# Near Earth space monitoring with LOFAR PL610 station in Borówiec

Hanna Rothkaehl[1], Mariusz Pożoga[1], Marek Morawski[1], Barbara Matyjasiak[1], Dorota Przepiórka[1], Marcin Grzesiak[1] and Roman Wronowski[1]

1. Space Research Centre, Polish Academy of Sciences Bartycka 18A, 00–716 Warszawa, Poland

We present the examples of possible studies for monitoring the near Earth space using a LOFAR. LOFAR is an advanced and powerful instrument with a wide range of capabilities. It can be used for radioastronomical studies of inter alia pulsars, or Sun and solar wind, or for monitoring and diagnosing near Earth space plasma and many others. Even a single station of the LOFAR interferometer can be used as a complementary tool for the space weather studies.

## 1 Introduction

Electromagnetic radiation in the radio range of the nearest space environment is a subject of investigation both as a constituent of the geophysical environment, as well as an element of physical processes in which particles and waves of ionospheric plasma participate. Those investigations are carried out by means of ground-based techniques and space borne instruments. The level of electromagnetic noises detected at the ionospheric altitude depends on geophysical condition properties, properties of the different Earth regions, influences from the Earth's surface, and the interaction between the spacecraft and the surrounding space plasma (Rothkaehl et al., 2008).

The LOw Frequency ARray (LOFAR) is a radio interferometer operating at a low frequency range from 10 to 240 MHz. Due to its capabilities, the instrument is a very powerful tool not only in the field of radio astronomy but also in the field of space weather. Single station consists of the two antenna fields: LBA (Low Band Antenna) which covers the frequency range 10-90 MHz and HBA (High Band Antenna) spanning from 110 to 240 MHz. Within the scope of the PL610 station in Borówiec the activities, inter alia, are as follows: diagnosis of the local ionosphere properties and ionospheric structures analysis. In addition, the station is equipped with 100 Hz GNSS (Global Navigation Satellite System) scintillation receivers for monitoring of small scale irregularities, riometer and radio receiver, which purpose is to track radio noises and digital radio induced noises within the station surroundings. All that creates a very useful tool for ionospheric plasma analysis, the continuous monitoring of which is fundamental in pursuance of the proper understanding of global space weather, likewise in radioastronomical observations which are very sensitive to the variation of ionospheric properties. The detailed research plan for PL610 station (Borówiec), beside the global plan for observations of astronomical objects in the frame of the International LOFAR Telescope (ILT), covers near Earth space diagnostics, and solar radiation in the radio frequency range monitoring as well as monitoring of radiation coming from other Solar System planets.

## 2 Space weather applications

One of the research subjects of SRC PAS (Space Research Center Polish Academy of Sciences) interest is analysis of ionospheric and magnetometer scintillations. Results of both theoretical studies and observation data analysis will serve to this phenomenon's model construction and will be applied to develop more realistic ionospheric corrections for radio astronomy observations as well as for space weather services. The magnetosphere-ionosphere-thermosphere system is strongly affected by electric and magnetic fields, particle precipitation, heat flows and small scale interactions. The magnetised solar-terrestrial space plasma is a highly non-linear medium which exhibits many different types of turbulence and instabilities. Those emissions are produced mainly by natural perturbations, but some of them also have an anthropogenic origin (Rothkaehl et al., 2011).

Fig. 1: The view of the LBA and HBA antenna fields at the Polish LOFAR station PL610 in Borówiec.

### *2.1 The ionosphere monitoring*

The ionosphere itself is highly variable medium the properties of which depend very much on the geomagnetic conditions i.e. time of the day or season. Fig. 2 presents three days (14-17 July 2017) of observations taken by a single station. It is clearly visible how the signal attenuation caused by the ionosphere varies during the day. After the sunset we can observe increase in radio noise. It is also visible how during the day critical frequency of F2 layer changes (denoted as f0F2) by the level of terrestrial radio signal reflection. Measurements were taken as a side-product of routine observation and can be a useful tool for ionospheric diagnostics.

Irregularities in the ionospheric plasma can lead to scintillation of the measured radio signal from distant sources. Thus the analysis of the signal variations can give us useful information about the local characteristic of the scattering medium. In Fig. 3 the variation of the signal amplitude from Cassiopea A during the time period when the geomagnetic storm occurred is presented. The increase of the signal amplitude scintillation associated with different phases of the geomagnetic storm is clearly visible.

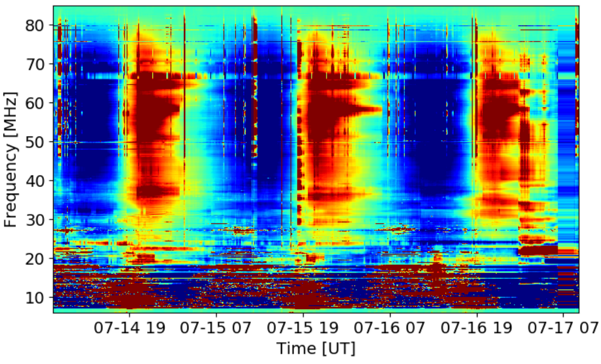



Fig. 2: Level of the radio emission in time-frequency domain measured on a single LBA antenna during 3 days of observations. High signal level is colored with red and low signal level is colored with blue.

