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Observations of the Sun using LOFAR Bałdy station

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Abstract

We report first results of solar spectroscopic observations carried out with the Bałdy LOFAR (LOw-Frequency ARray) station, Poland from October 2016 to July 2017. During this time, we observed different types of radio emission: type I and type III radio bursts. Our observations show that the station is fully operational and it is capable to work efficiently in the single station mode for solar observations. Furthermore, in this paper we will briefly describe the observational technique and instrument capabilities and show some examples of first observations.

Keywords: Telescopes; LOFAR; Radio; Sun

1. Introduction

The LOFAR science program is very broad and it is organized in six “Key Science Projects” (KSPs). They cover early Universe research, pulsars, astroparticle physics, magnetic fields in the Universe, solar physics and space weather, and sky surveys (van Haarlem et al., 2013). Research shows that LOFAR will also be suitable to study Jupiter-like planets and active moons (Turner et al., 2017).

In this paper we will focus on the first solar observations from the LOFAR station in Bałdy (Poland).

2. Radio bursts

Solar radio observations are usually carried out at a broad range of wavelengths from microwaves ($f > 3$ GHz), up to dekameter waves ($f < 30$ MHz) (Warmuth and Mann, 2005). Historically, there are five main types of solar radio bursts, from type I up to type V (Wild and McCready, 1950; Wild, 1950a,b; Wild et al., 1959; Boischot, 1957). In the frequency range covered by LOFAR, we can observe all these bursts. New and sensitive telescopes like LOFAR may well identify new burst types.

A large number of radio bursts were observed between October 2016 and July 2017 using LOFAR station in Bałdy, including type I and III radio bursts. These radio bursts are described in the following subsections.

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2.1. Type I bursts

Type I radio noise storms consist of countless numerous narrowband bursts (with duration of about a second or less) over a broadband, slowly varying continuum ranging from 60 to 400 MHz. The storms can last from hours to days and they accompany complex active regions. The radiation of type I bursts is not associated with solar flares but appears to be related with the active regions with complex configuration of its photospheric magnetic field. The research shows that type I bursts are generated by electrons accelerated to a few thermal energies by an ongoing local energy release in closed coronal magnetic structures (Benz, 2002; Sodré et al., 2015; Warmuth and Mann, 2005).

2.2. Type III radio bursts

Type III radio bursts are the most frequently occurring radio bursts in the corona and they were first identified and classified by Wild and McCready (1950). Type III bursts are observed in the frequency range 10 kHz–1 GHz, that represents the area between lower solar corona (at the higher frequencies) up to 1 AU (at kHz frequencies). Type III radio bursts can occur in groups of several bursts, with total duration of about few minutes or storms that can last for a day (Benz, 2002). Type III bursts are signatures of electron beams accelerated in the corona traveling along the open or quasi open magnetic field lines. The majority of type III radio bursts at low frequencies have a negative drift rate which indicates that they are traveling away from the Sun. Their drift rate is given by $-0.01f^{1.84}$ (in MHz/s) (Alvarez and Haddock, 1973), where f is a frequency of observations in MHz. The negative sign in the formula means that we observe a drift from high to low frequency. At 100 MHz, the middle of LOFAR frequency band, the drift rate is around −48 MHz/s. Benz (2002) showed that the type III radio bursts are generated by electron beams moving with velocities of 10 to 60% of the light speed. These electron beams move up in the solar corona along magnetic field lines stimulating the plasma oscillations at the local plasma frequency (Warmuth and Mann, 2005). The accelerated electron beams can therefore generate type III bursts via the plasma emission mechanism. The electron acceleration mechanism is most likely induced by the magnetic reconnection (Aschwanden, 2004).

3. The LOFAR telescope

LOFAR, the LOw-Frequency ARray (www.lofar.org) is a radio interferometer comprising of 51 stations distributed throughout Europe. The LOFAR "core" consists of 24 stations tightly packed within 2 km near Exloo, Netherlands. The innermost 6 core stations are on an "artificial island" with a diameter of about 350 m called the Superterp. An additional 14 "remote" stations are located outside the core at a distance of up to 90 km from the core. "International" stations are located in Germany (6 stations), Poland (3 stations), and one station each in France, Ireland, Sweden, and UK. The baselines of the interferometer extends from about 100 m up to 2000 km. This design provides unprecedented sub-arcsecond imaging capabilities at low frequencies (Ramírez-Olivencia et al., 2018). All the LOFAR stations are connected by a broadband network with a data centre in Groningen, Netherlands, where the correlator is located.

A single LOFAR station comprises of a phased array system and can operate individually. It contains two fields of dipole antennas: LBA (Low Band Antennas) and HBA (High Band Antennas) operating in the frequency range of 10–90 MHz and 110–240 MHz, respectively. Each type of station (from core to international) has a different layout and number of LBA and HBA antennas. Spatial resolution of one station is much worse than of the interferometer, with a beam size of the order of 2 degree in HBA (van Haarlem et al., 2013).

The Bałdy station will focus on pulsars and solar observations when used in local mode (Błaszkiewicz et al., 2016; Dąbrowski et al., 2016). This type of observations does not require high spatial resolution and high sensitivity. The main advantage for these observations is the wide frequency range and high time resolution of LOFAR.

4. Receiver system for Bady LOFAR station

The LOFAR field consists of 96 LBAs and 96 HBAs (Fig. 1). Each LBA antenna is composed of pair of perpendicular dipoles and each component of the HBA antennas is a system of 16 pairs of dipoles forming one element called tile. The signals of all dipoles in the tile is summed up to form output. The signal from both types of antennas is sent via coaxial cables (X and Y polarization) with the proper delay to back-ends located in a special container. Combined and digitized information is ready to be used after being processed in the container. Depending on the type of observation, data is sent to the correlator (international mode) or to locally used computers in single station observations.

The array of antennas is fixed in position and there is no mechanical beam steering (Fallows et al., 2014). LOFAR LBAs in particular are able to see the entire sky, however their sensitivity decreases significantly below 30 degrees elevation. Using the antenna system as a phase arrayed telescope allows to digitally select the direction of the observation.

For solar research we use a observational method that allows observations in the entire frequency range of LOFAR telescope using both LBA and HBA simultaneously (more details in McKay-Bukowski (2013)). The whole frequency band is divided into three parts:

- low band 10–90 MHz we selected 200 subbands, centered at 10.55 to 88.28 MHz with spacing of 0.39 MHz and time resolution equal 1 s,