FIVE YEARS OF SOLAR OBSERVATIONS WITH LOFAR STATION IN BALDY

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Abstract

We present exemplary observations of solar radio bursts collected in 2017 − 2021 with the use of LOFAR station PL612 located in Baldy (Poland), operating in local mode. In that period, the Sun was observed for 1190.3 hours over 235 days. We gathered high time (8 ms) and frequency (0.4 MHz) resolution spectra in the band 10 − 250 MHz. Despite the fact that this period can be characterized with relatively low solar activity, we managed to observe quite a large number of various bursts. Detailed analysis of these events will undoubtedly contribute to expanding our knowledge about physical properties of solar activity. Additionally, a single LOFAR station can be used to continuously monitor radio bursts in order to analyze the mechanisms affecting the so–called space weather.

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1 Introduction

The LOw–Frequency ARray (LOFAR) telescope (van Haarlem et al., 2013) is a large radio interferometer designed for observations in the range from 10 to 250 MHz. It can operate either using (a) core and remote stations or (b) core, remote and international stations (making up the International LOFAR Telescope). Single stations can also operate individually on their own observing programs. In this article, we present solar research with the use of LOFAR station PL612 in Baldy, Poland, owned by the University of Warmia and Mazury in Olsztyn.

Figure 1: *The LOFAR station in Baldy near Olsztyn. HBA (High Band Antennas) part is placed on the left, and LBA (Low Band Antennas) part can be seen on the right. A container with back–end instrumentation is shown in the middle*

2 The LOFAR telescope

The LOFAR telescope consists of 52 stations, 38 of which are located in the Netherlands and the remaining 14 in France, Germany, Ireland, Latvia, Poland, Sweden, and the United Kingdom. In the near future, two more stations are planned to be built in Bulgaria and Italy. Thanks to such arrangement of individual stations, we can observe with a resolution resembling a single telescope with diameter of around 2000 km. That gives us the sensitivity and angular resolution greater than any other instrument observing at similar wavelengths. Each LOFAR station consists of two antenna fields: LBA – Low Band Antennas, operating in the 10 – 90 MHz range, and HBA – High Band Antennas, operating in the 110 – 190 MHz and 210 – 250 MHz ranges. The station located in Baldy consists of 192 (96 pairs) LBA dipole antennas each one of which contains a pair of perpendicular dipoles, and 3072 HBA sensors grouped into 16 pairs of dipole antennas assembled in special tiles. More detailed specification of Baldy station and its contribution to solar observations can be found in Dabrowski et al. (2018).

The scientific observing programme for the LOFAR telescope is very extensive. It has been divided into six “Key Science Projects”. One of these is dedicated to solar physics and

Table 1: *Number of hours and days of solar observations at LOFAR station in Baldy in the years 2017 – 2021*

Year	Hours	Days
2017	364	73
2018	306.5	58
2019	206	41
2020	176.5	35
2021	137.3	28
Total	**1190.3**	**235**

space weather, including the study of solar activity and the Sun's effect on interplanetary space[1].

3 Solar radio bursts

Solar radio bursts mainly originate from flares and other events of the solar activity. Originally, in 1950, the solar radio bursts observed in the meter wave range were divided into three basic types: Type I, II, and III (Wild & McCready, 1950; Wild, 1950a,b), and supplemented around 1960 with two other types: Type IV and V (Boischot, 1957; Sheridan et al., 1959). Proposed classification was based on the distinguishable difference in the appearance of bursts in dynamic spectra – a 2D plot of showing the flux over frequency and time. The basic parameters used to describe solar bursts include: duration, spectral width and drift rate (in MHz/s). A detailed description of solar radio bursts types can be found in e.g. Warmuth & Mann (2005).

Type II solar radio bursts are characterized by a slow drift from high to low frequencies, equal to $0.1 - 1$ MHz/s. In dynamic spectra, they show emission in a fundamental and harmonic band. Type II bursts are usually observed at metric range, although they also appear in the decametre to kilometer range – so–called Type II interplanetary bursts (Cane et al., 1987; Mann, 1995). Observations indicate that this type of events are associated with flares and coronal mass ejections (CMEs). Type II bursts are generated by MHD shocks propagating in the solar corona. Their emission sources travel at velocities of about 1000 km/s. Type II bursts are often preceded by a group of Type III bursts (Warmuth & Mann, 2005).

