Pulsar Astrophysics the Next Fifty Years
Proceedings IAU Symposium No. 337, 2017
P. Weltevrede, B.B.P. Perera, L.L. Preston & S. Sanidas, eds.

doi:10.1017/S1743921317008638

The implementation of a Fast-Folding Algorithm in the PALFA survey

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Abstract. The PALFA survey, the most sensitive blind search for radio pulsars, has now discovered 180 pulsars in the Galactic Plane, the vast of which have periods shorter than 2 seconds. One reason that pulsar surveys may miss long-period radio pulsars is the strong effect of red noise at low modulation frequencies. It is possible to address this reduction in sensitivity by using a Fast-Folding Algorithm (FFA). We have adapted this algorithm for radio pulsar searching and applied it to PALFA observations. A sensitivity analysis of the algorithm has been conducted using synthetic pulsar signals injected in real observational data and this study shows that the FFA improves the PALFA survey sensitivity, as reported in Lazarus *et al.*(2015), by at least a factor of two at periods of ∼6 sec, implying that the PALFA survey should discover more long-period radio pulsars in the future.

Keywords. methods: data analysis, surveys, pulsars: general

1. Introduction

While Fourier-based search techniques have been commonly used to find pulsars in blind searches, red noise highly compromises their performance. Lazarus *et al.* (2015) showed that major discrepancies exist between the true sensitivity of the PALFA survey and the sensitivity predicted by the radiometer equation (Dewey *et al.*, 1995). This degradation becomes significant for pulsar periods as short as 100 ms, and grows with increasing period. The use of a Fast-Folding Algorithm (FFA, Staelin 1969), a time-domain search technique especially efficient at low modulation frequencies, is one way to partially address this sensitivity loss. The FFA folds a dedispersed time series at multiple trial periods, while avoiding redundant summations. The main advantage of the FFA over a FFT-type search is that by producing a phase-coherent result, it retains all harmonic structure, as opposed to FFT-based searches which sum only a limited number of harmonics incoherently.

We have designed a python program, ffaGo[†], that implements a FFA-based periodicity search into the PALFA analysis pipeline. ffaGo reads 32-bit float dedispersed time series and it includes a de-reddening procedure, dynamical rebinning routines, signal-to-noise ratio calculations, candidate selection and sifting routines. The parts of our code that wrap the time series, pad it, perform the folding and the summations were taken from Petigura *et al.* (2013). Each PALFA observation are searched for periodic signals ranging from a minimum period of 500 ms to a maximum of 30 sec, with DMs between 0 pc cm^{-3} and 3265 pc cm^{-3}. We perform rebinning at multiple stages during the search to explore the pulse width parameter. The amount of rebinning depends on the trial period, and it is performed at different phases to ensure optimal sensitivity (i.e., adjacent bins

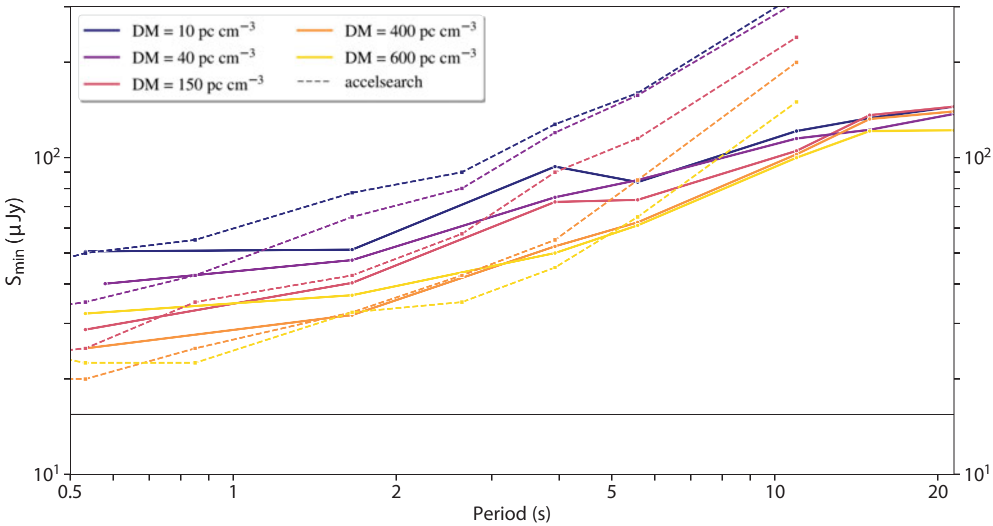

Figure 1. Minimum detectable average flux density for the PALFA survey as measured when searching with `ffaGo` for synthetic pulsar signals injected in real data (solid lines) for a fixed pulse duty cycle of 2.6, compared to values obtained from the FFT analysis (dashed lines) conducted in Lazarus *et al.* (2015).

are summed in different ways). The significance metric used to evaluate FFA-generated profiles assumes that the profile has one single-peaked pulse, that this pulse is constant in phase and that it is captured within a single bin. This implies that the detection is optimal when the bin size is equal to the width of the profile.

We reproduced the analysis described in Lazarus *et al.* (2015) to assess the sensitivity of the PALFA survey in the long-period phase space when using `ffaGo` to search for pulsar signals in real data. We injected synthetic pulsars at seven trial periods longer than 500 ms into the real survey data used in Lazarus *et al.* (2015). Five trial pulse duty cycles, ranging from 0.5% to ∼12%, and five trial DMs were selected for the analysis, resulting in 175 combinations of synthetic signals.

Comparing our results to those obtained by Lazarus *et al.* (2015), we show that for a pulse width of 2.6%, the FFA outperforms the FFT for DM∼ 10 pc cm^{-3} and for periods as short as ∼500 ms (see Figure 1). The survey sensitivity is improved by at least a factor of two for periods $\gtrsim$ 6 sec. For the same pulse width, the performance of the FFA exceeds that of the FFT for all trial DMs for periods longer than 5 sec. Moreover, for periods longer than ∼ 8 sec, the FFA outperforms the FFT for all trial DMs and all pulse duty cycles. These simulations demonstrate that the coherent summing of all harmonics greatly enhances the sensitivity of pulsar survey in the red noise regime, and that PALFA should discover more long-period pulsars, if they exist, in the future. Since the implementation of `ffaGo` in the PALFA pipeline, three new pulsars were discovered by both the FFA and the FFT, but none have been exclusively detected by the FFA.

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https://doi.org/10.1017/S1743921317008638 Published online by Cambridge University Press