Polish Part of LOFAR

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The three new LOFAR stations located in Poland and maintained by the POLFAR consortium, working in poorly explored part of the radio spectrum, will be an important tool for radio astronomers. The first results show that LOFAR is currently excellent tool for pulsar and solar observations. The telescope also allow obtain the data about state of the ionosphere with unprecedented precision. Together with solar monitoring the LOFAR will be great tool for space weather research.

1 Introduction

The LOw-Frequency ARray (LOFAR) is a large radio interferometer operating in the frequency range 10−240 MHz. The collaboration of the proposers from Poland is organized in the Polish Consortium LOFAR – POLFAR and was established in 2007. The science program for LOFAR is very broad and is organized in “Key Science Projects”. In this article we will focus on technical description of the LOFAR telescope.

2 LOFAR telescope

The LOFAR system design, configuration and the signal processing methods were described in detail by van Haarlem et al. (2013). The main idea of a single station phased array, as well as the operation principle of whole LOFAR interferometer are presented in Fig. 1.

The LOFAR interferometer consists of a large number (over 100 000) of omnidirectional dipole antennas, that are arranged to form 50 individual stations across Europe untill today and about 60 in the close future. The LOFAR receivers’ bandwidth spreads from 10 MHz to 240 MHz, but actually exclude the frequency range from 88 MHz up to 108 MHz because of the expected Earth-bound interferences. Each individual station consists of two antenna fields: (1) the Low Band Antennas (LBAs) which operates in the frequency range 10−90 MHz (a single station LBA field contains 48 or 96 antennas); antennas of the LBA field in full configuration occupy an area with a radius of about 40 meters; (2) the High Band Antennas (HBAs) are collected in tiles, and operate in the frequency range 110−250 MHz (again, 48 or 96 tiles per station). In the full 96 tiles configuration the diameter of the HBA field is 62 meters. The configuration of typical international LOFAR station is shown in Figure 2.

At the single station level the signals received by individual dipoles are digitally combined to form a phased array, by introducing time delays to the signals in a process which is known as beam-forming. Doing so mimics a single telescope dish,

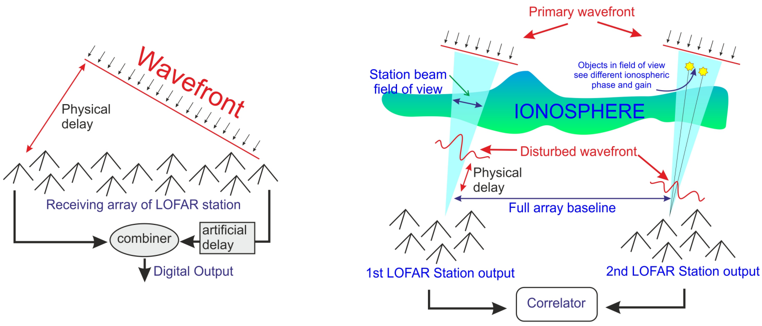

Fig. 1: Left: the LOFAR single station as the phased array antenna. Digital control allows to direct the beam in any part of the sky. Right: signal from many different stations goes to a correlator. The influence of the ionosphere on the signal wavefront distortion must necessarily be taken into account during correlation. The right part of the image was inspired by van der Tol & van der Veen (2007)

and such the virtual telescope can be steered electronically by adjusting the delays for individual receiver dipoles, which allows to “point” the telescope at any object on the sky and follow it in its daily motion.

Each individual station is connected via an optic fiber network link to a data center. The data transfer capability of 10 Gbits/s allows for a continuous data transmission in 244 sub-bands. Each of these sub-bands allows for the creation of an independent beam, which then can be pointed at the required position in the sky. The idea of multibeam observations is shown in Figure 3.

To this day the LOFAR network consists of 50 stations, of which 38 are in the Netherlands and 6 stations in Germany and one station each in UK, France and Sweden, and the new 3 Polish stations. The Polish part of LOFAR called POLFAR (Figure 4) has been described by Krankowski et al. (2014) as well as in Błaszkiewicz et al. (2016).

