Possible evidence of surface vibration of strange stars from stellar observations.

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ABSTRACT
Emission lines in the $eV$ and $keV$ range by certain stellar candidates from their recent analysis invoke the question of their possible origin. These stars under consideration, are the 4U 0614+091 (0.65, 0.86, and 1.31 keV), 2S 0918−549 (0.8 keV with width 55 eV), 4U 1543−624 (0.7 keV), 4U 1850−087 (0.7 keV) and 4U 1820−30 (0.6 and 0.9 keV) and also the 0.6 keV excess emission in RX J170930.2−263927. Recently, it has been suggested that the resonance absorption at ~ in 0.7, 1.4, 2.1 and 2.8 keV 1E1207−5209 and 0.35, 0.7 and 1.4 keV RX J1856.5−3754 are due to harmonic surface vibrations in strange stars. We propose that these harmonic vibrations may also responsible for emission lines in the above mentioned compact stellar candidates.

Key words: dense matter – stars : realistic strange stars.

1 INTRODUCTION

Line emissions below and above the keV region have been observed in many compact star sources. It is intriguing to note that often their frequencies are multiples of each other - showing a harmonic origin. It is well known that such harmonic vibrations are seen in large nuclei and are called breathing mode oscillations whose origin is the compressional modes of surface vibrations. To see such behaviour in a compact star, it should have a sharp surface and the star should be self bound with pressure $p = 0$ at the surface. For such criterion, it is required that the star be described by an equation of state (EOS) which has a minimum value of E/A at a non-zero density, where E is the binding energy and A is the baryon number. All of the existing neutron star EOSs have surface density zero, while for most of the strange star EOSs have the feature of sharp surface. Besides the existing MIT Bag model EOSs for strange matter (Farhi & Jaffe, 1984; Haensel et al., 1986; Alcock et al., 1987, etc.), Dey et al. (1998)(henceforth, D98) gave an EOS for strange matter and used it to model strange stars having such property. Another strange star model having such phenomena is by Malheiro et al. (2003), where they have the feature of sharp surface. We shall use the D98 model in our further discussions and shall consider only the EOS1 in D98 which is the same as the SS1 in Li et al. (1999a). Recently, it has been shown that the resonance absorption in 1E 1207.4−5209 and RX J1856.5−3754 can be plausibly interpreted as being due to surface vibrations in strange stars (Sinha et al., 2003 - henceforth called as SDDR). In particular, the former star shows evidence of 4 harmonics (Bignami et al. 2003) and has been studied extensively by XMM-Newton making it the most deeply scrutinized galactic target of the mission (De Luca et al. 2003).

The presence of the vibrational frequencies we discuss, is related to surface compressional modes and it is only possible if (uds) quark matter is self-bound as for example in D98. There cannot be harmonic compressional modes in neutron stars because of the lack of a minimum in the E/A of its EOS which results in the absence of a sharp surface.

The direct estimate of the mass-radius relation of the compact stars are still far from accuracy and depends on a lot of assumptions, like the surface temperature, luminosity, distance estimates, etc. With the size of the conventional neutron stars being slightly more than the more exotic strange stars, and they themselves being so far away, it is hardly possible to make any distinction between the two. Ambiguities arise in the estimates of these objects even with the most modern satellites and telescopes. A particular example is the recently debated object RX J1856.5−3754. Drake et al. (2002) claimed it to be a strange star, while at the same time Walter and Lattimer (2002) showed that if they assumed the surface temperature of 33 eV, instead of 61.2 eV as taken by Drake et al. (2002), then it gives a mass-radius relation, perfectly consistent with the normal neutron stars. So, to bypass these kind of uncertainties and debates, an alternative signature is desperately sought in order to prove the existence of the strange stars. The estimates of the surface vibrations for the strange stars (for the D98 model, which is a realistic model of uds quark confinement and asympto-
2 BREATHING OSCILLATIONS IN STRANGE STARS.

The u and d quarks are believed to be light (4 and 7 MeV respectively) and the strange quark s, moderately light (150 MeV) at very high density, whereas in hadrons they have a mass of roughly one third of the hadron mass. One therefore thinks of a chiral symmetry restoration as one moves from low to high density. When this is included along with a Debye screening for gluon propagation, a model may be described as a realistic one for exploring the possibility of a high density strange quark phase comprising of u, d and s quarks. Considering the above mentioned properties, D98 developed their model for strange quark matter and strange star. The EOS1 of D98 has a minimum of energy per baryon (E/A) at a relevant value of the breathing resonance line.

