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PULSAR OBSERVATIONS WITH NENUFAR

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Abstract. NenuFAR (New Extension in Nançay Upgrading loFAR) is the new low-frequency radiotelescope in Nançay. It can observe from 10 to 85 MHz with a high sensitivity across the full band. We present the first observations of this instrument using the pulsar and dynamic spectrum backend UnDySPuTeD (Unified Dynamic Spectrum, Pulsar and Time Domain).

The observations are coherently dedispersed to correct for interstellar medium dispersive delay and folded or downsampled in real time with a GPU (Graphical Processing Unit). Two modes are implemented: the folding mode for routine pulsar observations and the downsampling mode for single-pulse observations.

Keywords: NenuFAR, pulsar, low frequency, backend

1 Introduction

NenuFAR has been designed to be highly sensitive across the full band. This capability is extremely useful for the low frequency pulsar science case due to the strong frequency dependence of pulsar signals (dispersion, scattering, scintillation and intrinsic variability). The aim of this paper is to demonstrate the possibilities offered by NenuFAR for pulsars observations. We present preliminary results from observations of strong pulsars in folding mode and single-pulse mode.

2 NenuFAR

NenuFAR is officially labelled SKA pathfinder. In its present state NenuFAR_1, it is composed of 56 miniarrays of 19 antennas. The final NenuFAR will be composed of 96 such miniarrays and will exceed 1.7 times the sensitivity of the LOFAR core. Because NenuFAR has a high gain across the full band, the sensitivity relative to the LOFAR core is even more pronounced at low frequencies. For example, at 20 MHz, NenuFAR_1 is 5 times as sensitive as the LOFAR core. This is mainly due to the new design of NenuFAR antennas and preamplifiers. Observations shown in this paper are made in commissioning mode, without proper coherent summation between miniarrays. When the calibration phase will be completed with a proper coherent summation (end 2018) the sensitivity of NenuFAR_1 will reach that of the LOFAR core.

3 Pulsar Backend

Low frequency coherent dedispersion in real time is a challenge due to the extreme time delay inside the lowest frequency channel. For example, with a single channel of only 195 kHz and for an observation at 20 MHz, B0329+54 (dispersion measure of 26.7 pc.cm^{-3}) has a dispersive delay of 5 seconds in the last channel, which corresponds to several times the pulse period. In the pulsar pipeline a time constant twice as high is required to get an overlap. In consequence, for each channel we need an FFT (Fast Fourier Transform) on 2^{21} complex values of 5.12 microseconds, corresponding to more than 10 seconds of waveform in a single FFT. For the total bandwidth (384 channels) we need 6 GB of memory in a single GPU.

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UnDySPuTeD is the BHR (Beamformed High Rate) backend of Nenufar on which is installed LUPPI (Low frequency Ultimate Pulsar Proccesing Instrument) a dedispersing and folding code with GPU parallelisation. This software is a low frequency adaptation of NUPPI (Nançay Ultimate Pulsar Proccesing Instrument) which is the software used on the decimeter radio telescope of Nançay, NUPPI is directly inspired by GUPPI (Green Bank Ultimate Pulsar Processing Instrument, DuPlain et al. (2008)).
LUPPI is installed on two machines with in total 4 GPUs (GTX 1080 8 GB). It has been designed to be able to coherently dedisperse and fold up to 4 numerical beams of 37.5 MHz of bandwidth simultaneously (192 channels per beam). Observations are processed using $PRESTO^*$, $PSRCHIVE^\dagger$, and $DSPSR^\ddagger$.

4 Observations

In this section we illustrate two types of observations: The folding mode (Fig. 1 first 3 panels) where the pulsar is sampled in subintegrations of 10 seconds and the single-pulse mode where a high time resolution is preserved and the data are computed with the downsampling mode and $DSPSR$ (Fig. 1 bottom right). This allows to decrease the subintegration length to the period of the pulsar. The length of the observations varies from 10 hours for the observation of the frequency evolution of B0809+74 (Fig. 1 top right) to 6 minutes for the individual pulse observation of B0809+74 (Fig. 1 bottom right). The total bandwidth is 37.5 and 50 MHz.

4.1 B0329+54

B0329+54 was observed during 7.5 hours with 37.5 MHz of bandwidth. Frequency variations of the profile are shown in Figure 1 (top left). We are able to see four different locations of emission at phases 0.32, 0.38, 0.41, 0.55. This pulsar shows an exponential tail in the lowest part of the band, which is the signature of the multi-path propagation in the interstellar medium.

4.2 B0809+74

This pulsar is interesting for its drifting subpulses (Hassall et al. (2013)) and for the inversion of the ratio between the amplitudes of both pulse components (Fig. 1 top right). On this object a single-pulse observation has been conducted with NenuFAR (Fig. 1 bottom right) in which we can observe the drift of the subpulse.