The majority of the stations are located in the Netherlands, which includes 24 stations located within a radius of about 2 km called “core”, and a round island of a 320 meter diameter referred as “Superterp” in the middle of core region. The remaining

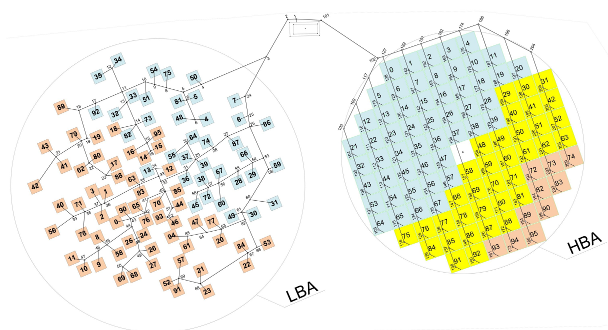

Fig. 2: The configuration of an international station. The larger upper circle represents the LBA antennas and the lower one depicts HBA tiles. Picture taken from van Haarlem et al. (2013)

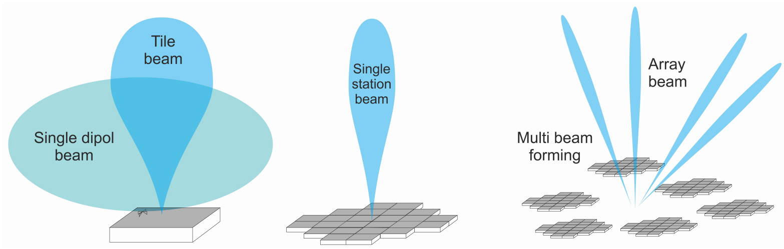

Fig. 3: The beam sizes for HBA LOFAR elements. From left: single dipol beam and whole tile beam (16 dipole pairs), single station beam and multi-beam for a few stations' system

14 Dutch stations referred as "remote" are located beyond the core in a distance up to 90 km and placed more or less (due to land availability) in a logarithmic spiral distribution. A full list of stations (excluding the newest one at Norderstedt) with accurate coordinates is available in Table A.1 in van Haarlem et al. (2013).

The individual station outputs are split into narrow frequency bins, correlated, averaged over short intervals, and stored for offline processing. The whole instrument with the longest baseline of about 1000 km allows for an angular resolution close to 0.21 arcsec at the frequency of 240 MHz and about 3.3 arcsec for longest waves (at 15 MHz). The sensitivity of LOFAR Core measured for 8 hours of integration and an effective bandwidth of 3.66 MHz at 2 polarizations is about 9 mJy at 30 MHz and 0.6 mJy at 200 MHz (van Haarlem et al., 2013). In the case of an independent use of three Polish stations (as a separated interferometer) the expected angular resolution could be about 1 arcsec[1].

2.1 Signal processing

The very high spectral and time resolutions required in the observations of transient sources (such as pulsars) and the large analog-to-digital converters range is able to generate up to 13 Tbits/s of raw data by whole LOFAR array when using a typical 200 MHz sampling rate. For a single station processing this amount reduces to about 150 Gbits/s. The storage space requirements are very demanding as well: one hour of interferometric imaging observations yields about 35 Tbyte of correlated visibilities. This amount of raw data requires a high computing power real time analysis and correlation and a huge disc space storage.

Until 2014 the IBM Blue Gene/P supercomputer located in the computing center of University of Groningen offered about 28 Tflops of processing power. Currently the correlation for interferometric imaging, tied-array beam forming for high time resolution observations and other computationally demanding modes of observation are handled by the COBALT system. It is a cluster of 32 extremely efficient NVIDIA Tesla GPUs. The description of the new correlation system can be found in a paper by (Broekema, 2013).

[1]Resolution of LOFAR is given by $\alpha\lambda/L$, where L denotes longest baseline, $\alpha = 0.8$ and λ is wavelength in meters (van Haarlem et al., 2013).