Below we discuss the evidence for the line emissions from various stars :

(i) 4U 0614+091 is a moderately bright X-ray source. Three emission lines at around 0.65, 0.86, and 1.31 keV are proposed by Schulz (1999). This would correspond to a mass of about 1.1 $M_\odot$ with radius 7.02 km.

In terms of this $d$

$$m_{\text{skin}} = 4\pi R_{\text{star}}^2 d \rho_{\text{surf}} \frac{M_u + M_d}{2}.$$  

$M_u = 132$ and $M_d = 135$ MeV for SS1 at the star surface. Mark that this shows chiral symmetry restoration is setting in already at the surface of the star, being much more prominent at the centre where the density is 15 $\rho_0$ or 46.85 $\times 10^{14}$ gm/cm$^3$.

Due to strong interaction binding, the strange star surface is very firm and the portion that can oscillate symmetrically is thin, typically a one quark layer as we have discussed above.

The star mass and radius are given in Figs. 1 & 2 for the relevant value of the breathing resonance line.

3 DISCUSSION.

Below we discuss the evidence for the line emissions from various stars:

$$\frac{dp}{dr} = -\frac{G(p(r) + e(r))(m(r) + 4\pi r^3 p(r))}{r^2 (1 - \frac{2Gm(r)}{r})}$$  

is the TOV equation with conventional notation.

The frequency of the vibration is given by

$$\nu = \frac{c}{2\pi} \sqrt{\frac{k(R)}{m_{\text{skin}}}}.$$  

where the mass of the skin ($m_{\text{skin}}$) is in energy units.

The $m_{\text{skin}}$ is estimated to be very small (SDDRB). The very small depth of the surface $d$ must be larger than the effective diameter of the ud quarks $D_{\text{eff}} : d \geq D_{\text{eff}}$.

For the extreme case when the equality sign holds, which means the layer is just one diameter thick, we can replace $D_{\text{eff}}$ by $d$. This yields an estimate of the Maxwellian mean free path :

$$\lambda = \frac{1}{\sqrt{2\pi \rho_{\text{surf}} d^2}} = 4.28 \text{ mm},$$  

where the surface density $\rho_{\text{surf}} = 4.586 \rho_0$ for SS1 with $\rho_0 = 0.51/fm^3$. The dimension of $\lambda$ is clearly macroscopic. It shows the onset of asymptotic freedom even at the surface of the strange star.

In terms of this $d$

\begin{align*}
  m_{\text{skin}} &= 4\pi R_{\text{star}}^2 d \rho_{\text{surf}} \frac{M_u + M_d}{2}, \\
  M_u &= 132 \text{ and } M_d = 135 \text{ MeV for SS1 at the star surface.}
\end{align*}
in trying to explain why coherent radiation are detected in the
above MSPs, one may use the model of Titarchuk et al. (2002),
giving more credibility to our calculations.

\textbf{4 CONCLUSIONS AND SUMMARY}

In conclusion we point out that there are bits and pieces of evidence in support of the existence of strange stars. For example, the short range pairing of ud quarks by a few MeV can provide for events parallel to fusion bursts which release about 5 MeV per event. Whereas the latter last typically for only 10 seconds - the pairing can go on for hours (minutes) after a star has suffered prolonged accretion and all (some of) the pairs are broken. This can explain superbursts which are recurrent within 5 years as seen in 4U 1636−53. The alternate scenario involving carbon burning may work for 4U 1820−30 but cannot be uniformly applied to all superbursters and long bursts (Sinha et al., 2002b). The absorption spectra of 1E 1207.4−5209 (De Luca et al. 2004) is another case in evidence which may turn out to be a strange star showing resonance absorption (Sinha et al. 2003).

In summary, we point out that lines observed in many stars at more or less around 1 keV may be due to harmonic surface oscillations, if they are strange stars. We also reaffirm that the millisecond X-ray pulsars SAX J1808.4−3658 may be a strange star. Confirmation of the existence of strange stars would lead to a rich interplay between X-ray astrophysics and QCD.

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\textbf{REFERENCES}


\textsuperscript{1} In strange stars the quark matter is bound tightly by strong interaction so that the star is very stable against possible fast rotation (Gondek-Rosińska et al., 2000; Bombaci et al., 2000) and vibration (Sharma et al., 2002; Sinha et al., 2002a). However the electrons are not affected by the strong interac-