4.3 B1919+21

B1919+21 is the first pulsar observed by Jocelyn Bell in 1967. In Figure 1 (bottom left) we can observe its three main components at a phase of 0.05 0.06 and 0.07 respectively. It is interesting to observe that only the central component is visible below 30 MHz.

4.4 Milliseconds Pulsars

The pulsations of milliseconds pulsars (MSP) are difficult to observe at low frequencies and only a few of them have been detected below 100 MHz (J0030+4051, J0034-0534, J0437-4715, J2145-0750), see Kondratiev et al. (2016), Kondratiev et al. (2018), Stovall et al. (2015) and Bhat et al. (2018).
Due to the short rotating period, MSP are particularly affected by the interstellar medium turbulence (scattering, multipath propagation...), with temporal pulse broadening which can exceed many pulsar rotations. However, MSP don't show spectral turnover at 100 MHz contrary to the bulk of normal pulsars (Kuzmin & Losovsky (2001)). We attempted to detected additional MSP using the high sensitivity of NenuFAR. We have already detected four millisecond pulsars that had never been detected below 100 MHz (Fig. 2).

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[*] https://www.cv.nrao.edu/ sransom/presto/

[†] http://psrchive.sourceforge.net/

[‡] https://github.com/demorest/dspsr

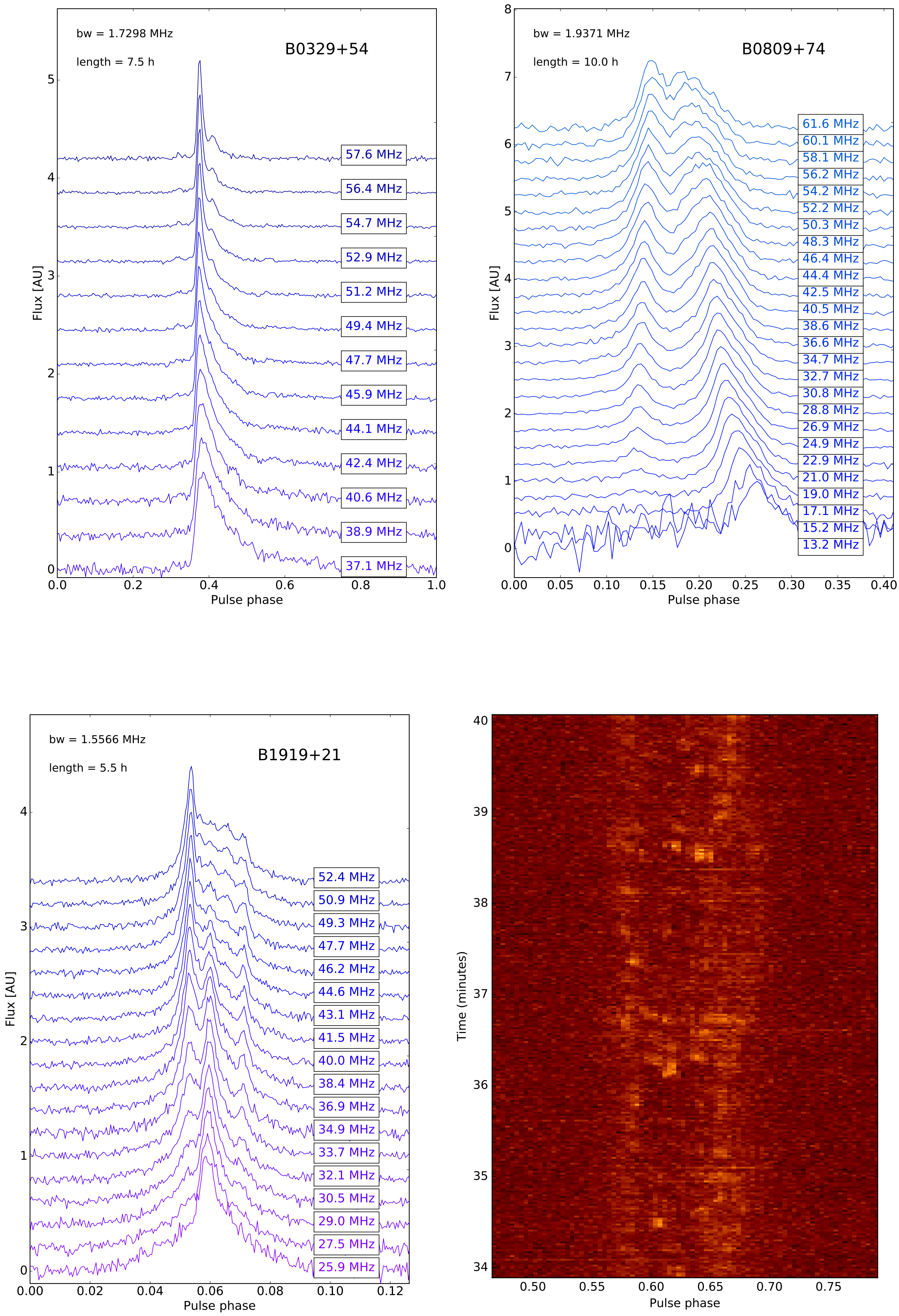

Fig. 1. Frequency stacked profiles of three pulsars and a single-pulse: **Top left:** B0329+54. **Top right:** B0809+74. **Bottom left:** B1919+21. **Bottom right:** Zoom on 6 minutes of a single-pulse observation of B0809+74.

