A survey for Ultra-Long Period Pulsars with ALPACA

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Justification

Over the last five decades since the discovery of neutron stars, more than 3000 of these enigmatic stars have been discovered (Hewish et al., 1968; Lorimer, 2004). While most are discovered as radio pulsating stars or pulsars, we now know that neutron stars come in a variety of flavours. For example, there is a class of neutron stars with extremely small spin-periods (milliseconds) called millisecond pulsars that possess extremely stable rotational properties and are currently being used to detect the stochastic gravitational wave background. On the other hand, there are slowly spinning, highly magnetized neutron stars called magnetars that emit across a significant fraction of the electro-magnetic spectrum and are primary progenitor candidates for the elusive Fast Radio Bursts (FRBs) (Bochenek et al., 2020; CHIME/FRB Collaboration et al., 2020); bright, millisecond duration radio flashes of unknown origin. In spite of the giant strides we have taken in characterizing this neutron star zoo, there are many questions that still puzzle astronomers to date. We still do not know whether magnetars and canonical radio pulsars are formed differently or whether their evolutionary paths are similar or what dictates the presence or absence of radio emission in these stars. The mystery has deepened even further with the discovery of long period pulsars that challenge the current notion of the pulsar death-line, the spin period beyond which, coherent radio emission is physically impossible (Hurley-Walker et al., 2022). This highlights the importance of discovering not just more neutron stars but more long period radio loud neutron stars that will probe a hitherto unexplored parameter space in neutron star evolution. With this in mind, we will commence a Galactic Plane survey using one of the most advanced Phased Array Feeds (PAF) on one of the world's most sensitive radio telescope with the focus of finding long-period pulsars. The science goals of the project are as follows:

- **Constraining the physical models for radio emission death-line**: We now know that there a few radio pulsars that are radio loud despite being below the pulsar deathline (Ruderman & Sutherland, 1975; **?**). Finding radio loud pulsars close to or beyond the expected radio loud region in the P-$\dot{\rm P}$ parameter space is crucial to rule out models of pulsar radio emission and will put tight constraints on them.
- **Consolidating the connection between magnetars and FRBs**: FRBs have been a mystery since their discovery more than a decade ago (Lorimer et al., 2007). With the discovery of repeating FRBs and the subsequent FRB from a Galactic neutron star has led some authors to propose Ultra-long period magnetars (ULPMs) as the source of at least a sample of repeating FRBs (Beniamini et al., 2020). Such sources were unknown to us until the discovery of a potential magnetar with an 18-minute rotational period (Hurley-Walker et al., 2022). This has raised tremendous interest in the field and made it imperative to find this elusive population of ULPMs in order to understand the evolution of neutron stars and their physical links to FRBs.

Proposal

All the archival time-domain surveys have been heavily biased against finding long-period neutron stars. Typically, a survey pointing spans from a couple of minutes to 10 minutes and the periods searched for never exceed a few tens of seconds. Furthermore, any searches for bright single pulses exclude widths larger than a few hundred milliseconds thus, rendering any bright, wide pulse from an ultra-long period neutron star undetectable. Hence, using the sensitivity of the Green Bank Telescope combined with the 0.35 sq.deg instantaneous Field of View (FoV) of ALPACA, we aim to search the Galactic Plane for these ultra-long period neutron stars. By the virtue of a large FoV, we can conduct a deep pilot survey using a modest amount of telescope time. Assuming a 0.35 sq.deg FoV per pointing and three hours of integration time per pointing, we hope to cover an area of approximately 10 sq.deg in this pilot survey. We show that this is an optimal amount of integration time to detect any long periodicity up to 1000 seconds with a S/N of 10 or more with a limiting flux density of $\sim$60μJy even in the worst case scenario. We are planning for a total of 30 pointings with 15 minutes per pointing for slewing and other overheads. Hence, we would like to request for a total of 97.5 hours to carry out this survey.

References

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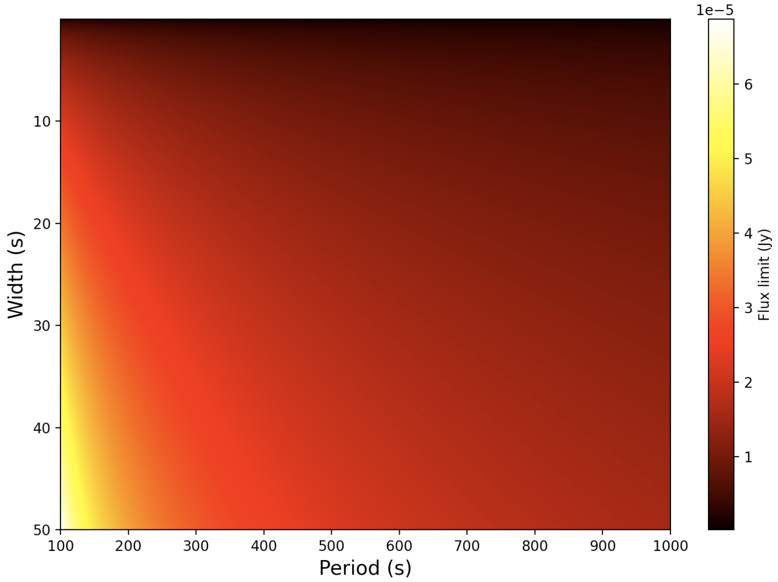

Figure 1: A heat map showing the flux limit from a 3-hour search for pulsars for a S/N of 10 as a function of pulse width and period. This shows that even for a pulse duty cycle as high as 50%, we can reach a flux limit of 60 μJy.

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