First solar observations with Polish LOFAR station in Bałdy

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We presented the very first observations of the Sun taken with the Bałdy LOFAR station, PL612, in Poland. The date were collected during the period from October 2016 to July 2017. Two types of radio bursts: type I and III have been detected. These observations show that the LOFAR radio telescope, working in the single station mode, is a good instrument for solar research.

1 Introduction

The LOw-Frequency ARray (LOFAR) is a large radio interferometer operating in the frequency range from 10 MHz up to 240 MHz. One of its main objectives is the solar observation (Dąbrowski et al., 2016; Błaszkiewicz et al., 2016). In this article we concentrate on the very early results of solar observations made with the international LOFAR station PL612 located in Bałdy, Poland.

2 The LOFAR telescope

The LOFAR telescope is an interferometer that consists of a large number (>100 000) of omnidirectional dipole antennas, arranged in 51 stations across the Europe. The system design, configuration and the signal processing methods were already described in details by de Vos et al. (2009), and van Haarlem et al. (2013). The interferometer operates in the $10-240$ MHz frequency range excluding the region of radio frequency modulation at $88-108$ MHz. Each station consists of two antennas fields presented at Fig. 1:

- LBA (Low Band Antennas) antennas to receive waves in frequency range of $10-90$ MHz. There are 48/96 pairs of LBA dipoles per station.
- HBA (High Band Antennas) antennas collected in tiles prepared for receiving waves in frequency range of $110-250$ MHz. There are 48/96 tiles with 16 pairs of HBA dipoles per station.

At the single station level the signal received by ordinary dipoles is digitally combined to phased array. The single antennas in each station are connected to mimic a telescope dish, which is electronically steered into the desired direction. The outputs of the stations are split into narrow frequency bins, correlated, averaged over short intervals, and stored for offline processing. The very high spectral and time resolution of the LOFAR stations requires big analog to digital converters to

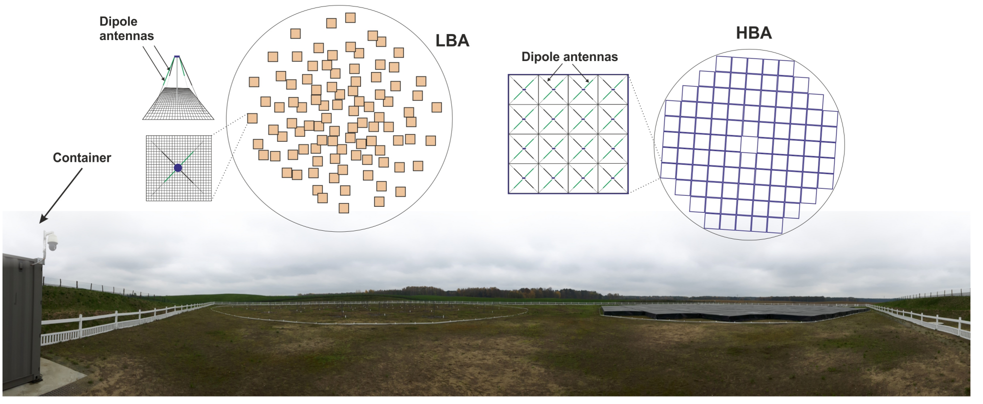

Fig. 1: The LOFAR station in Bałdy, Poland. From left to right: container with electronics, LBA field and HBA field.

generate 13 Tbits s^{-1} of raw data by the whole LOFAR array for a typical 200 MHz sampling rate. The single station processing reduces this amount of data to about 150 Gbits s^{-1}. Again, the required storage space is also very large. One hour of interferometric imaging observations is about 35 Tbyte of correlated visibilities.

3 First solar observations with Bałdy station

In the local single mode, LOFAR recorded dynamic spectra i.e., time-frequency-intensity data of the Sun. Our observational program for Bałdy station began with series of tests. They were carried out from October 2016 to January 2017 in order to know how the station works and how to receive the data and work on the spectrum of the Sun. Regular solar observations started from February 2017. Because the LOFAR station in Bałdy works mainly in ILT (International LOFAR Telescope) mode four workings days per week, for our own observations we have time from Friday up to Sunday. At this time, apart from the Sun observations, the LOFAR station in Bałdy conducted scintillation observations of Cyg A and Cas A sources and pulsars. Therefore, observation time for the solar research was very limited. This is from around 7 hours in the winter months up to around 12 hours in the summer months per week. Moreover, the activity of the Sun is very low now, its minimum is predicted for 2020.

From January up to July 2017 we have observed five radio events like type I and III radio bursts. They were detected at 22 January 2017, and at 14, 16 and 21 July 2017, respectively.