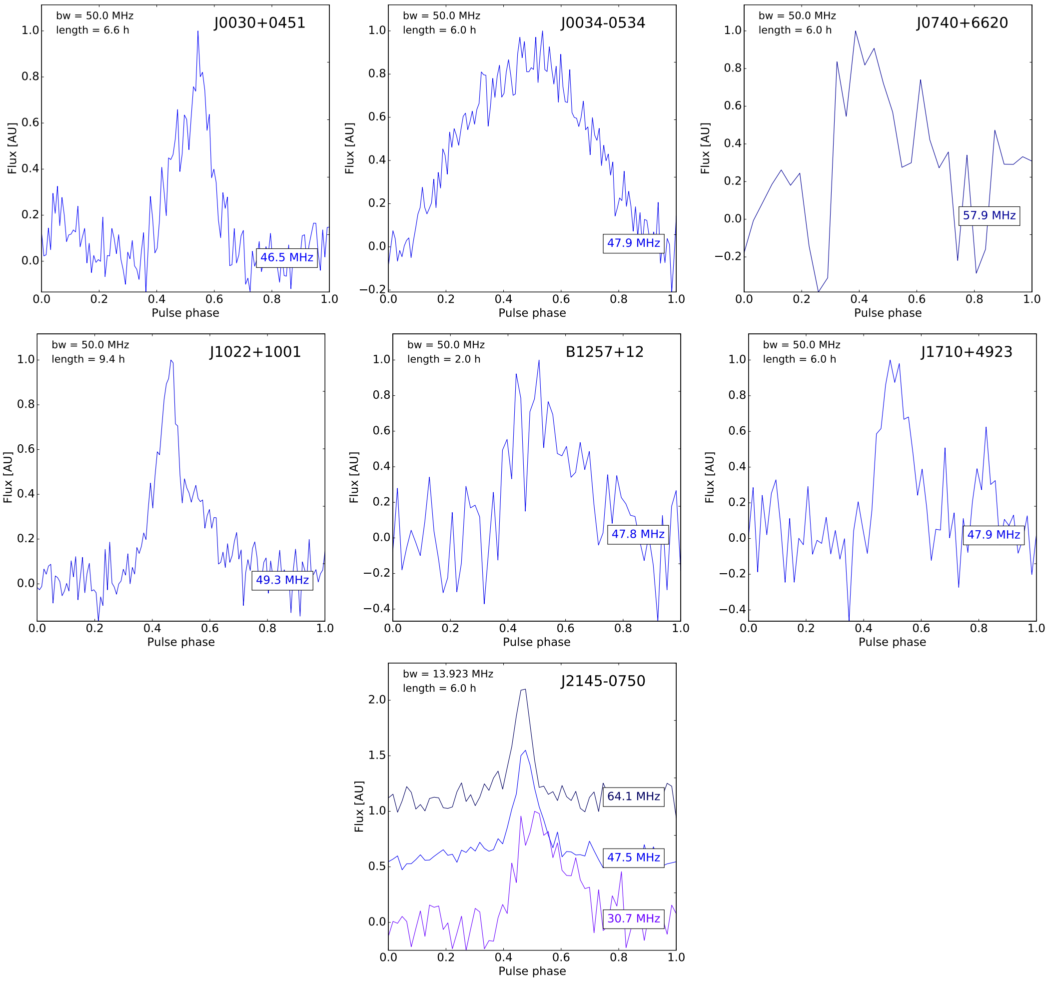

Fig. 2. Seven profiles of millisecond pulsars detected with NenuFAR. Four of them are detected for the first time below 100 MHz.

5 Conclusions

This paper demonstrates that real time coherent dedispersion is possible at low frequencies despite the long dispersive delays. Furthermore we have been able to implement and test two modes of pulsars observation (folding and single-pulse) and reveal the sensitivity of NenuFAR on the full observed band. Four new MSP have been detected. With this instrumentation we plan to conduct a census of known pulsars (on more than 500 sources) and monitor the activity of the 40 most powerful pulsars visible from Nançay to do a high-precision spectral study and DM monitoring of pulsars at low frequencies.

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