# Mode switching of PSR B0329+54 with LOFAR PL-612 station

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We present the results of 60 hours of observations of PSR B0329+54 with the LOFAR PL-612 station located in Bałdy Poland, and managed by University of Warmia and Mazury in Olsztyn (UWM). Observations were conducted in 2016 and 2017, at the central frequency of about 140 MHz, and they were conducted in form of six 10-hour semi-continuous observing sessions. The main goal of the analysis was the study the mode switching phenomenon in this pulsar. Our results show that the abnormal profile mode is present for about 12% of time on average at the observed frequency. Such result is similar to the analysis of a very large set of 1.5 GHz observations performed at Urumqi Observatory in 2011. The results shown in this paper also demonstrate the first scientific output concerning pulsar observations with the PL-612 station.

## 1 Introduction

The phenomenon of the mode switching was discovered in the early years of pulsar study. It was reported by Backer (1970) that the radio profile of PSR B1237+25 is abruptly switching between two distinctly different pulse shapes. Identifications of pulsars behaving in a similar manner were soon followed, and amongst them was the PSR B0329+54, one of the brightest pulsar in the northern hemisphere.

The B0329+54 pulsar has a roughly triple profile (see Fig. 1 left panel) however more components have been identified and their number changes with the observing frequency (Hesse 1973; Gangadhara & Gupta 2001). Long term monitoring of mode switching in PSR B0329+54 was performed by Chen et al. (2011). In their analysis the authors found that the pulsar radiates in the normal (A) mode for 84.9% of its time, while the abnormal mode (B) is present in the remaining 15.1% of its time.

In this paper we present the results and the analysis of six 10-hour observing sessions of PSR B0329+54 conducted with the LOFAR PL-612 station located in Bałdy, Poland (Błaszkiewicz et al. 2016; Krankowski et al. 2014), one of the three POLFAR (POlish Low Frequency ARray) stations. These are the first scientific results of pulsar observations from this telescope that were obtained in local observation mode. Our analysis proved that even a single LOFAR station may be successfully used as a pulsar observing tool, providing interesting scientific results.

## 2 Observations

The observations presented here were conducted using Polish LOFAR station, the PL-612. The data we gathered on August, Septemeber 2016 (2 sessions) and May,

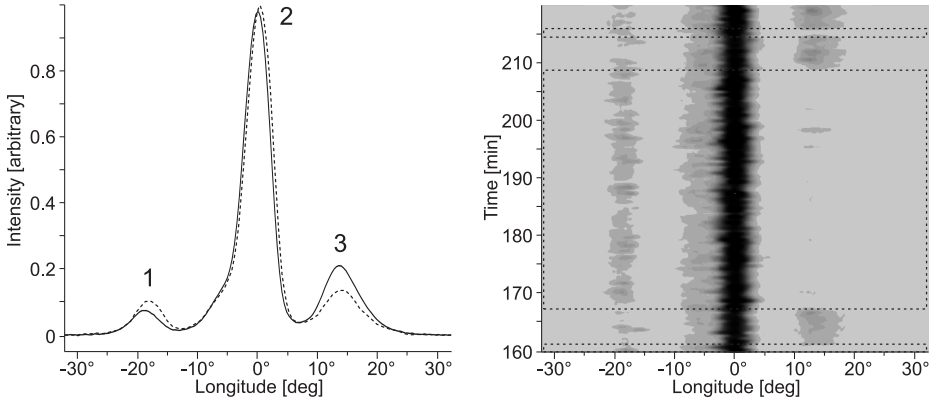


Fig. 1: Left panel presents September 2016 observation average profiles of PSR B0329+54 for the A (solid black) and B (dashed) modes. The plot also marks three components of the profile. Right panel shows the sequence of 1-minute pulse profiles showing both the A and B (dashed rectangles) modes, observed in August 19th, 2017.

Table 1: The occurrence rate of the abnormal (B) mode obtained for six observing sessions, and for the entire dataset. The fractional ratio of the B mode occurrence was calculated separately using 1-minute and 3-minute signal integration.

| Epoch | 3 min (%) | 1 min (%) |
|---|---|---|
| 2016-08-19 | 4.5 | 4.6 |
| 2016-09-04 | 7.8 | 9.6 |
| 2017-05-20 | 2.9 | 6.5 |
| 2017-08-18 | 5.9 | 5.8 |
| 2017-08-19 | 34.5 | 36.0 |
| 2017-08-20 | 10.3 | 12.5 |
| Total | 11.1 | 12.6 |

August 2017 (4 sessions). The observing sessions lasted for at least 10 hours each, centered on the time at which the pulsar was at its highest elevation. Center frequency was taken to be 137 MHz (bandwidth 36 MHz) in 2016 and 155 MHz (bandwidth 72 MHz) in 2017. The data was saved in the form of 10-second subintegrations, or in single pulse mode (September 2016 session). After radio-frequency interference (RFI) cleaning, the data was dedispersed and folded to form 1-minute and 3-minute integrated pulse profiles.

