Flux Density measurements of GPS pulsar J1740+1000 with LOFAR

Małgorzata Curyło[1], Karolina Rożko[2], Jarosław Kijak[2], Wojciech Lewandowski[2], Krzysztof T. Chyży[3], Andrzej Krankowski[4], Sarrvesh S. Sridhar[5], Leszek Błaszkiewicz[4] and Tim Shimwell[5]

1. Astronomical Observatory of the University of Warsaw, Al. Ujazdowskie 4, 00–478 Warszawa, Poland
2. Janusz Gil Institute of Astronomy, University of Zielona Góra, ul. Prof. Szafrana 2, 65-516 Zielona Góra, Poland
3. Astronomical Observatory of the Jagiellonian University, ul. Orla 171, 30-244 Kraków, Poland
4. Warmia and Mazury University in Olsztyn, ul. M. Oczapowskiego 2, 10-719 Olsztyn, Poland
5. ASTRON, Netherlands Institute for Radio Astronomy, Oude Hoogeveensedijk 4, 7991 PD, Dwingeloo, The Netherlands

Observations of Gigahertz-Peaked Spectra (GPS) pulsars (characterized by a decreasing flux density below 1 GHz) on the lowest frequencies are challenging mainly because of high resolution and sensitivity requirements that are not easily achievable by current telescopes. A proper and complicated calibration process may thus be the key element for studying faint sources with signal only scarcely exceeding the detection limit. Hereby we present the analysis of PSR J1740+1000 LOFAR observations with two distinct calibration methods where we aim at accurate flux density measurements at central frequency of 150 MHz.

1 Introduction

LOFAR (Low Frequency ARray) is a new generation radio telescope, which is offering an unprecedented resolution and sensitivity in the lowest frequencies observable from the ground from 10 MHz to 240 MHz (van Haarlem et al., 2013). It is build up from two types of dipole antennas (low and high band) assembled into 52 stations that are spread all over Europe. The two important advantages of LOFAR construction are possible various modes of observations covering both short and very long baselines and also flexible digital formation of a phased array. Unfortunately, these properties along with operation in low frequencies bring some serious challenges into data analysis, caused mainly by complicated beam shape and direction dependent variability of the ionosphere. These effects cause additional instrumental errors and phase shifts that, without proper correction, increase noise levels and significantly reduce resolution of images obtained via interferometric observations (van Weeren et al., 2016)

The aim of our project was to measure the flux density of pulsar PSR J1740+1000 at the low part of its spectrum - around central frequency of 150 MHz. Previous studies (Dembska et al., 2014; Bilous et al., 2016) did not succeed to finally arbitrate whether the pulsar spectrum can be described with a standard power law or if it is a GPS type. In order to obtain a reliable flux measurements we decided to use interferometric imaging technique which could provide sensitivity as good as 0.2 mJy and allow accurate study of the pulsars spectrum.

2 Observations and calibration methods

Our observations of PSR J1740+1000 were performed in two 4-hour runs simultaneously with the LOFAR Tier 1 survey on 12 December 2017 and 1 February 2018. We used HBA (High Band Antennas) to measure the pulsars flux density using all available stations in the international interferometric mode (50 stations).

The two standard pipelines we used in our data analysis are Factor for facet calibration (see van Weeren et al. 2016) and ddf-pipeline (see Shimwell et al. 2019). They both start with direction independent corrections (removal of RFI, averaging, calibrator gains and clock solutions) and then apply different solutions for direction dependent effects (DDE). In case of the latter one, it is constantly under development and it is now divided into two versions (DR1 and DR2) and for our analysis we used DR2.

3 Results

We analyzed both two maps obtained with FACTOR and ddf DR2 pipelines using AIPS and CASA packages and the values of peak and integrated fluxes as well as RMS are listed in Tab. 1. Both maps are presented in Fig. 1 and Fig. 2, respectively.

Tab. 1: Our measurements obtained by FACTOR and ddf DR2 pipelines. Peak and integrated flux densities vary because of the imperfection of any calibration method and directly correspond to instrumental errors and ionosphere variability. Thus, we take integrated flux densities as the correct values for further study.

