* are functions that depend on the stellar structure, **ξ** the eigenfunction (related to radial displacement) and **ω** the radial pulsation.

Slow transition

A slow transition occurs when the characteristic time-scale of the conversion of one phase into the other is much larger than that of the perturbation [4,5]. This case applies to SDs in which **B_{core} is kept constant**. A slow transition implies the continuity of the eigenfunction **ξ** and the stability of every star from the left of solid curves in Fig. 1 up to each maximum allowed mass.

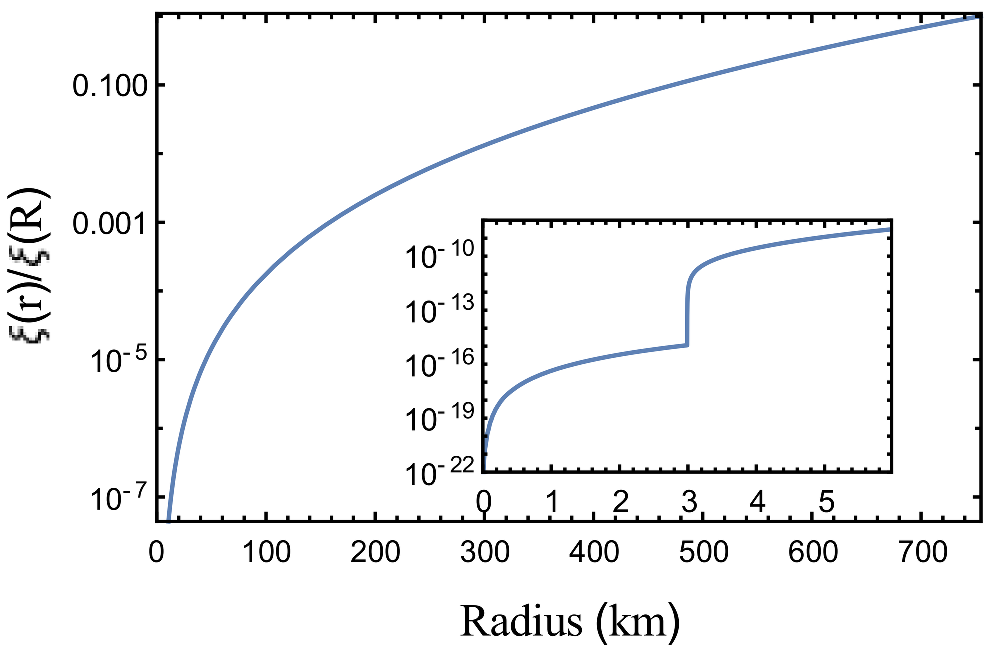


Figure 2: First eigenfunction of radial modes in the "slow" scenario in which hadrons do not deconfine into quarks (and viceversa) during the oscillation time-scale. Here the mode is stable: $\omega^2 = 0.788275$ Hz². In the inner plot the the region around $r = r_t$ is magnified: here the eigenfunction Is continuous and has a kink.

Rapid transition

When the timescale of the conversion of the two phases is shorter than that of the perturbation, **mass transfer** between the two phases is possible [5]. Although the surface separating the two phases is in thermodynamic equilibrium the eigenfunction **ξ** has a discontinuity. The mass transfer originates the instability and therefore the collapse of the star.

