Observations of Pulsars with LOFAR

Leszek Błaszkiewicz[1,2], Wojciech Lewandowski[3], Andrzej Krankowski[2], Jarosław Kijak[3] and Bartosz P. Dąbrowski[2]

1. Faculty of Mathematics and Computer Sciences, University of Warmia and Mazury Słoneczna 54, 10-720 Olsztyn, Poland
2. Space Radio-Diagnostics Research Center, University of Warmia and Mazury R. Prawocheńskiego 9, 10-720 Olsztyn, Poland
3. Institute of Astronomy, University of Zielona Gora Szafrana 2, 65-516 Zielona Góra, Poland

LOFAR (LOw Frequency ARray) is a new generation, digitally controlled radio telescope consisting of phased array antenna stations with sensitivity, bandwidth, range of frequency, and digital processing power that makes it an excellent tool for the observations of pulsars. This interferometric instrument is able to work in single-station mode as well as in group-of-selected-stations mode. This proeceeding discusses discusses the great opportunity offered by the three LOFAR stations located in Poland and maintained by the POLFAR consortium[1] for conducting unique and independent research of pulsar sources.

1 Introduction

The first detection of a pulsar signal was made in the mid-60s at the observing frequency of 81 MHz by Hewish and collaborators (the history of pulsar research, the methods of observation, and their physics are described in detail in Lorimer & Kramer 2005), and it was soon discovered that the pulsating radio signal that was detected is generated by a rapidly rotating neutron star with an extremely high magnetic field.

Nearly half a century of pulsar research with radio astronomical methods allowed us to develop a reasonably acceptable model explaining the properties of pulsar radiation. Nowadays, after early LOFAR observations of pulsars by Hessels et al. (2010) and latter detailed study of selected pulsars (Bilous et al., 2014), we can be certain that LOFAR is currently one of the best instruments that can be used to study the pulsar's radio signals in great detail, at a level that was previously unattainable.

2 First LOFAR results of pulsar observation

The results of pilot surveys presented in Coenen et al. (2014) showed the high effectiveness of the multibeam method of observation used with the LOFAR instrument. The outcomes of broadband low-frequency observations of PSR B0943+10 (Bilous et al., 2014) resulted in a lot of new information about this peculiar pulsar. These results allow us to hope for remarkable progress in the study of individual pulsars. The most recent results of observations carried out with the LOFAR telescope and outlined by Noutsos et al. (2015), focus on the polarimetric properties of the emission of 20 bright pulsars.

[1] The basis of POLFAR foundation can be found in Krankowski et al. (2014)

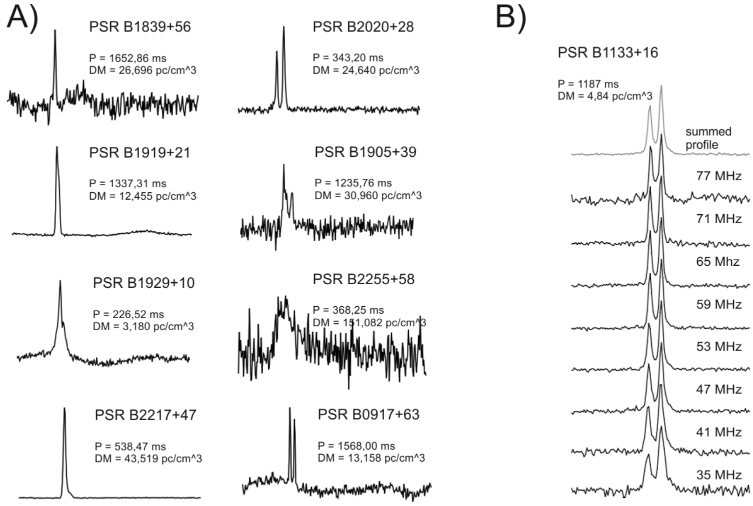

Fig. 1: A) Examples of pulsar profiles obtained with LOFAR pilot surveys taken from Coenen et al. (2014). B) Pulsar profiles obtained with LBA part of LOFAR taken from Stappers et al. (2011). The catalogue name (PSR), period (P) and dispersion measure (DM) are given.

3 Signal processing in pulsar mode observations

The very high spectral and time resolutions required in the observations of transient sources (such as pulsars) and the large analog-to-digital converters range will generate up to 13 Tbits/s of the raw data for the whole LOFAR array when using a typical 200 MHz sampling rate. For a single station processing this amount reduces to about 150 Gbits/s. The storage space requirements are very demanding as well: one hour of interferometric imaging observations yields about 35 TB of correlated visibilities.