Type III solar radio bursts observations are exceptionally important for understanding of the processes that occur during solar flares. These bursts are among the most common solar radio activity events. On the dynamic spectrum, they often appear in groups (consisting of many individual bursts) lasting a few minutes, where a single burst usually lasts only a few seconds. Type III bursts are generated by electron beams moving along the magnetic field lines towards the chromosphere (then the Type III bursts can be observed at millimeter waves), and up, towards the solar corona (in this case we observe them at meter waves). Acceleration of electron beams most likely occurs in the regions, where the energy of the magnetic field is being released (Reid & Ratcliffe, 2014).

[1] https://spaceweather.astron.nl/SolarKSP

4 Solar observations

LOFAR provides both radio images and dynamic spectra of the Sun. Images are obtained using standard interferometric techniques as well as the so–called tied–array method (van Haarlem et al., 2013). A single LOFAR station is suitable only for spectral observations of the Sun, which is the case of the station located in Baldy (Figure 1). The first solar observations using this station were conducted on October 12, 2016. From then until January 2017, test observations were made in order to understand how the station works, and how to maintain it to provide the best quality of observations. A systematic solar activity survey began in February 2017 (Dabrowski et al., 2018). As the Baldy station operates primarily in the international mode (about 90% of the time), the data for the individual programme were gathered for several hours per week, since a part of time not occupied by international key science projects was also distributed between observational projects of pulsars and ionospheric scintillations.

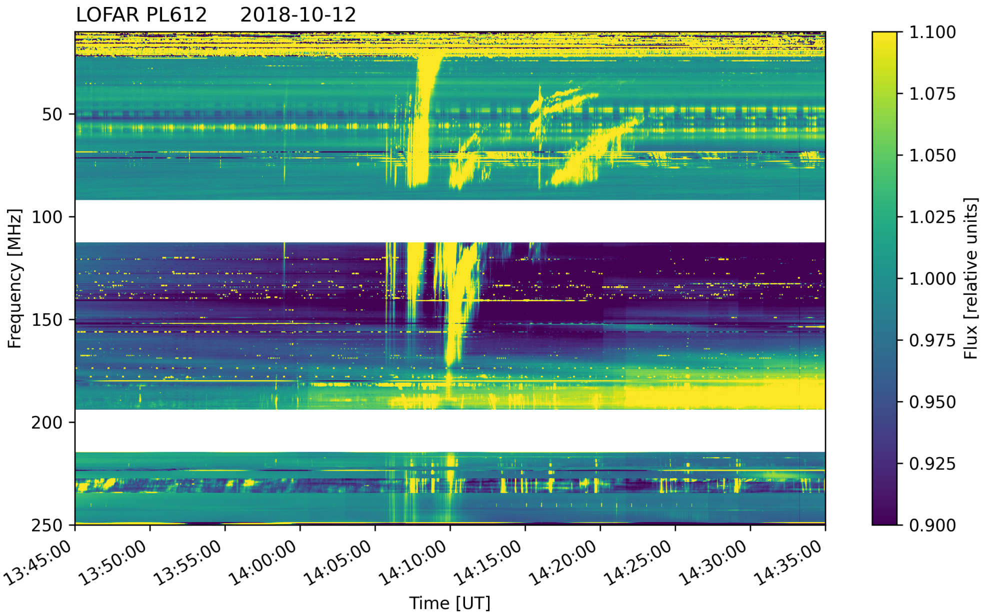

Figure 2: *Dynamic spectrum of the Type II (diagonal, between 14:10 and 14:22 UT) and Type III bursts (almost vertical traces, around 14:08 UT) registered on October 12, 2018 using the LOFAR station in Baldy, in the band 10 – 250 MHz. Horizontal lines visible at some regions of the spectrum are interferences. The white stripes represent frequencies not observed by the LOFAR telescope (90 – 110 MHz and 190 – 210 MHz, McKay-Bukowski, 2013)*

Observations were carried out in 2017 – 2021, during the period of low solar activity, corresponding to the final phase of cycle 24 and initial phase of cycle 25, where the minimum of solar activity was recorded in December 2019. During this period, the Sun was observed for 1190.3 hours over 235 days. Most of the observations were performed in 2017 (364 hours per 73 days). Table 1 shows the number of hours and days of observations for each year. During that time, Type III bursts were the most common ones, among all recorded events.