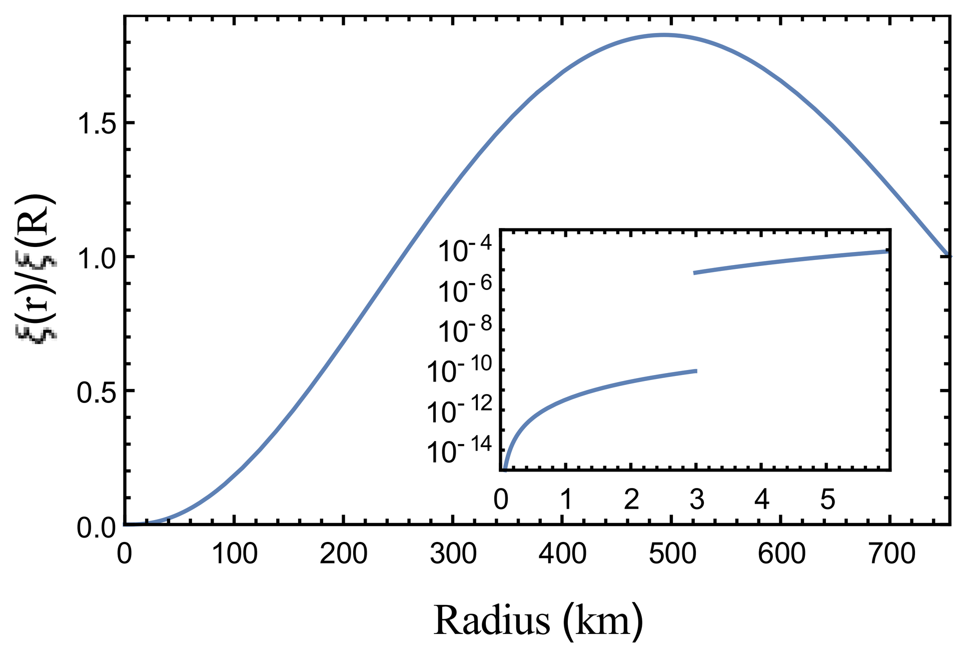
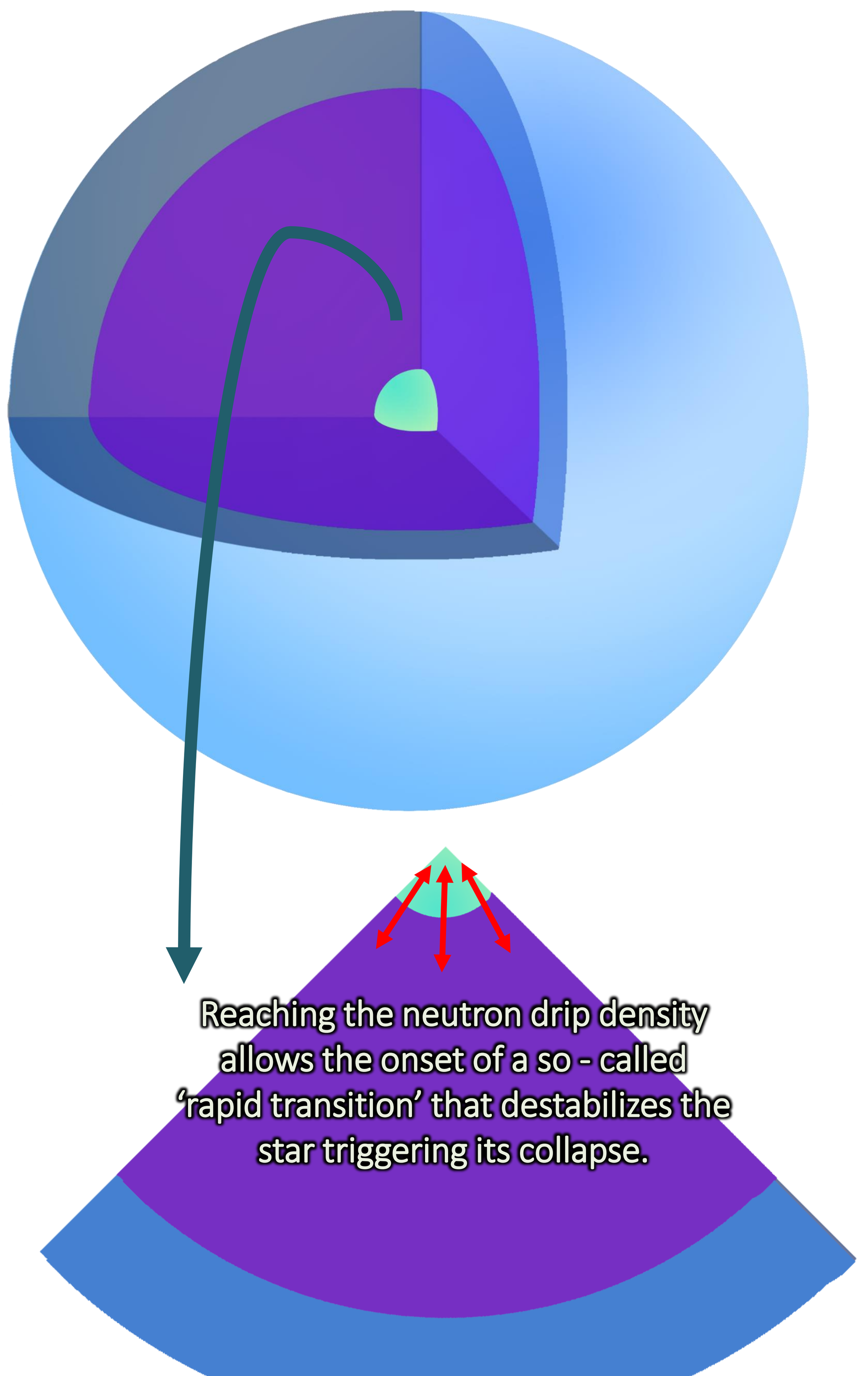


