Structure of rapidly rotating strange stars: salient differences from neutron stars

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1 Introduction

The existence of a third class of compact objects (apart from white dwarfs and neutron stars) has been debated for some time now (e.g. [1]). Attention may be drawn, particularly, to suggestions of "bare" strange stars as the candidates [2]. Although an important question in this regard would be the formation mechanisms for such objects, an issue of equal import is that of observationally distinguishing these objects from neutron stars and black holes. In this work, we juxtapose the parameters of structure of compact stars ("bare" strange stars and neutron stars) in an attempt to glean the salient differences between these two classes of compact object - a first step in proving (or disproving) the existence of strange stars.

The discussion presented here is, therefore, expected to have relevance when modelling future sensitive observational data from low mass X–ray binaries (LMXBs). LMXBs are compact objects in binary orbit with an evolved low mass or dwarf companion star. The closeness of the orbit permits the compact object to peel off the outer layer of the companion star. Owing to it possessing substantial angular momentum, the matter so accreted (or peeled off), forms an accretion disk around the compact star.

Astrophysical models of LMXBs (in particular, the X–ray burst sources) play an important role in the constraining the equation of state of high density matter of the central object. It is, therefore, imperative that the models so constructed be realistic. Including general relativisitic effects is inescapable. General relativity not only decides the internal structure of compact stars, but also their external spacetime.

General relativity implies the existence of an innermost marginally stable orbit around compact objects with a radius $r_{\rm in}$. For non–rotating (Schwarzschild) compact objects, $r_{\rm in} = 3GM/c^2$. For rotating compact objects, the $r_{\rm in}$ decreases (for a given

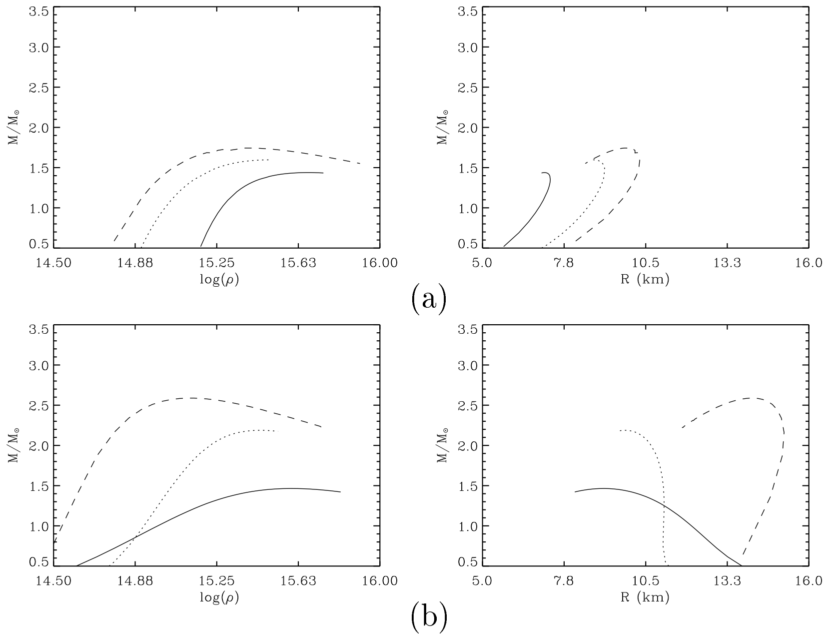

Figure 1: Structure parameters for non–rotating compact stars. The upper panel corresponds to strange stars and the lower to neutron stars. The curves correspond to: Upper Panel: EOS A (solid), B (dotted), C (dashed) and Lower Panel: EOS BPAL12 (solid), WFFII (dotted) and SBD (dashed) respectively.

rest mass) with increasing angular momentum. Accretion disks around compact objects will have an inner–edge located at $r = r_{\rm in}$. Neutron stars as well as strange stars may have radii $R > r_{\rm orb}$.

The matter spiralling in from the inner–edge of the accretion disk, transfers angular momentum to the compact star, spinning it up to high rotation rates ($\sim$ millisecond periods) over dynamical timescales. Realistic astrophysical models must incorporate the effects of rotation of the accreting compact object.

In this work, we point out some of the salient differences between rotating neutron and strange stars. We refer the reader to [3], [4], [5], for details on the results presented here.