Currently there are two transient-dedicated hardware/software solutions that can be implemented at each station, described in Błaszkiewicz et al. (2016). POLFAR stations in Bałdy and Borówiec chose the system previously adapted for ILT (International LOFAR Telescope) stations associated in the GLOW (German LOng Wavelength) Consortium. The Polish system will be based on computers with complex and powerful architecture (two Xeon E5-2660v3, 128 GB of RAM and HDD with 18 TB of space). The data recording system for pulsar used by a single LOFAR station, called LuMP, was developed in MPIfR, Effelsberg. The DSPSR format of data as well as many other useful features were developed recently and are constantly being improved.

4 Prospects for interstellar medium study

The main propagation effects observed in pulsar data and caused by the ionized matter of the interstellar medium (ISM) are the dispersion, scattering, scintillation, and Faraday rotation (see Fig. 2). Observations of these phenomena are definitely possible in the LOFAR frequency range, as was demonstrated by Stappers et al. (2011) or Bilous et al. (2014). In our research we want to focus mainly on the long-term monitoring (lasting from a few months to several years) of a few selected sources, which will help us to improve our understanding of the interstellar medium.

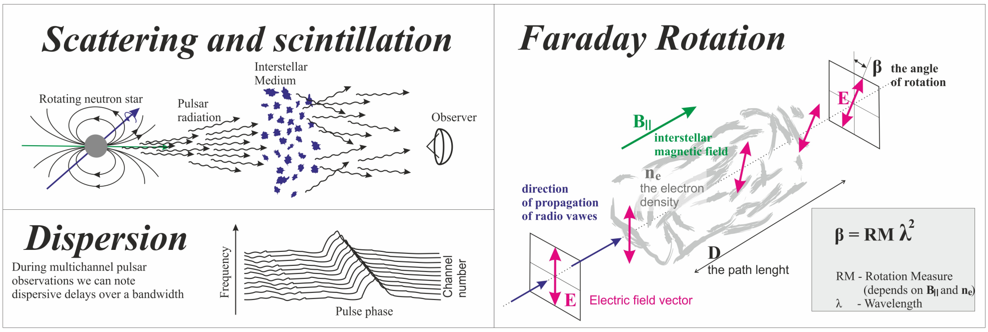

Fig. 2: Explanation of the phenomena associated with pulsar signal propagation through interstellar medium. Taken from Błaszkiewicz et al. (2016).

5 Conclusions

The LOFAR is working and first results for pulsars survey were already published Coenen et al. (2014); Bilous et al. (2014); Noutsos et al. (2015). It shows the great potential of observations in the single station mode. The construction of three new stations in Poland was finished and a few more in the rest of Europe are also planned. The revolutionary design of this instrument is an important step towards the future of radio astronomy and space research. Inherent is also the possibility of making significant progress in a wide range of technical areas. The specialized equipment hardware and software which is continuously being further developed and improved raises hopes for great possibilities in the future.

The LOFAR single station mode provides the opportunity to perform long-term monitoring of interesting pulsars, as well as single pulse and variability studies over very wide bandwidths.

References

Bilous, A. V., et al., *LOFAR observations of PSR B0943+10: profile evolution and discovery of a systematically changing profile delay in bright mode*, A&A **572**, A52 (2014), 1408.5272

Błaszkiewicz, L., et al., *Prospects for Scrutiny of Pulsars with Polish Part of LOFAR, Acta Geophys.* **64**, 1, 293 (2016)

Coenen, T., et al., *The LOFAR pilot surveys for pulsars and fast radio transients*, A&A **570**, A60 (2014), 1408.0411

Hessels, J. W. T., et al., *Early Pulsar Observations with LOFAR*, in ISKAF2010 Science Meeting, 25 (2010), 1009.1758

Krankowski, A., et al., *POLFAR – Polish incarnation of the LOFAR. Scientific objectives and system realization*, in Microwaves, Radar, and Wireless Communication (MIKON), 2014 20th International Conference on, 1–4 (2014)

Lorimer, D., Kramer, M., in Handbook of Pulsar Astronomy, Cambridge University Press (2005)

Noutsos, A., et al., *Pulsar polarisation below 200 MHz: Average profiles and propagation effects*, A&A **576**, A62 (2015), 1501.03312

Stappers, B. W., et al., *Observing pulsars and fast transients with LOFAR*, A&A **530**, A80 (2011), 1104.1577