The exemplary observations of Type II and III solar radio bursts are shown in Figure 2 and Figure 3. Figure 2 shows the dynamic spectrum of Type II (observed between 14:10 and 14:22 UT in 35 – 250 MHz band) and Type III (observed around 14:08 UT in 10 – 250 MHz band) bursts recorded on October 12, 2018. During this time, GOES registered a faint B7.1 class flare that began at 14:04 UT and ended at 14:13 UT (peak at 14:08 UT). Its source was located in the active region AR 12724. The time and frequency resolution were 8 ms and 0.4 MHz, respectively. Figure 3 shows the dynamic spectrum of the Type III bursts observed on March 1, 2022. These bursts appeared between 11:04 UT and 11:19 UT. Just before, GOES observed a faint B3.4 class flare that began at 10:48 UT and ended at 11:04 UT (peak at 10:59 UT). The time and frequency resolution were 8 ms and 0.4 MHz, respectively.

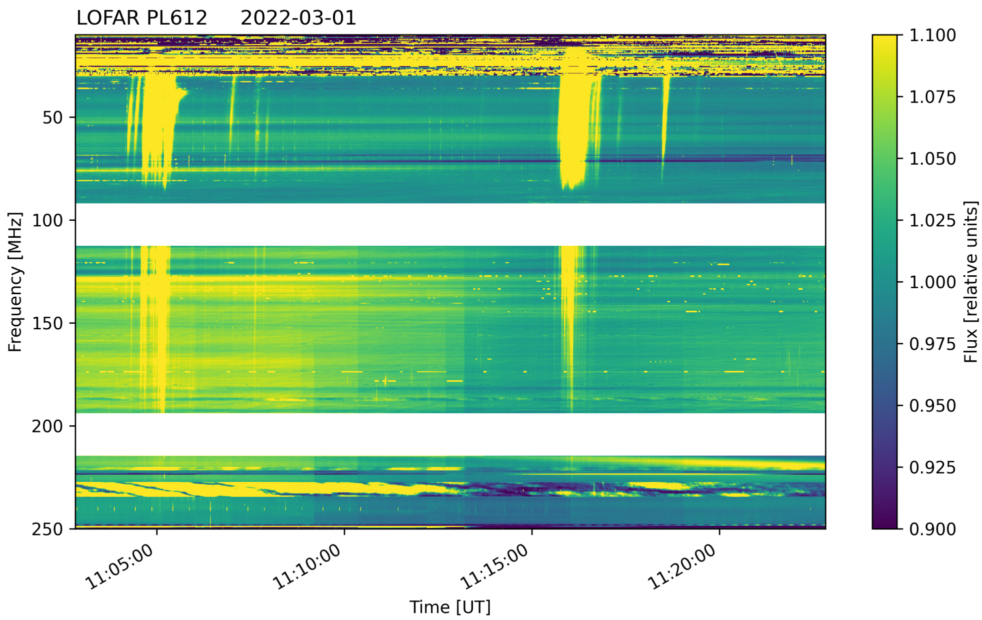

Figure 3: *Dynamic spectrum of the Type III bursts registered on March 1, 2022 using the LOFAR station in Baldy, in the band 10 – 250 MHz (McKay-Bukowski, 2013)*

5 Conclusions

Solar observations conducted from February 2017 to December 2021 using the station in Baldy has shown that LOFAR is a good instrument for studying the Sun at low frequencies from 10 to 250 MHz (Zhang et al., 2022; Dabrowski et al., 2023; Chen et al., 2023; Clarkson et al., 2023). During this period, we managed to observe many radio bursts of various types with high time and frequency resolution. Their detailed analysis will undoubtedly enrich our knowledge of such events. Observations gathered with other instruments operating at different wavelengths will also provide additional information about the nature of solar bursts (e.g. the SDO – Solar Dynamics Observatory (Lemen et al., 2012) – in the extreme ultraviolet or GOES[2] and RHESSI (Lin et al., 2002) at X–ray wavelengths). It will be particularly important to compare them with the data recorded by instruments on the Parker Solar Probe (Fox et al., 2016), which was designed especially to study the corona and circumsolar interplanetary space (solar winds).

