Neutron Star Astrophysics at the Crossroads: Magnetars and the Multimessenger Revolution
Proceedings IAU Symposium No. 363, 2023
E. Troja & M. G. Baring, eds.
doi:10.1017/S1743921322000990

The Magnetar Connection

Tanmay Tushar Chowhan[1], **Sushan Konar**[2] **and Sarmistha Banik**[1]

[1]Dept. of Physics, BITS Pilani, Hyderabad Campus,
Shameerpet Mandal, Hyderabad-500078, India.

[2]NCRA-TIFR, Pune 411007, India

Abstract. We investigate the combined evolution of the dipolar surface magnetic field (B_s) and the spin-period (P_s) of known Magnetars and high magnetic field ($B_s \gtrsim 10^{13}$ G) radio pulsars. We study the long term behaviour of these objects assuming a simple Ohmic dissipation of the magnetic field. Identifying the regions (in the P_s-B_s plane) in which these neutron stars would likely move into, before crossing the death-line to enter the pulsar graveyard, we comment upon the possible connection between the Magnetars and other classes of neutron stars.

Keywords. stars: neutron, pulsars: magnetic fields, pulsars: evolution

---

More than fifty years have passed since the discovery of neutron stars. In this period, ~3500 neutron stars, belonging to many distinct observational classes, have been observed. This has led to an important direction of neutron star research, in trying to find a unification scheme (evolutionary or otherwise) connecting these different observational classes. In particular, the connection between different types of isolated neutron stars (i.e, the Magnetars, the RRATs, the CCOs, the XDINS, and ordinary radio pulsars) through magnetic field evolution has received serious attention in recent years (Kaspi 2011). Therefore, it is worthwhile to study the time-trajectory of such isolated neutron stars in the spin-period - surface magnetic field (P_s-B_s) plane to understand possible connections between these distinct observational classes. With this aim, we consider the evolution of the Magnetars and the high magnetic field ($B_s \gtrsim 10^{13}$ G) radio pulsars.

As there exist much uncertainty about the exact nature/configuration of the magnetic field, we assume a purely crustal field (the currents supporting the field are entirely confined to the crust) for this work. We further assume the magnetic field ($\mathbf{B}$) to evolve through simple Ohmic dissipation according to (Jackson 1975) -

$$\frac{\partial \mathbf{B}}{\partial t} = -\frac{c^2}{4\pi} \nabla \times \left(\frac{1}{\sigma} \nabla \times \mathbf{B}\right), \tag{1}$$

adopting the formalism developed by Konar (1997). Ohmic dissipation has been investigated in detail in the context of neutron star field evolution (see recent reviews by Igoshev & Popov (2015); Konar (2017); Pons & Vigano (2019)). Ertan & Alpar (2021) has recently reiterated the effectiveness of this mechanism by providing an explanation for the observed minimum spin-period of millisecond pulsars.

The free parameters of the model, entering the above equation through the electrical conductivity σ, are - a) the density, ρ_c, at which the currents are concentrated (σ increases steeply with ρ_c), and b) the impurity content, Q of the crustal material (σ decreases with Q). Since there is no way of knowing the exact parameter values applicable for a particular neutron star, we calculate the trajectory of each object assuming the following ranges

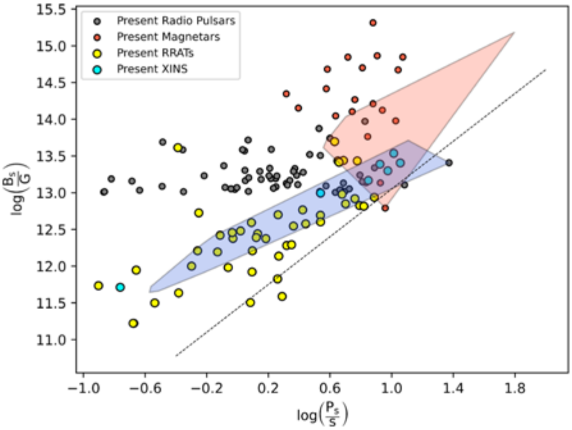

Figure 1. The current locations of the Magnetars and the high magnetic field radio pulsars along-with the region where they evolve into, in the P_s-B_s plane. The currently known RRATs and XDINSs have also been shown. Data Source : Magnetar, Radio Pulsar & XDINS (ATNF Catalogue), RRAT (arXiv:2201.00295).

for these parameters - a) $\rho_c \sim 10^{11} - 10^{13}$ gm.cm^{-3}, b) $Q \sim 0.0 - 0.05$. These parameter ranges are expected to be appropriate for long-lived crustal fields (Konar 1997).

The fundamental measured quantities of a neutron star are its spin-period (P_s) and the period derivative ($\dot{P}_s$). The large-scale dipole magnetic field is estimated, assuming the magnetic dipole radiation is solely responsible for the spin-down.

We track the evolutionary trajectories of - a) 19 Magnetars, and b) 65 radio pulsars (with $B_s \gtrsim 10^{13}$ G, beginning with their current values of P_s and B_s. Thereafter, with each incremental change in B_s, we dynamically calculate P_s. The Magnetars are evolved for 2×10^5 years and the radio pulsars for 5×10^5 years. The timescales are chosen such that the trajectories are arrested before they reach the death-line (Chen & Ruderman 1993) shown as a dashed line in Fig. 1.

Our results are shown in Fig. 1. The shaded areas in red and blue correspond to the regions where the Magnetars and the radio pulsars are found after $2{\times}10^5$ years and $5{\times}10^5$ years respectively. Recent work by Jawor & Tauris (2022) indicate that Magnetars are likely to evolve into XDINS. Our simple model of Ohmic dissipation clearly corroborates that finding. Moreover, most of the currently known RRATs are located where either Magnetars or Radio Pulsars are likely to evolve to. In a recent work, we have shown that the population of RRATs do not have a positive correlation (statistically speaking) with the population of nulling pulsars, as is usually assumed, but may have evolutionary connection to other classes of neutron stars (Abhishek et al. 2022). The current results, connecting the RRATs to Magnetars and high-magnetic field radio pulsars through an evolutionary pathway, appear to also corroborate this statistical conclusion.

References

Abhishek et al., 2022, *submitted to JApA*, arXiv:2201.00295
Chen K., Ruderman M., 1993, *ApJ*, 402, 264
Ertan, U & Alpar, M. A., 2021, *MNRAS*, 505, L112
Jackson, J. D., 1975, *Classical Electrodynamics, Wiley*
Jawor, J. A., & Tauris, T. M., 2022, *MNRAS*, 509, 634
Igoshev, A. P., Popov, S. B., 2015, *AN*, 336, 831
Kaspi V. M., 2011, *ApJ*, 741, L13A
Konar, S., 1997, *PhD Thesis*, Indian Institute of Science, Bangalore
Konar, S., 2017, *JApA*, 38, 47
Pons, J. A., Vigano, D., 2019, *LRCA*, 5, 3