Observations of Pulsars with PL611 and PL612 LOFAR stations

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In this article we shortly present the pipeline used for pulsars observation as well as some statistics of observations done with two Polish LOFAR (LOw Frequency ARray) stations: PL611 in Łazy and PL612 in Bałdy. We also show some partial result as an exaple of work concentrated in a few projects related to the study of pulsars, the interstellar matter and the closest surroundings of the Earth.

1 The LOFAR system

The LOFAR interferometer, which design, configuration and the signal processing methods were described in detail by van Haarlem et al. (2013), consists of over 110 000 pairs of dipole antennas with omnidirectional characteristics alone, that are arranged to form of 52 individual stations across Europe as of now. Most of the stations are located in the Netherlands. In our output we concentrate on two Polish stations locatet in Bałdy (PL612) and administrated by the University of Warmia and Mazury in Olsztyn, and in Łazy (PL611) administrated by the Jagiellonian University in Cracow.

Polish stations mentioned above (aa well as Borówiec - PL610) are a part of the ILT - International LOFAR Telescope together with the six stations located in Germany and one station each in UK, France, Sweden and Ireland. Three Polish were created by the POLFAR Consortium, as it has been described by Błaszkiewicz et al. (2016) and Dąbrowski et al. 2016. Another LOFAR stations has recently been opened (Irbene in Latvia, LV614) or being planned (Medicina in Italy).

The LOFAR receivers' bandwidth spreads from 10 MHz to 240 MHz, but actually excludes the frequency range from 88 up to 108 MHz because of the expected Earth-bound interference. The Low Band Antennas (LBAs) are sensitive to the wavelengths from 30 to 4 meters (10–90 MHz). A single station LBA field contains of 96 pairs dipoles; antennas of the LBA field in this configuration occupy a circular area with a radius of about 62 meters. The High Band Antennas (HBAs) are collected in tiles, and operate in the wavelength range between 3 to 1.2 meters (110–240 MHz). Typically in full configuration the diameter of the HBA field is 40 meters and contains 96 tiles within (48 tiles in PL611 station only). Each tile contains 16 pairs of dipoles which means 3072 dipoles per HBA field.

It has been shown many times that the LOFAR telescope is one of the best tools for observing and testing pulsars (see eg. Stappers et al. 2011, Bilous et al. 2014, Noutsos et al. 2015). Therefore, in the case of PL611 and PL612 stations, we focus on observations of these objects.

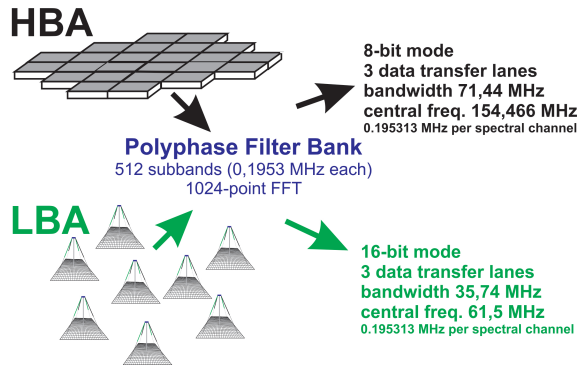

Fig. 1: Basic data relatd to data transfer for the HBA and LBA parts

2 The observational Pipeline

The pipeline for single station pulsars observations and data reduction used is quite similar to the one used by the GLOW (German LOFAR stations' Consortium). For pulsar observations with the Polish stations we adopted most of the solutions used by GLOW, especially when it comes to hardware specification and data acquisition. However, data processing is a modification of the previously existing software adapted to LOFAR specification (Błaszkiewicz et al., 2018).

In the first stage the beam-forming process takes place. This process uses specific commands to prepare complex-voltage coherently summed data from antennas in a total observing bands as data stream that is properly prepared. In the next step we are using the LuMP data recording system (LOFAR und MPIfR[1] Pulsare) which is a software package for recording beamformed data from LOFAR station in single station mode. The ready to distribute data has also been split (in the PL611 and PL612 pipeline) into three independent lanes and transferred through a dedicated Ethernet connection (see scheme in Fig. 1). The raw data signal sent to the analyzing computer is recorded. After receiving the entire raw data file, the processing is executed and finally data is recorded with full polarization information included. The post-processing of observational data is performed using the PSRCHIVE[2] software package (see for details Błaszkiewicz et al. 2018).

3 The observational statistics

The ILT observational policy for each of the international stations 2 days for single mode work. Pulsar observations with HBA part of the PL612 station were started at the begin of 2017. Until today the observations of 111 pulsars have been done (76 with signal detection $> 10\ \sigma$). The total observation time exceeds 1000 hours with typically 1 and 2 hour durations and with 10 s integrations. We also do single pulse mode observations for selected pulsars (see profile examples in Fig. 2 b).

The LBA observations are carried out using the PL611station mainly. So far, about 25 pulsars have been observed on the LBA (see profile examples in Fig. 2 a),

[1] Max Planck Institute for radio Astronomy
[2] http://psrchive.sourceforge.net

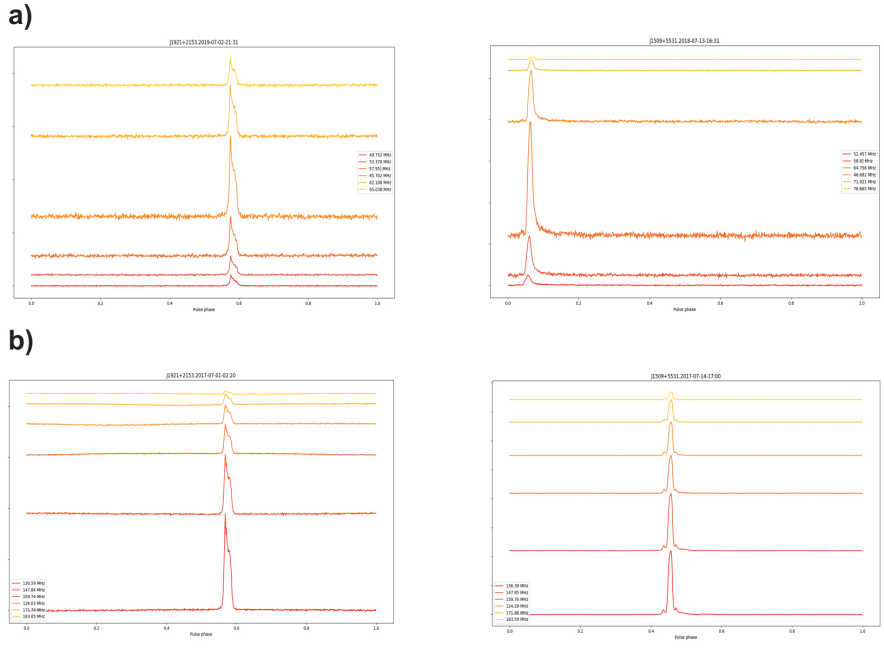

Fig. 2: Exemplary pulsar profiles observed with LOFAR: a) LBA part of PL611 and b) HBA part of PL612

of which 12 are in constant observations (on average every 3 weeks). The fact that the HBA field of the PL611 station is only 48 tiles causes less system sensitivity. It makes that observations of about 40 pulsars are possible. Main research topics on which pulsar observations are based on PL611 and PL612 stations are: scattering, interstellar scintillation and also single pulses morphology. Observations to search for giant pulses recently have also been conducted.

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