Figure 2: First eigenfunction in the case of "rapid" transitions. The star considered here and in Fig. 2, for illustrative purposes, has $M \simeq 0.02 M_\odot$, $B_{core} \simeq 2.69 \times 10^{55}$ baryons and $\varepsilon_t = \varepsilon_{drip}$. The star seats at the right of the minimum of the dashed blue curve in Fig. 1. Here the mode is unstable: $\omega^2 = -1.62785$ Hz². In the inner plot the region around $r = r_t$ is magnified: here the eigenfunction is discontinuous.



Implications

The presence of the strange core can help the object to collapse instead of following the path that leads to a deflagration. It is difficult to produce an **accretion induced collapse** (AIC) in a white dwarf since strong nuclear reactions start taking place when the star is close to the Chandrasekhar limit ($\omega \simeq 0$) and they disrupt the star before AIC takes place. Nevertheless, if a strange core is present, it can trigger the collapse by converting nuclear matter in quark matter. In particular, if $B_{core} > 10^{46}$ the typical time of growth of the instability drops well below 1 *s* (Fig. 4), suggesting that the collapse can be faster than the development of the deflagration. This collapse can lead to the production of **a km-sized subsolar mass objects** [6]. The presence of SDs can also help to explain the **Gamma-Ray excess** signal from the galactic center [7] if we assume that **dark matter** is made by strangelets.

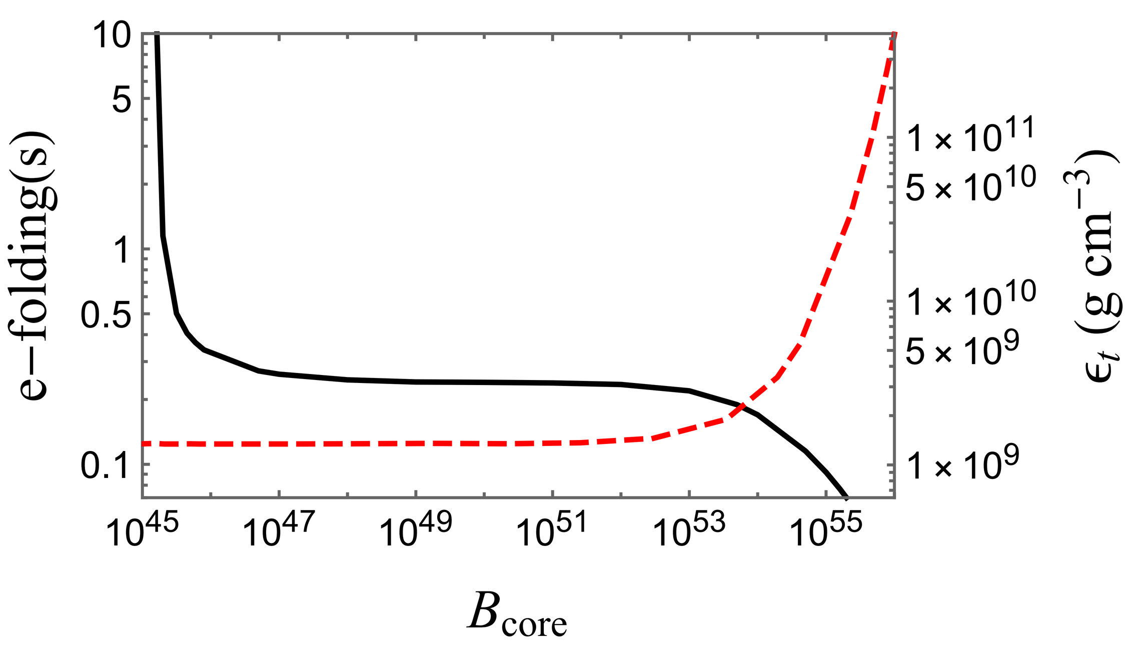


Figure 4: Properties of maximum mass stars as a function of their quark content. Solid black: time-scale of the mechanical instability as a function of B_{core}. Dashed red: interface density of the nuclear matter. The static structure of a SD having $M \sim M_\odot$ does not change till $B_{core} > 10^{52}$. For smaller values of B_{core}, ε_t equals the central density of a white dwarf having a Chandrasekhar mass, indicating that the quark core affects the stability of the star for values of B_{core} smaller than those needed to affect its static properties.

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For further references please refer to our preprint on arXiv!

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