2 Rotating compact stars

The first calculation of the structure of non–rotating bare strange stars [2], established the mass-radius relationship to be the chief difference between the structure of non–

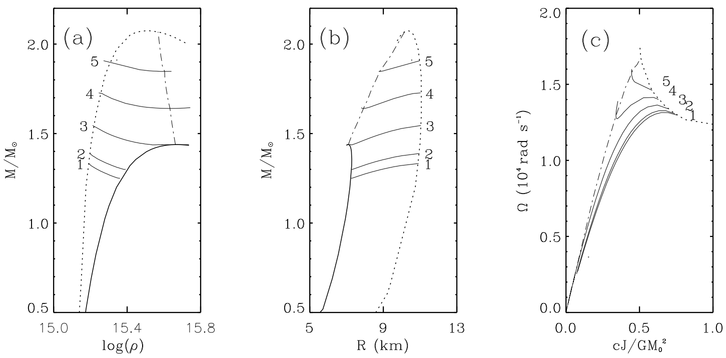

Figure 2: Rapidly rotating strange star structure parameters. EOS model used is EOS A. Labels 1–5 correspond to M_0 = 1.59, 1.66, 1.88, 2.14, 2.41 (where M_0 is the baryonic mass and the numbers are in units of solar mass $M_\odot$: $1.9 \times 10^3 3$ gms) respectively.

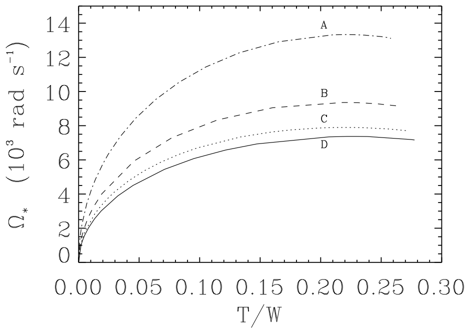

Figure 3: Strange star rotation rate as a function of the ratio of rotational kinetic energy to the total gravitational energy. The labels on curves correspond to the strange star EOS models used. All curves correspond to gravitational mass sequence $M = 1.4\ M_\odot$.

rotating strange stars and neutron stars (Fig. 1). In the calculations reported here, we make use of 4 equations of state (EOS) models for strange stars (in what follows B, α_c, m_s, m_u, m_d refer to the Bag constant, QCD structure constant, and masses of strange, up and down quarks respectively): EOS A: [6], and MIT Bag model [7] with EOS B: $B = 90$ MeV/fm^3, EOS C: $B = 60$ MeV/fm^3, $\alpha_c = 0$, $m_s = 200$ MeV and $m_u = m_d = 0$, EOS D: $B = 60$ MeV/fm^3, $\alpha_c = 0$ and 3 EOS models for neutron stars: BPAL12 [8]; WFFII [9]; SBD [10]. NSEOS model SBD is a very stiff EOS,

