Solar Studies with the LOFAR Telescope

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The LOw-Frequency ARray (LOFAR) is a large radio interferometer operating in the frequency range 10−240 MHz. Its science program is very broad and organized in "Key Science Projects". One of them is dedicated to solar and space weather studies. We are expecting that in the near future, the LOFAR telescope will bring some interesting observations and discoveries in this field. It will also help to observe solar active events that have a direct influence on the near-Earth space weather.

1 Introduction

LOFAR, the LOw-Frequency ARray (`www.lofar.org`) is a radio interferometer operating in the frequency range 10−240 MHz designed and constructed by ASTRON (the Netherlands Institute for Radio Astronomy). In the same issue, LOFAR has been described in details by Błaszkiewicz, L. and Dąbrowski, B. (2016).

The science program of LOFAR is very broad and organized in "Key Science Projects"; one of them is dedicated to solar and space weather studies (van Haarlem et al., 2013). In this article we will focus on solar studies.

2 Solar observations by LOFAR – first results

Solar radio observations are made at large range of wavelengths. They are divided into microwaves ($f > 3$ GHz), decimeter/meter ($f < 3$ GHz), dekameter ($f < 30$ MHz) and hectometer/kilometer ($f < 3$ MHz) (Warmuth & Mann, 2005). All this is the result of solar radiation properties in different wavelength ranges.

In general, we distinguish five main types of solar radio bursts (Figure 1), from Type I up to Type V (Wild & McCready, 1950; Wild, 1950a,b). LOFAR operates in the frequency range 10−240 MHz where it can observe all these events.

Solar observations with the LOFAR telescope will be carried out in different basic modes: 1) routine imaging, 2) solar bursts mode, 3) joint observation campaigns, and 4) single stations as spectrometers. For observations in these modes we can use a single station or small number of stations.

Unfortunately, due to the scattering of radio waves within the solar corona, the spatial resolution of the radio maps is limited to a few 10 arcsec. For this reason, it is necessary to use the central core and the nearest remote stations with baseline up to a few 10 km (Mann, 2007).

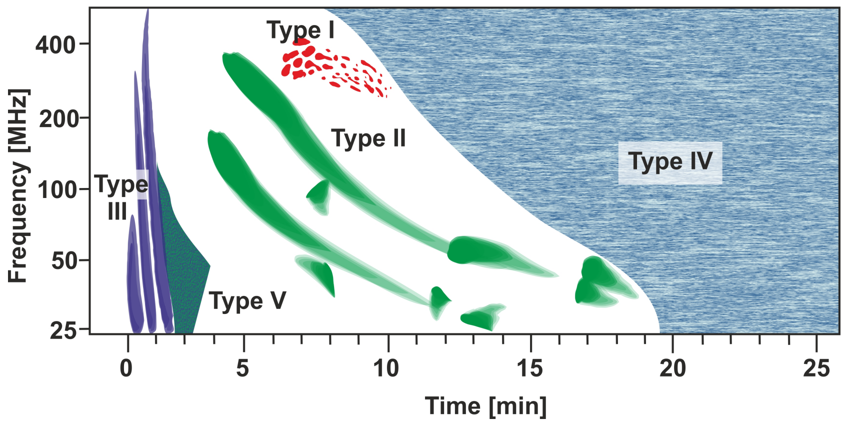

Fig. 1: Schematic diagram shows the basic classification of solar radio bursts in the frequency range 25−400 MHz. Picture based on Ganse et al. (2012).

On March 17, 2011, during the commissioning phase, LOFAR observed a solar radio burst for the first time. It was a Type I radio burst, seen at 150 MHz on the West limb of the Sun (see the left part of Figure 2). Detailed studies showed that it was located above the active region (van Haarlem et al., 2013).

On October 2011, LOFAR telescope observed Type III solar radio burst. Detailed studies showed that its source was located at the East limb above an active region (van Haarlem et al., 2013).

On February 28, 2013 multiple Type III radio bursts were observed within a period of 30 minutes by LOFAR. A number of bursts were found to be located at high altitudes, around four solar radii from the solar center in the case of the 30−35 MHz bursts (Morosan et al., 2014).

On July 9, 2013 between 07:00 UT and 14:30 UT, over 3000 S bursts (fast drift storms) were observed by LOFAR (see the right part of Figure 2). They appear as groups of short-lived (< 1 s) and narrow-bandwidth ($\sim$2.5 MHz) features, the majority drifting at $\sim$3.5 MHz/s. Investigations suggest that S bursts were associated with a trans-equatorial loop system that joins the active region in southern hemisphere to a bipolar region of plage in the north (Morosan et al., 2015).

3 Conclusions

The first solar observations with the LOFAR telescope indicate that it is well suited for solar research at low frequencies (from 10 up to 240 MHz). In the near future it will certainly bring further interesting observations and discoveries. It will also help to observe solar active events that have a direct influence on the near-Earth space weather, a good knowledge and forecasting of which is of essential importance for our ever increasing dependence on technology from and in space and for the increasing presence of humans in space.

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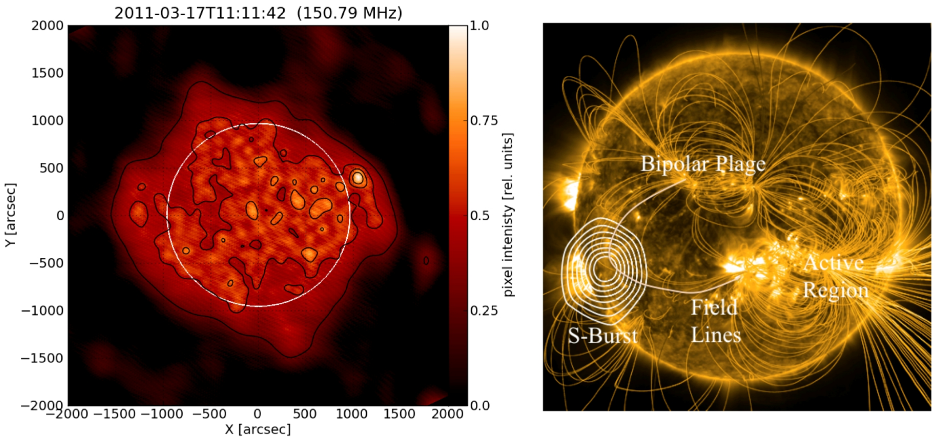

Fig. 2: *Left:* March 17, 2011, LOFAR image of a Type I radio burst, seen at 150 MHz. The white circle correspond to the edge of the solar photosphere. This figure was published in van Haarlem et al. (2013). *Right:* S bursts source position overlaid on extreme ultraviolet image at 171 Å from the Atmospheric Imaging Assembly onboard NASA's Solar Dynamic Observatory taken on July 9, 2013 at 11:24:12 UT. The contours represent the LOFAR S bursts source at 11:24:56 UT and a frequency of 74–75 MHz. This figure was published in Morosan et al. (2015).

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