Quark Phase Transition & Time-structure of Pulsar Spin-down*

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Pulsars—highly magnetized rotating neutron stars—emit magnetic dipole radiation and a wind of electron-positron pairs. Through the energy and angular momentum loss the angular velocity decreases. As a pulsar spins down it becomes less deformed and the central density rises. For some pulsars the mass and initial angular velocity Ω may be such that the central density rises from below to above the critical density for dissolution of baryons into their quark constituents. Because the compressibility of quark matter is greater than that of the confined phase, the phase change will be mirrored in structural changes in the star such as its size and moment of inertia: the star has entered an era in which it shrinks anomalously as it spins down over time because an increasing proportion of the stellar mass is converted to the more compressible deconfined phase. The star's mass becomes ever more concentrated near its center—more so than would be the case for a star composed of a simple fluid on which a weakening centrifugal force was acting. The concentration arising from the greater compressibility of quark matter is *amplified* by its greater gravitational attraction on the outer parts of the star.

At the stage described, the tendency of the star to shrink as the region occupied by quark matter grows in radius, counteracts (by angular momentum conservation) the spin-down rate ($\dot{\Omega}$) caused by radiation. The development of a growing central region of reconfined quark matter acts, so to speak, as a governor. Therefore the rates at which the mass becomes concentrated near the center and the star shrinks are *large* as functions of decreasing angular velocity but *small* as functions of time. A *strong* anomalous time-structure, which will endure for a *long time*, is introduced into the spin-down of a pulsar by conversion of the core to quark matter.

The anomaly in time-structure will appear in the value and behavior of the so-called braking index, a dimensionless measurable quantity,

$$n(\Omega) \equiv \frac{\Omega \ddot{\Omega}}{\dot{\Omega}^2} = n - \frac{3I'\Omega + I''\Omega^2}{2I + I'\Omega}, \qquad (1)$$

where $I' \equiv dI/d\Omega$ reflects the response of the moment of inertia to centrifugal and structural changes and $n=3$ for magnetic dipole radiation. The behavior of $n(\Omega)$ for a model star is shown in Fig. 1 where the anomaly is clearly visible in the departure from the smooth curve.

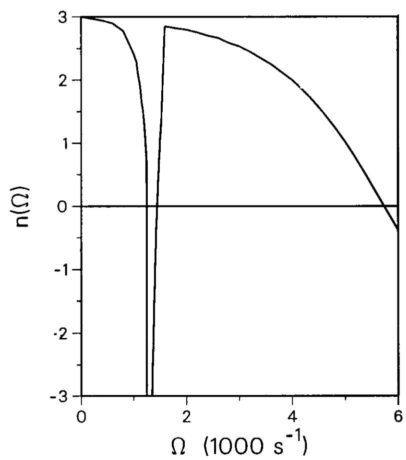

Figure 1: Braking index anomaly.

We estimate the plausibility of observing the phase transitions in the pulsar population. The duration over which the observable index is anomalous is $\Delta T = -\Delta\Omega/\dot{\Omega}$ where $\Delta\Omega$ is the frequency interval of the anomaly. For a typical period derivative, $\dot{P} \sim 10^{-16}$, we find $\Delta T \sim 10^5$ years. During a typical pulsar's active lifetime, about 10^7 yr, the signal (negative index) would endure for 1/100 of the lifetime. Given that $\sim 10^3$ pulsars are known about 10 of them may be signaling the phase transition.

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