Is RX J1856.5-3754 a Strange Star?

Jillian Anne Henderson & Dany Page

Instituto de Astronomía

Universidad Nacional Autónoma de México

Abstract

RX J1856.5-3754 has been proposed as a Strange Star candidate due to its very small apparent radius measured form its X-ray thermal spectrum. However, its optical emission requires a much larger radius and thus most of the stellar surface must be cold and undetectable in X-rays. In the case the star is a neutron star such a surface temperature distribution can be explained by the presence of a strong toroidal field in the crust (Perez-Azorin et al 2005, Page et al. 2005). We consider a similar scenario for a Strange Star with a thin baryonic crust to determine if such a magnetic field induced effect is still possible or excludes RX J1856.5-3754 as a Strange Star.

It could be a Neutron Star...

In the presence of a strong magnetic field the heat flow, transported by the electrons, is channeled along the magnetic field lines. This effect can occur even in the deepest crustal layers and is reflected in the surface temperature distribution. Regions around the magnetic poles, where the field is radial, are hence much warmer than the magnetic equatorial belt, where the field is tangential to the surface. Moreover, a toroidal magnetic field component confined to the crust can act as a supplementary heat blanket and significantly increase the width of the cold equatorial belt. Using the three basic components for a dipolar field, core and crustal poloidal and crustal toroidal (illustrated in Fig. 1), the effects of the magnetic field on temperature distribution and observable spectrum are illustrated in Fig. 2 and shown to be able to provide a reasonably good fit to both the X-ray and optical spectra of RX J1856.5-3754.

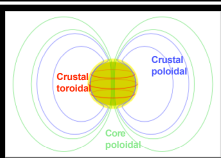


Figure 1: The three components of the magnetic field.

The **poloidal core field** is maintained by proton supercurrents (and other possible charged superconducting components of the core). The **crustal (poloidal and toroidal) fields** are maintained by electron currents sqeezed in the crust which *cannot penetrate the superconducting core* (and may partially come from magnetic flux *expelled from the core* during the pulsar spin-down).

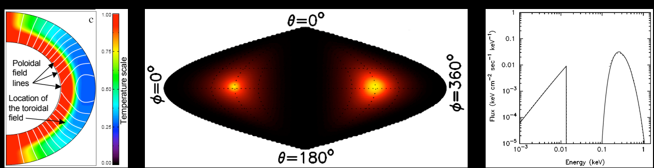


Figure 2:

Left panel: temperature profile in the crust (its thickness has been exagerated by a factor five for clarity). Internal maximum temperature (red) is $6\square10^{7}$ K and the blanketing effect of the toroidal field is clearly seen. Temperature in the core is assumed not to be affected by the magnetic field since the latter is confined in fluxoids by the superconductor.

Central panel: resulting surface temperature distribution (in an area preserving map). $T_{max} = 1.01\square10^{6}$ K (yellow), $T_{min} = 1.66\square10^{5}$ K (black), $T_e = 5.46\square10^{5}$ K and $T_e = 4.62\square10^{5}$ K

Right panel: resulting observable spectrum (continuous line) compared to observed data of RX J1856.5-3754 (dotted lines). The model star has $M=1.4\ M_{sun}$ and $R = 17.06$ km (R=14.4 km) at a distance of 122 pcs with $N_H = 1.6\square10^{20}$ cm^{-2}. (*Geppert, Küker & Page, 2006*).

Strange Stars - The Model

A **Strange Star** (or strange quark star) share many similarities with a neutron star. Depending on the quark matter model it may be more compact that a neutron star, but it may also be as large or even larger.

Nevertheless, a *distinctive difference* between these two kinds of compact stars is that a strange star cannot have an inner crust. Hence, if the quark matter is covered by a layer of normal matter this crust is much thinner. Fig. 3 illustrates this important point.

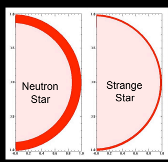
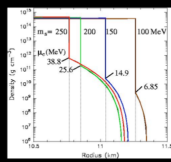


Figure 3:

Left: sketches of the comparative thicknesses of neutron and strange star crusts.

Right: three explicit examples of strange star crusts on top of quark matter modeled with the *Fahri & Jaffe (1984)* model (with $\square_s = 0.3$ and $B^{1/4} = 140$ MeV). Different strange quark masses lead to different electron chemical potentials $\square_e$ (as indicated) which result in a broad range of crust thicknesses, with maximum of 400 m when the crust reach the neutron drip density ($4.3\square10^{11}$ g cm^{-3}).



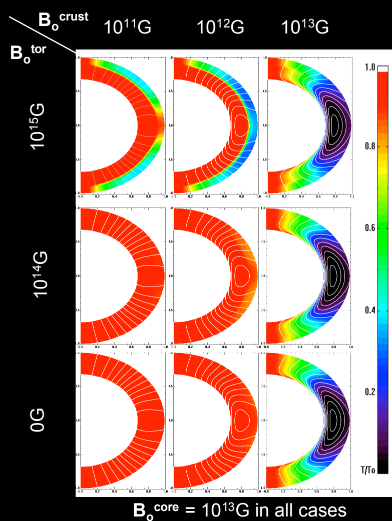
The model we are probing is a carbon-copy of the neutron star model with the following features:

- The observed X-ray spectrum comes from a small hot region on the star while the optical spectrum is due to an extended cold region.
- The non-uniform surface temperature is due to the magnetic field.
- The magnetic field does not affect heat transport in the quark core (because quarks form a superconductor and the field is confined in fluxoids): only the thin crust can induce a non uniform surface temperature.

The question we want to answer is: can such a thin crust produce such a strongly localized hot region as in the neutron star case ?

Strange Star - Results

We consider a strange star model with a radius of ~11 km and a baryonic crust of thickness ~250 m. We keep B_o^{core} at 10^{13} G and vary the strength of the two crustal components B_o^{crust} and B_o^{tor}. The resulting crustal temperature profiles are displayed in Fig.4.



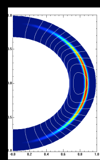


Figure 4: Crustal temperature profiles for various Strange Star magnetic field scenarios according to the aforementioned model parameters. The radial aspect of the crust has been stretched by a factor of 15 in order to see the thermal structure (compare with Fig. 3).

The upper right profile shows the field lines of the poloidal components and (in colors) the intensity distribution of the toroidal component.

Temperature distribution similar to the successful neutron star case of Fig. 3 can be obtained only in cases of a strong crustal poloidal field ~ 10^{13} G or a very strong toroidal crustal field ~10^{15} G.

Conclusion

Considering that the optical + X-ray spectrum of RX J1856.5-3754 can be modelled by a strongly non uniform crustal temperature resulting in two small hot region at the surface (Fig. 2) we deduce that:

- **Crustal temperature distribution producing small hot region at the surface can be generated within the shallow crust of strange star (Fig. 4).**
- **The strengths of the field confined to the crust, either the poloidal or the toroidal component need to be very high**
- **It is an open question if the thin crust of a strange star can sustain such high magnetic field, but the answer is probably NO.**

It is dificult to justify the presence of such large fields in a crust whose thickness is on the order of 100's of meters, and so it is unlikely that RX J1856.5-3754 can be interpreted as a strange star with this crustal field model.

A short list of references:

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