4 Type I noise storm registered on 22 January 2017

An example of spectroscopic observations made with Bałdy LOFAR station is the type I noise storm registered on 22 January 2017. This was the first radio event of solar activity observed by this station. The type I solar bursts usually occur in the form of large numbers of irregular structures, of short duration (normally below 1 second) superposed on a continuous background ranging from 60 to 400 MHz

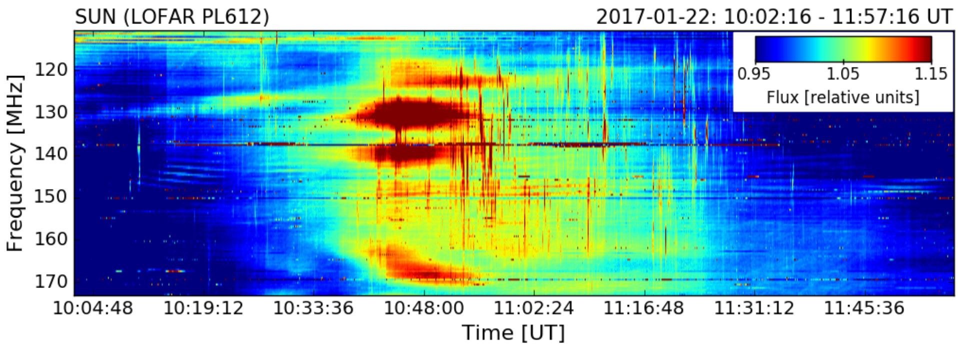

Fig. 2: Solar dynamic spectrum of the type I noise storm recorded on 22 January 2017 between 10:02:16 – 11:57:16 UT in the frequency band of 110.55 – 173.05 MHz with LOFAR Bałdy station.

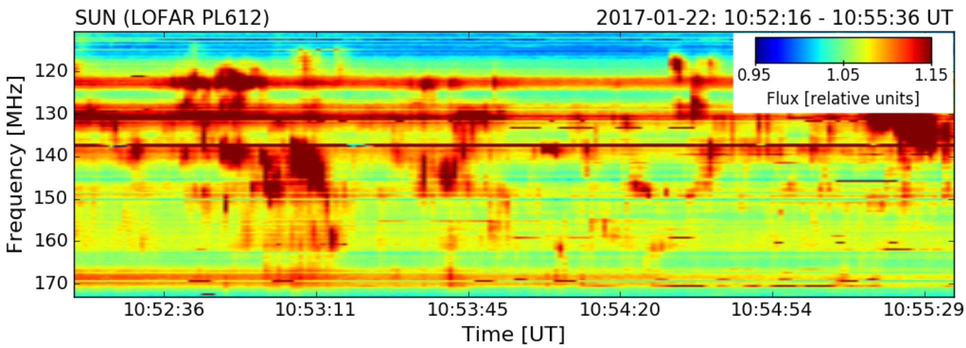

Fig. 3: Solar dynamic spectra of the type I noise storm recorded on 22 January 2017 between 10:52:16 – 10:55:36 UT in the frequency band of 110.55 – 173.05 MHz.

(Warmuth & Mann, 2005).

The event observed on 22 January 2017, occurred between 10:12 and 11:53 UT in high frequency band of 110.55 – 173.05 MHz (Fig. 2). This event is presented in detail in Fig. 3. It is only 200 seconds of observations between 10:52:16 – 10:55:36 UT in the frequency band of 110.55 – 173.05 MHz. The four red areas on the spectrum are probably caused by reflection from the container with electronics (see Fig. 2). Such effect could be observed that day because the Sun at noon was very low, about 13 degrees above the horizon. Other explanations of these red areas are also discussed. The temporal and frequency resolutions of the observation is 1 s and 0.39 MHz respectively.

5 Conclusions

The solar observations carried out from October 2016 to July 2017 with PL612 Bałdy station shown that LOFAR is a good instrument for research of the Sun at low frequencies from 10 up to 240 MHz. We recorded good quality dynamic spectra, that can be used to trace solar activity in a near future. Unfortunately, falling solar activity makes very difficult to observe the radio events in the near future. The short time – about ten hours per week – dedicated for solar observations is also a problem. Despite these minor difficulties, we are sure that this station was a perfect investment.

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References

Błaszkiewicz, L., et al., *Acta Geophys.* **64**, 1, 293 (2016)

Dąbrowski, B. P., Krankowski, A., Błaszkiewicz, L., Rothkaehl, H., *Acta Geophys.* **64**, 3, 825 (2016)

de Vos, M., Gunst, A. W., Nijboer, R., *IEEE Proceedings* **97**, 1431 (2009)

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

Warmuth, A., Mann, G., in K. Scherer, H. Fichtner, B. Heber, U. Mall (eds.) Lecture Notes in Physics, Berlin Springer Verlag, *Lecture Notes in Physics, Berlin Springer Verlag*, volume 656, 49 (2005)