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References

Boischot A., 1957, Caractères d'un type d'émission hertzienne associé à certaines éruptions chromosphériques, *Academie des Sciences Paris Comptes Rendus*, *244, 1326*

Cane H. V., Sheeley N. R. J., Howard R. A., 1987, Energetic interpanetary shocks, radio emission, and coronal mass ejections, *Journal of Geophysical Research*, *92, 9869*

Chen X., Kontar E. P., Clarkson D. L., Chrysaphi N., 2023, The frequency ratio and time delay of solar radio emissions with fundamental and harmonic components, *Monthly Notices of the Royal Astronomical Society*, *520, 3117*

Clarkson D. L., Kontar E. P., Vilmer N., Gordovskyy M., Chen X., Chrysaphi N., 2023, Solar Radio Spikes and Type IIIb Striae Manifestations of Subsecond Electron Acceleration Triggered by a Coronal Mass Ejection, *The Astrophysical Journal*, *946, 33*

[2] https://ngdc.noaa.gov/stp/satellite/goes/doc/GOES_XRS_readme.pdf

Dabrowski B. P., et al., 2018, Observations of the Sun using LOFAR Baldy station, *Advances in Space Research*, *62, 1895*

Dabrowski B., et al., 2023, Interferometric imaging of the type IIIb and U radio bursts observed with LOFAR on 22 August 2017, *Astronomy & Astrophysics*, *669, A52*

Fox N. J., et al., 2016, The Solar Probe Plus Mission: Humanity's First Visit to Our Star, *Space Science Reviews*, *204, 7*

Lemen J. R., et al., 2012, The Atmospheric Imaging Assembly (AIA) on the Solar Dynamics Observatory (SDO), *Solar Physics*, *275, 17*

Lin R. P., et al., 2002, The Reuven Ramaty High-Energy Solar Spectroscopic Imager (RHESSI), *Solar Physics*, *210, 3*

Mann G., 1995, Theory and observations of coronal shock waves, *in Coronal Magnetic Energy Releases, eds Benz, Arnold O. and Krüger, Albrecht*, Springer Berlin Heidelberg, Berlin, Heidelberg, pp 183–200

McKay-Bukowski D., 2013, Making Observations with Mode-357, *Technical Note KAIRA-SGO-INF-011*, *pp 1–13*

Reid H. A. S., Ratcliffe H., 2014, A review of solar type III radio bursts, *Research in Astronomy and Astrophysics*, *14, 773*

Sheridan K. V., Trent G. H., Wild J. P., 1959, The extension of solar radio spectroscopy to decametre wavelengths, *The Observatory*, *79, 51*

Warmuth A., Mann G., 2005, The application of radio diagnostics to the study of the solar drivers of space weather, *in Space Weather: The Physics Behind a Slogan, eds Scherer, Klaus and Fichtner, Horst and Heber, Bernd and Mall, Urs*, Springer Berlin Heidelberg, Berlin, Heidelberg

Wild J. P., 1950a, Observations of the Spectrum of High-Intensity Solar Radiation at Metre Wavelengths. II. Outbursts, *Australian Journal of Scientific Research A Physical Sciences*, *3, 399*

Wild J. P., 1950b, Observations of the Spectrum of High-Intensity Solar Radiation at Metre Wavelengths. III. Isolated Bursts, *Australian Journal of Scientific Research A Physical Sciences*, *3, 541*

Wild J. P., McCready L. L., 1950, Observations of the spectrum of high-intensity solar radiation at metre wavelengths. I. The apparatus and spectral types of solar burst observed, *Australian Journal of Scientific Research A Physical Sciences*, *3, 387*

Zhang P., et al., 2022, Imaging of the Quiet Sun in the Frequency Range of 20-80 MHz, *The Astrophysical Journal*, *932, 17*

van Haarlem M. P., et al., 2013, LOFAR: The LOw-Frequency ARray, *Astronomy & Astrophysics*, *556, A2*