## 3 Data analysis and results

For the purpose of our analysis, we focused on three main components of the profile, as they are the best indicators of the mode changing behaviour of this pulsar. The average profile of A and B modes is shown in left panel of Fig. 1. In our analysis we adopted the method used by Chen et al. (2011), who noticed, that the most prominent indicator of the mode change is the radio of the relative intensity of

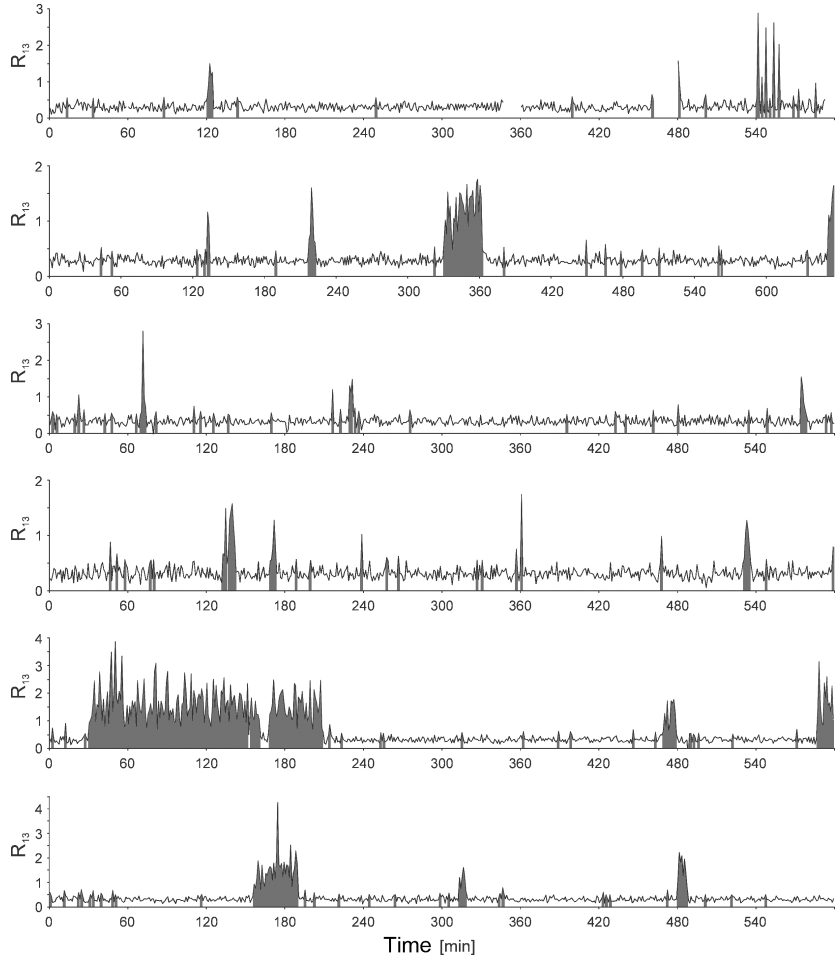


Fig. 2: Time sequence of the intensity ratio $R_{13}$ between the components 1 and 3 averaged by 1-minute. Observations (top to bottom) have been performed in August, September 2016 and May, August 18th, 19th, 20th, 2017, respectively.

the side components (no. 1 and 3): $R_{13} = I_1/I_3$, where $I_j$ is the total intensity received over the j-th component's longitude range. In the right panel of Fig. 1, we present the example of the sub-integration profile stacks, which clearly show that the pulsar's mode is changing. The history of the mode indicating parameter $R_{13}$ for PSR B0329+54 is shown in Fig. 2. We classified the pulse shape based on the value of $R_{13}$. The boundary between the modes was set to value close to 0.5. The average value of $R_{13}$ for the A mode was 0.309 with a standard deviation of 0.080, while for the B mode $R_{13} = 1.08$ with rms equal to 0.5. The distributions of $R_{13}$ for mode A and B are consistent with the normal distribution. Based on the obtained classification of the pulse shape, we calculated the mode statistics, and the results are shown in Tab. 1. Summarizing, for the total of 60 hours of observing time the B mode was detected in 11.1% of the 3-minute integrated profiles, and the number increases to 12.6% for 1-minute sub-integrations.

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