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THE NENUFAR PULSAR BLIND SURVEY

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Abstract. Pulsars are rapidly rotating neutron stars, from which we receive periodic pulses of coherent radiation. NenuFAR is a phased array telescope located in Nançay which can measure their spectral energy distribution and beam geometry in the bandwidth 10 – 85 MHz. The NenuFAR pulsar blind survey is a program to observe the entire sky above 39° of declination in the bandwidth 39 – 77 MHz, with the aim to find new pulsars, with a period from about 80 ms to about 30 s. Observations have begun in August 2020, and 97.5% of the 7 692 pointings were observed. The data processing is currently done at 29%, using a custom processing pipeline based on a Fourier method. The observation setup and pipeline have been validated by the re-detections of known pulsars.

Keywords: pulsar, NenuFAR, survey, low frequency, radio astronomy

1 Introduction

Pulsars are rapidly rotating neutron stars, with a high surface magnetic field which produces a coherent emission. Due to the misalignement between the rotation and magnetic axes, the observer receives a train of periodic pulsations, similar to a lighthouse. The NenuFAR pulsar blind survey (NPBS hereafter) has the objective to observe the entire sky above 39° of declination, using the new radio telescope NenuFAR. NenuFAR (Zarka et al. 2020) (new extension in Nançay upgrading LOFAR, `https://nenufar.obs-nancay.fr/en/astronomer/`) is a phased array telescope located at the Nançay Radio Observatory. It has a diameter of 400 m, and is currently composed of 1 520 antennas which can observe between 10 and 85 MHz. Using the specific pulsar instrumentation of NenuFAR (Bondonneau et al. 2021), the aim of the NPBS is to discover new pulsars, with a relative long period from 80 ms to 30 s, and/or featuring steep spectra.

2 Progress of the survey

2.1 Expectations

Pulsars have a continuous spectrum in radio, with an increasing flux towards low frequencies. However, it appears that an important number of pulsars show a spectral turnover at about 100 MHz (e.g. Bilous et al. 2020). We have made simulations depending on the fraction of the pulsar population with a spectral turnover. Based on the NenuFAR pulsar census results, from 81 to 97 detections are expected, including the discovery of between 0 and 3 new pulsars.

However, the size of the emission cone of pulsars is proportional to their period, and in addition, lower the observed frequency larger the size (Thorsett 1991). Thus, at the frequencies of NenuFAR, the probability for the cone to hit the Earth is larger, in particular for the slow pulsars (Tan et al. 2018). Due to this fact, the NPBS discoveries expectations can be multiplied, at least, by a factor 2 or 3, leading to a number of new pulsars from 0 to 10, with a predominance of slow pulsars.

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2.2 *Observing program*

In order to cover the sky above 39°, 7 692 pointings were performed at frequencies from 39 to 77 MHz. The observations of the NPBS were carried out using a sub-array of 25 mini-arrays of NenuFAR (representing 475 antennas), allowing to obtain an angular beam size of 1.2° at the central frequency of 58 MHz. To optimize the sky coverage, the observing program is divided into two successive phases of interleaved beams (illustrated in the Figure 1), where the pointings of the phase 2 are displaced by about a beam radius compared to the phase 1. The phase 1 was begun in August 2020. The main program was finished since July 2021, and was totally completed during 2022. The phase 2 has begun in July 2021, and is observed at 95% at the end of August 2022. The NPBS observing program is then almost complete at the end of August 2022 with 97.5% of the whole program which is observed. The remaining areas are planned to be observed in spring 2023.

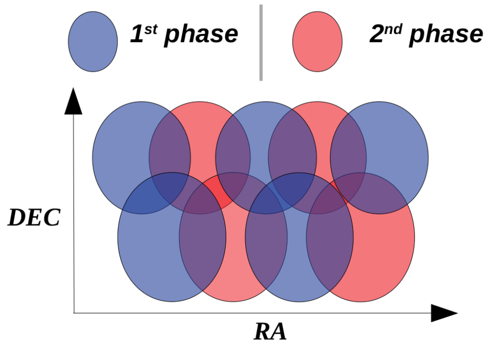

Fig. 1. Scheme presenting the principle of the two phases of the observing program of the NPBS. The beams of the pointings observed during the first phase are represented by the blue ellipses, and those of the second phase by the red ellipses.

2.3 *Data processing and redetections*

To find pulsars, periodic signals are searched using a custom processing pipeline based on a Fourier method (Ransom 2011). The capacity of detection of the NPBS has been tested with known pulsars. At the end of August 2022, 58% of the data of the phase 1, representing 29% of all the data, have been processed. Compared to the NenuFAR pulsar census (Bondonneau et al., in prep.), we expect to redetect between 4 and 8 known pulsars in the processed data. Indeed, 5 are easily detected (as B0809+74 in the Figure 2). The processing of the data of the phase 1 is still ongoing, and is planned to be complete by the beginning of 2023. The analysis of the first processed data has recently begun, and will be carried out in parallel for the next months. Concerning the data of the phase 2, they will be processed during 2023, in order to complete the whole processing at the end of 2023. The analysis of the processed data has begun in parallel, in order to obtain first results for autumn 2023.

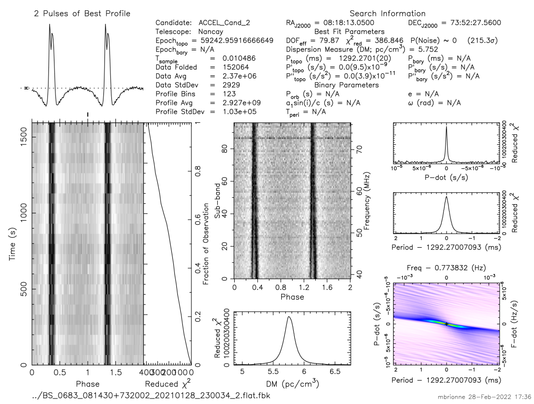

Fig. 2. Redetection of the pulsar B0809+74.

3 Conclusions

The NenuFAR pulsar blind survey covers the northern polar cap above 39° of declination using NenuFAR in order to find new pulsars. According to the simulations and the pulsar cone theory, we expect approximatively 100 detections, to discover between 0 and 10 new pulsars. The NPBS observing program has started in August 2020. 97.5% of the observing program is done, and is expected to be completed during the spring 2023. 29% of the data are processed, and 5 known pulsars are easily redetected, validating the observation setup and the blind search pipeline.

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