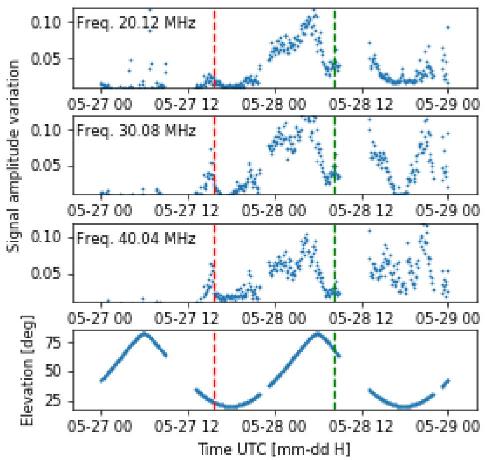



Fig. 3: The signal amplitude variation calculated for 3 different frequencies (3 top panels) of the radio Cassiopea A for a time period of 26-29.05.2017. Bottom panel: elevation of observed radio source. The red dashed line represents the moment when a sudden commencement took place and the green line corresponds to the minimum Dst value of -125.

## 2.2 Solar radio emissions and solar wind conditions

Observations of the Sun at radio frequencies can provide useful information about the state of our closest star. The powerful thermal emission of the quiet Sun and intense radio bursts associated with solar flares and coronal mass ejections (CME) can eject clouds of ionized plasma into interplanetary space and directly affect the Earth's magnetosphere. One of the easily observed radio events on the Sun with the LOFAR instrument are type III bursts. They result from mildly relativistic (0.1 - 0.3 c) electron beams propagating through the solar corona and interplanetary space that excite plasma waves at the local plasma frequency. The density model of the solar heliosphere (Mann et al., 1999) directly relates the frequency of the burst emission up to the coronal height: higher frequencies originate closer to the surface, while lower frequencies originate further out. Thus dynamic spectrograms and coronal height-time diagrams provide a detailed information of the movement of plasma through the solar corona and out into interplanetary space. Fig. 4 presents the solar type III radio burst observed at 31.03.2017 by polish station PL610 in Borówiec.

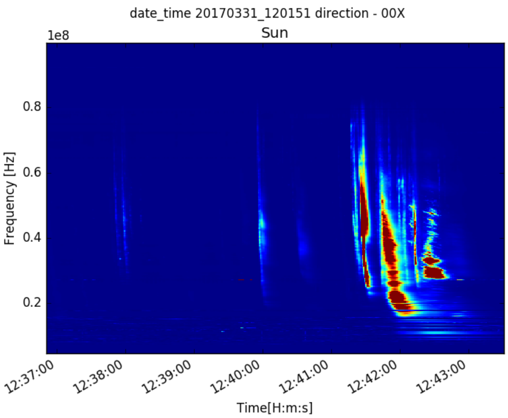
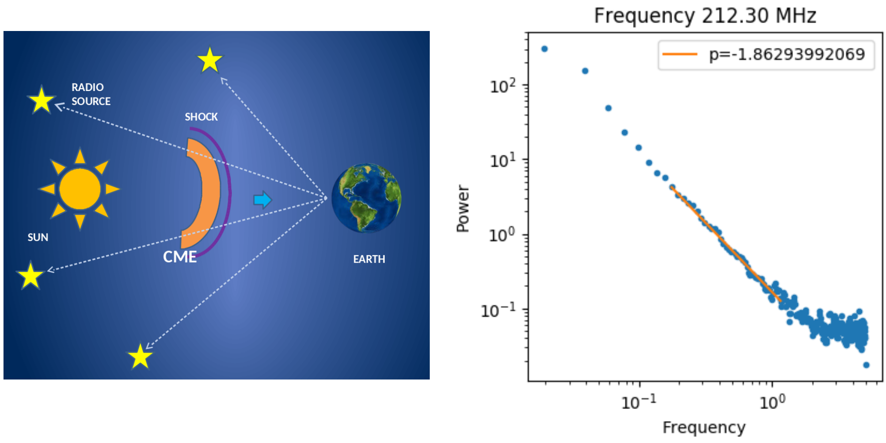



Fig. 4: Type III solar radio burst observed by station PL610 in Borówiec at 31.03.2017.

Another way to obtain valuable informations about the impact of our host star is the monitoring of solar wind conditions. By measuring the radio signal variation from distant radio sources we can determine solar wind parameters. The interplanetary scintillation analysis can be used then to verify data provided by an American mission IBEX. Fig. 5 b) presents exemplary power spectrum of the signal amplitude variation (caused by interaction with the solar wind) from radio source measured by station PL610. Measurements were done for frequency of 212.30 MHz.