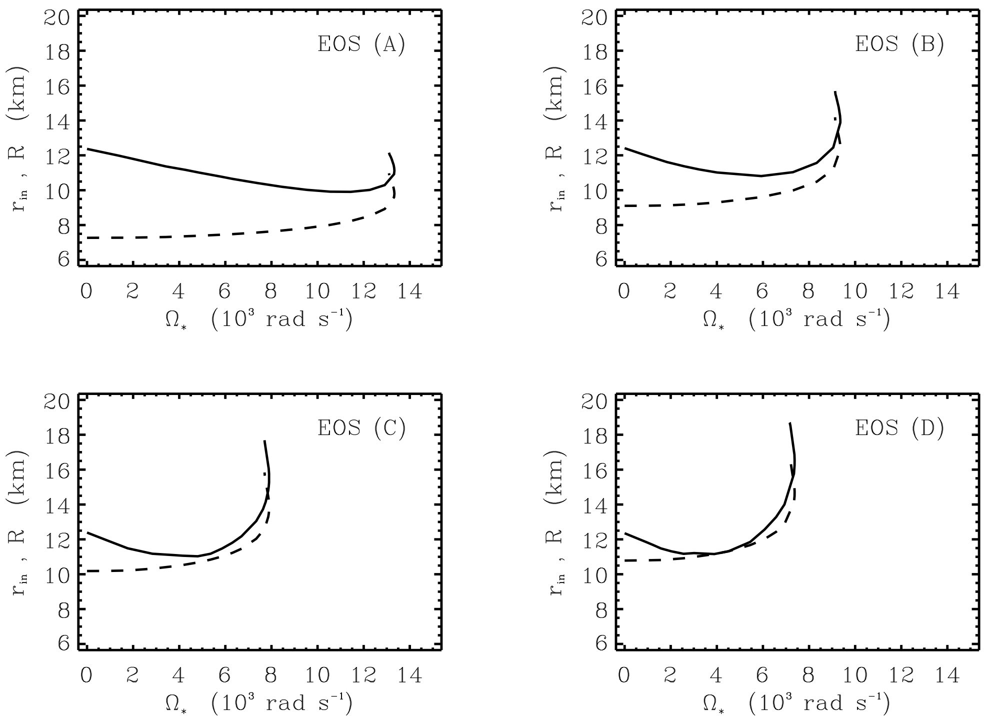

Figure 4: Strange star radii (R) and innermost stable circular orbit radii ($r_{\rm in}$) variations with rotation rate for graviational mass sequences corresponding to $M = 1.4$ $M_\odot$.

while WFFII is moderate in stiffness and BPAL12 is very soft. In addition to these EOS models, we also use (for displaying the effect of EOS on Kepler frequencies) a strange star EOS model due to [11].

To construct rapidly rotating strange stars, we perform numerical computations based on the formalism by [12]. We construct sequences all the way from the static limit to mass–shed limit where centrifugal forces balance the inward gravitational pull. We also construct constant gravitational mass (M) and constant baryonic mass ($M_{\rm B}$) sequences. The results of our calculations, for one SSEOS: ... is shown in Fig. 2: the thick solid curve is the non–rotating limit, the dotted curve is the mass shed limit and the horizontally directed curved lines are constant baryonic mass sequences.

The constant gravitational mass sequences help studying the effect of spin on the strange stars. From Fig. 3, we notice that there exists a maximum rotation rate for the strange stars, with a value that is higher than the rotation rate at mass shed (an effect that is absent in neutron stars: [13]). This maximum occurs at $T/W \sim 0.2$, indicating that such angular velocities are perhaps not attainable in strange stars due

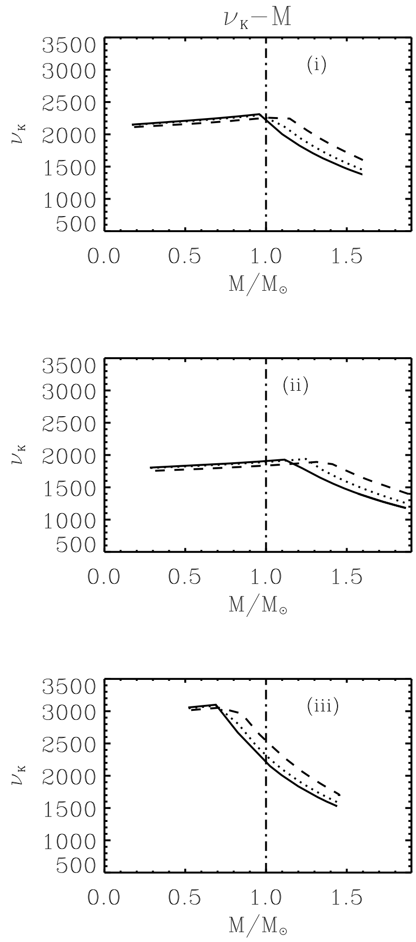

Figure 5: Kepler frequencies of test particles around rotating strange stars. The panel (i) corresponds to EOS B, and panel (iii) to A. Panel (ii) corresponds to EOS model due to [11]. The curves in each of these panel correspond to strange star rotation rates of 0 (solid), 200 (dotted) and 580 (dashed) Hz. The vertial dot–dashed lines in the panel represents a 1 $M_{\odot}$ configuration.

to triaxial instabilies [14].

Fig. 4 showing $r_{\rm in}$ v/s Ω for constant gravitational mass sequences imply that $r_{\rm in}$ decreases with increasing Ω_* for low values of the rotation rate (similar to Kerr black holes and rotating neutron stars), but reaches a minimum and increases for higher rotation rates. The increase in $r_{\rm in}$ with rotation is purely an effect of the large quadrupole moment of the strange star [15].

We also compute the Kepler frequencies of test particles around rotating strange stars (Fig. 5). On comparing these with the Kepler frequencies expected for neutron stars (see [16]), we see that frequencies in the range (1.9 - 3.1) kHz if observed in future in X–ray burst sources, can be understood in terms of strange stars rather than neutron stars.

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