	FACTOR	DDF DR2
Peak flux [mJy/beam]	1.00 ± 0.26	1.64 ± 0.57
Integrated flux [mJy]	2.85 ± 0.98	3.42 ± 1.65
RMS [mJy/beam]	0.25	0.19

4 Conclusions

In this work we present flux density measurements of PSR J1740+1000 obtained by means of interferometric imaging technique on central frequency of 150 MHz. We used two different calibration methods (FACTOR and ddf-pileline DR2 version), but due to the fact that the source is very faint only the latter one provided resolution and sensitivity high enough to confirm the detection with the integrated flux value of 3.42 ± 1.65 mJy and RMS equal to 192.78 μJy. As for the other map obtained in our work, we note that lower resolution images (here FACTOR) of faint sources which cannot be fully deconvolved during calibration process may lead to an underestimated flux density value. On this image pulsar signal is blurred due to poor angular resolution and we find flux density measurement not reliable.

Our work confirms that the spectrum of PSR J1740+1000 cannot be described

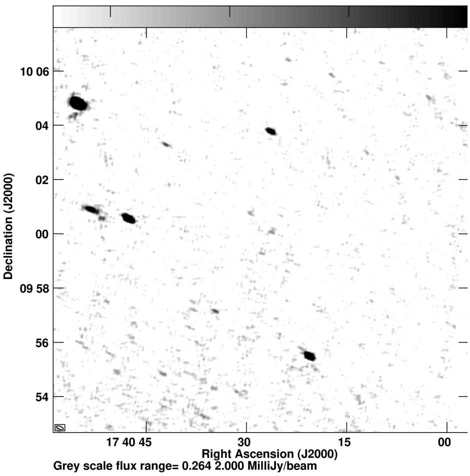

Fig. 1: The map obtained by FACTOR pipeline. The angular resolution is $16.5'' \times 6.2''$ and measured RMS is about 250 μJy/beam. PSR J1740+1000 is located in the very center of the map.

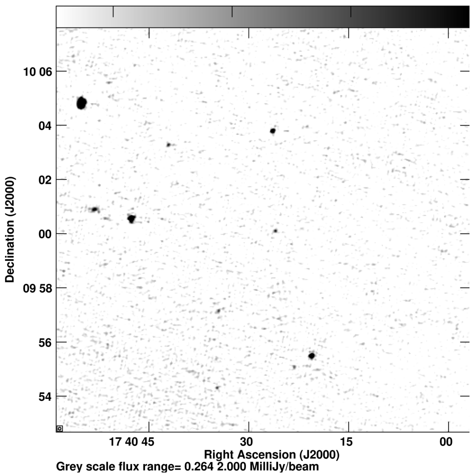

Fig. 2: The final map obtained with DR2 pipeline. The angular resolution is $6'' \times 6''$ and measured RMS is about 190 μJy/beam. PSR J1740+1000 is located in the very center of the map.

by a standard power law, but at the same time it is also more flat in its lowest part than for a typical GPS type pulsar. More detailed analysis of this case will be presented in Rożko et al. 2020 (in prep.). The forthcoming research also includes the comparison of the PSR J1740+1000 spectrum with other GPS pulsars in order to extend our understanding of the physical processes responsible for the decrease of the flux density below 1 GHz.

Acknowledgements. This paper is based on data obtained with the International LOFAR Telescope (ILT) under project code LC9_004. The ILT resources have benefitted from the following recent major funding sources: CNRS-INSU, Observatoire de Paris and Université d'Orléans, France; BMBF, MIWF-NRW, MPG, Germany; Science Foundation Ireland (SFI), Department of Business, Enterprise and Innovation (DBEI), Ireland; NWO, The Netherlands; The Science and Technology Facilities Council, UK; Ministry of Science and Higher Education, Poland.

References

Bilous, A. V., et al., *A&A* **591**, A134 (2016)

Dembska, M., et al., *MNRAS* **445**, 3, 3105 (2014)

Shimwell, T. W., et al., *A&A* **622**, A1 (2019)

van Haarlem, M. P., et al., *A&A* **556**, A2 (2013)

van Weeren, R. J., et al., *ApJS* **223**, 1, 2 (2016)