### *2.3 Jupiter emissions*

The LOFAR instrument can also be used for monitoring radio emissions from the solar system planets with magnetospheres, e.g. Jupiter. The polish station PL610 is involved in the follow-up observations for mission JUNO (NASA space probe orbiting Jupiter) and in the future it will provide similar observation routine for mission JUICE (JUpiter ICy moons Explorer by ESA). The observations of Jupiter at low frequencies were made to proceed in decametric (DAM) radio emission observations. Fig. 6 presents the observations of Jupiter Io-related emissions at low frequencies.




a) b)

Fig. 5: a) Visualization of the solar wind which affects the signal from a distant radio source. b) The power spectrum of the radio source signal measured at the frequency of 212.30 MHz with power-law function fitted. The power-law index is given in the figure corner.

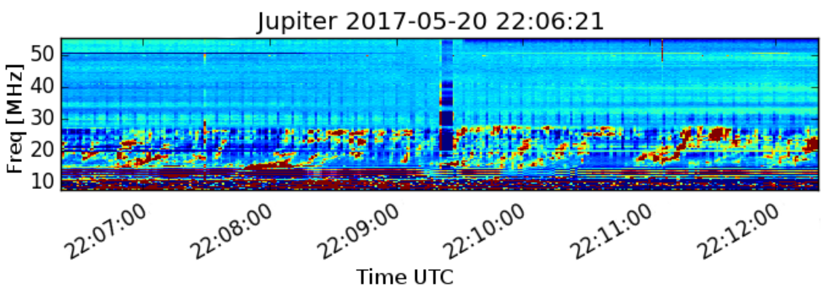



Fig. 6: Io-driven radio emissions from the Jupiter observed by LOFAR station PL610 at 20.05.2017.

## 3 Future plans

The Chang'E-4 DSL-P (Discovering the Sky at Longest wavelengths) mission is a pathfinder for future higher-resolution, higher-sensitivity ultra-long radio wavelength diagnostic missions. The pathfinder of DSL (DSL-P) experiment is approved by Chinese Lunar Exploration and Space Program Center. The DSL-P project is the result of cooperation between the National Space Science Centre of the Chinese Academy of Sciences and the SRC PAS. The current Chang'E-4 mission offers an opportunity to join a pair of microsatellites that share the launcher with the relay satellite.

In order to mitigate the radio-frequency interference and man-made noise contribution as well as the natural ionospheric disturbances related to the unstable ionospheric plasma condition, the decision was taken to fly radio diagnostics instruments onboard of two satellites on the Lunar orbit. A 50 kg payload has been approved for a demonstration of interferometric techniques across satellites. The DSL-P pathfinder is the minimum configuration of future DSL projects (eight microsatellites and mother satellite), and will be launched in mid-2018.

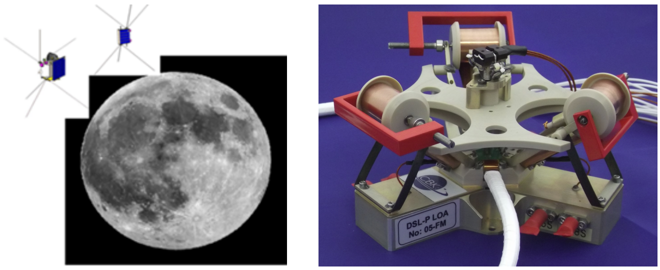



Fig. 7: Concept of the Chang'E4 mission (left). The part of the Radio Fequency Analyzer developed by SRC PAS (right).

The Sun, our closest star, fundamentally affects the Earth's ecosystem and our daily life. The physical mechanisms governing CME events are poorly understood, which results in a lack of both: accurate models and reliable prediction tools. The proposed future high-performance DSL mission will provide diagnostics with much better temporal and spatial resolution than currently available. So called "Type II" bursts and their ensuing CME's can be followed by DSL much further out than the few solar radii possible from Earth (Rothkaehl, 2016). The specific objective of the DSL mission will cover the following problems and scientific areas:

- dark ages of the Universe;
- the extragalactic sources;
- the galactic interstellar medium and cosmic rays;
- transients and variable sources;
- heliophysics and solar science;
- planetary radio emissions;
- pulsars.

## 4 Summary

Although we can describe many different magnetospheric and ionospheric activities driven by changes in the Sun–Earth system and ionosphere magnetosphere coupling, we still have problems with forecasting geospace conditions, particularly during disturbed geomagnetic conditions. In order to achieve this goal it is an imperative to simultaneously conduct and analyse data coming from both: ground based and space borne missions. LOFAR ground based measurements, combined with the topside satellite in situ diagnostic can be put to good use in solar science and space weather, covering the following topics: ionospheric and magnetospheric environmental diagnostics, solar wind, Sun diagnostics, service of ionospheric modelling and corrections, and ground support for planetary mission JUNO and JUICE.

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