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Are pulsars strange ?

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Abstract. Pulsar radio pulses are made up of the so called core and conal components. A remarkably precise relation for core component widths, found observationally, in effect specifies the size of the polar cap on pulsars. Inclusion of general relativistic effects makes the theoretical size dependent on the pulsar mass. The observed core width relation thus provides constraints on masses and radii of pulsars leading to a very stringent selection from the available equations of state for the pulsar matter, strongly indicating that pulsars are strange stars rather than neutron stars.

Pulse components of radio pulsars have been classified as 'core' and 'conal' components (Rankin 1990). By analysing the core components of many pulsars a remarkably precise relation between the pulse width W and P the pulsar period (in seconds) was found. In the currently accepted 'polar cap model' of pulsar radio emission the radiation originates at some radial distance r on the open magnetic field line polar flux tube. We refer to the surface of emission as the *emission cap* which coincides with the polar cap when $r = R_*$. The width vs. P relation in essence specifies the longitudinal diameter of the emission cap 2ρ as

$$2\rho = \frac{2.^\circ 45}{\sqrt{P}} . \qquad (1)$$

This relation (henceforth the Rankin relation) provides an extraordinarily good fit to data. From the dipole geometry (Goldreich and Julian 1969) one finds

$$2\rho = \frac{2.^\circ 49}{\sqrt{P}} \sqrt{\frac{r}{10\ km}} . \qquad (2)$$

On the assumption that the full emission cap participates in the core emission, agreement between equations 1 and 2 immediately allows the conclusion that $r = 10\ km$ providing compelling evidence for favouring the origin of the core emission from the stellar surface.

In analysis of radio pulse structure, inclusion of effects due to the spacetime curvature caused by neutron star's mass makes it a significant parameter. The stellar gravitational field affects the dipole field geometry and also causes bending of the rays of the emitted pulsar radiation. Details have been described in Kapoor and Shukre (1998). An analytic but approximate version of how Eq. 2 is modified, is

$$2\rho = \frac{2.^{\circ}49}{\sqrt{P}} \sqrt{\frac{r}{10\ km}}\, f_{sqz}\ f_{bnd} \tag{3}$$

where the factors f_{sqz} and f_{bnd} are respectively due to squeezing of the dipole magnetic field and bending of light by the stellar gravitation and are approximately given by

$$f_{sqz} = (1 + \frac{3m}{2r})^{-1/2} \tag{4}$$

$$f_{bnd} = (\frac{2}{3} + \frac{\frac{1}{3}}{\sqrt{1 - \frac{2m}{r}}}) \tag{5}$$

where $m = \frac{G\,M}{c^2}$, i.e., $2m$ is the Schwarzshild radius.

Eq. 3 describes the variation of 2ρ with r for a given value of M. Its comparison with the Rankin relation leads to the conclusion that observational widths can not be obtained from Eq. 3 unless

$$M \leq M_0 \simeq 2.5\ M_{\odot}. \tag{6}$$

This is an indication that all radio pulsars have masses $\leq M_0$ because incidence of core emission among radio pulsars is ~ 70%.

For masses below this limit, the Rankin relation can be used to derive the emission altitude for a given mass. For reasonable masses these values of r lie very close and leads us to the other constraint:

$$R_* \leq 10.5\ km. \tag{7}$$

We have searched earlier works for neutron star M - R relations. For about 40 EOS M - R plots were available. Among these 14 are not favored by inequality 7. Imposing further condition from observations that their mass range allow the value 1.4 $M_{\odot}$ rules out all but the EOS BPAL12 and given the present theoretical uncertainties in the EOS of neutron stars no EOS may survive the inequality 7. Pulsars are then not neutron stars but strange stars.

Some stars considered so far to be neutron stars have been proposed to be actually strange stars mostly based on the compactness of stars being more than what a neutron star can accomodate. Pulsars being strange stars fits well with our constraints. Whether they are bare strange stars, strange stars with normal cursts etc. is difficult to answer at present, although some answers have been proposed. In conclusion our constraints provide a strong indication that pulsars are strange stars.

References

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