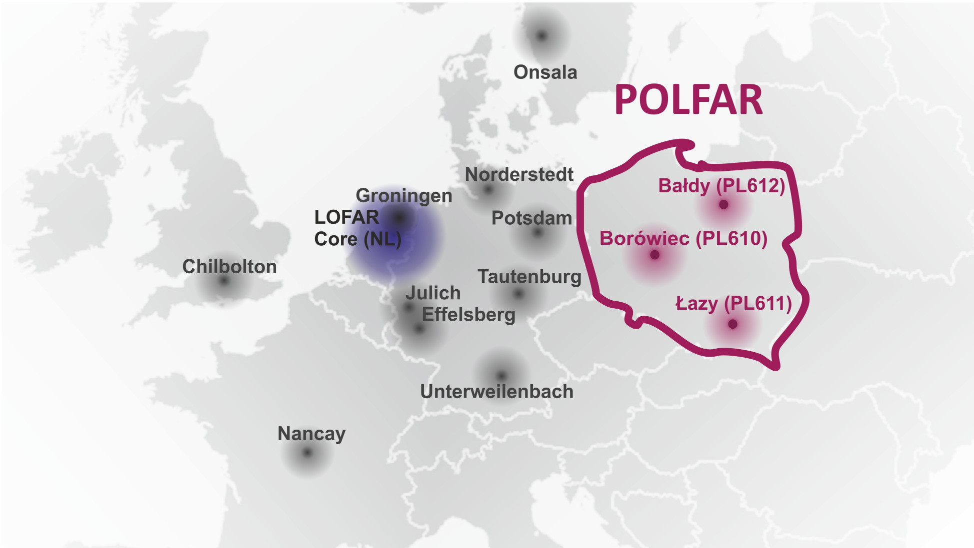

Fig. 4: International LOFAR stations network in Europe. It is formed by 50 stations, of which 38 are in the Netherlands and the rest are scattered across Europe. POLFAR includes three stations: Bałdy, Borówiec, and Łazy each of them marked by a special code given in parentheses.

3 POLFAR as a part of LOFAR

The collaboration of the proposers from Poland is organized in the Polish Consortium LOFAR – POLFAR and was established in 2007 (Krankowski et al., 2014). The agreement was signed by the representatives of the Jagiellonian University (owner Łazy station near Kraków), the Space Research Center of Polish Academy of Sciences (owner Borówiec sation near Poznań), the University of Warmia and Mazury (owner Bałdy sation near Olsztyn), the Nicolaus Copernicus University, the University of Zielona Góra, the Nicolaus Copernicus Astronomy Centre of Polish Academy of Sciences, the University of Szczecin, the University of Environmental and Life Sciences and the Pionier company – Polish Optical Internet. Parameters of the three Polish stations are in Table 1.

From the end of 2015, all three LOFAR stations in Poland: Bałdy, Borówiec and Łazy are ready for observations. The data from all our stations are sent to Poznań via fast ($\sim$10 Gb/s) Pionier network and then to the correlator in the Netherlands. Additionally the three stations of POLFAR is the smallest number that allows for the operation of Polish stations as an independent interferometer when they are not used as a part of the LOFAR system.

4 The LOFAR station in Bałdy

Nowadays, the LOFAR sation in Bałdy (Fig. 5) is fully operational. This is the first station where the HBA teils were assembled with prefabricated elements on site, in a special tent. Field preparation for the construction of the station started in the fall of 2014. The commissioning occurred in the second half of August 2015. At the present time, the station provides observations in both ILT and local modes (mainly pulsars

Table 1: The summary for three Polish stations of LOFAR telescope

Station Name	Bałdy	Borówiec	Łazy
Station code	PL612	PL610	PL611
Longitude	20°35′26″E	17°04′28″E	20°29′23″E
Latitude	53°35′45″N	52°16′37″N	49°57′53″N
Number of LBA elements	96	96	96
Number of HBA elements	96	96	48
Distance to the Core [km]	920	710	930

Fig. 5: The LOFAR station in Bałdy (code: PL612)

and solar observations). Detailed informations related to observations of the Sun and pulsars with Bałdy LOFAR station were placed in separate articles in this issue.

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