Detecting the EoR with LOFAR: steps along the road

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Abstract

In December 2010 we started observations with a partially completed LOFAR, to prepare ourselves for the calibration and processing of deep (hundreds of hours) integrations in a number of Galactic halo windows. These observations are aimed at detecting the redshifted 21cm signals from the Epoch of Reionization using the LOFAR HBA antennas (115-190 MHz, z_{HI}=11.4 – 6.5). Two fields (windows) have been observed for about a dozen (6-hour) nights in the Spring of 2011. The data have been mostly processed on a dedicated EoR-project cluster. Some results and first conclusions from the analysis of these data is presented.

1. Introduction

One of the most exciting projects to be undertaken with LOFAR is the search for redshifted 21cm signals from the Epoch of Reionization (EoR) [1]. The EoR project team, based at ASTRON and the Kapteyn Institute of the University of Groningen (see http://www.astro.rug.nl/~LofarEoR) has been working towards this goal for about 7 years now. During this period three PhD-theses were completed (by Thomas, http://irs.ub.rug.nl/ppn/317294571, Jelic, http://irs.ub.rug.nl/ppn/326544364, and Lampropoulos, http://irs.ub.rug.nl/ppn/328871966). These theses, as well as a large number of papers [2,3,4,5,6,7,8,9,10] have dealt with a wide range of topics ranging from signal modeling and prediction, foreground simulation and removal, the experiment data model, calibration and inversion, as well as sophisticated foreground fitting. Potential target fields have also been observed with the WSRT using receivers working in the range of 115-175 MHz [11,12]. Proper observing, with a complete LOFAR array, is expected to start in the Autum of 2011.

2. LOFAR and commissioning projects

With the completion, at the end of 2010, of about 20 (split-) core stations (CS), 7 remote stations (RS) in the Netherlands, and 5 stations in Europe, serious commissioning observations of LOFAR could be commenced. An additional 4 core stations and 9 Dutch remote stations, at distances of up to 80 km from the core of the array will be rolled out in 2011. The latter will be required to make high quality high resolution (4 arcsec PSF) images. For an overview of the LOFAR project we refer to [13]. Before regular and smooth operations can start a large number of system components still have to be commissioned. Among these are the station hardware, the station calibration software, analog and digital beamformers, the scheduling, monitoring and control software. The imaging pipeline, including RFI-mitigation, data averaging, calibration and imaging is currently being tested and integrated [14]. The correlator has already been producing excellent data for a number of years.

The LOFAR EoR group is heavily involved in the commissioning of LOFAR and has recently started taking weekly data on a couple of fields. At the end of the spring of 2011 we expect to have collected and processed about a dozen 6-hour observations. Each observations recorded a bandwidth of about 48 MHz, ranging from 115 – 163 MHz.
The spectral and time resolution of the current commissioning data is 3.2 kHz and 2 seconds, respectively. In future observations these will be improved by a factor four and two respectively. The goals of the commissioning observations are many:

- monitor longterm performance and stability and estimate frequency dependent noise levels
- monitor the RFI occupancy levels

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- search for subtle problems in the data
- investigate wide-field ionospheric calibration approaches
- test the EoR pipelines on actual data

Once the commissioning data have been fully processed (sometime in the Summer of 2011) these observations should deliver the deepest integrations and images currently possible with LOFAR. Most of the efforts in our group in the next 6 months are dedicated to the processing and analysis of these data. It will allow us to refine the calibration and imaging pipeline to the needs of the EoR project.

3. Analysis and results

At the time of writing we were still in the process of analyzing the data from the first few epochs. A sample of the quality and stability of the raw data is shown in Figure 1. It displays the visibility phases on 15 interferometers for two epochs separated by 4 weeks; baseline lengths vary from 70-300 meters. The visibility phase is dominated by a central compact source (3C196) of about 90 Jy at the frequency of 117 MHz. The temporal structure on the phases is due to an ensemble of background sources, each typically a few Jy, in the approximately 5^o field-of-view. In an ideal world the raw phases should exactly reproduce from day to day because they are determined by (i) the brightness distribution in the field, (ii) the station beam, and (iii) the ionosphere. The sky is unlikely to change and the station beam is hopefully stable. Moreover ionospheric phase effects on these short baselines are expected to be very small (in the absence of ionospheric turbulence that leads to scintillation, observed once in about 6 epochs). A comparison of identical baselines in the left and right panels reveals the excellent stability of the raw data. However, this is only a first requirement. To detect the feeble signals from the EoR we will need to understand issues far below the observed visibility levels. The processing of these data to produce spectral image cubes is presently ongoing. The calibration and imaging, iusing direction dependent calibration, will be done in the next months and first results will be shown at the meeting.

4. Conclusions

We have presented LOFAR commissioning data at a frequency of 117 MHz taken in the spring of 2011 using about 20 (x2) HBA stations in the core and about 7 remote station in the Netherlands. Baselines of up to 30 km were routinely recorded. At some epochs we also included baselines well into Europe. The overall quality of the data is excellent and we have taken an important step on the way to commence our search for the redshifted 21cm signals from the Epoch of Reionization. Important tasks in the year ahead are the proper modeling of the station beams, the modeling of (currently still mild) ionospheric non-isoplanatism effects, and the application of these to produce deep high spectral and spatial resolution image cubes for the frequency range from 115-190 MHz (corresponding to HI at redshifts from 6.3 to 11.4).

5. Acknowledgments

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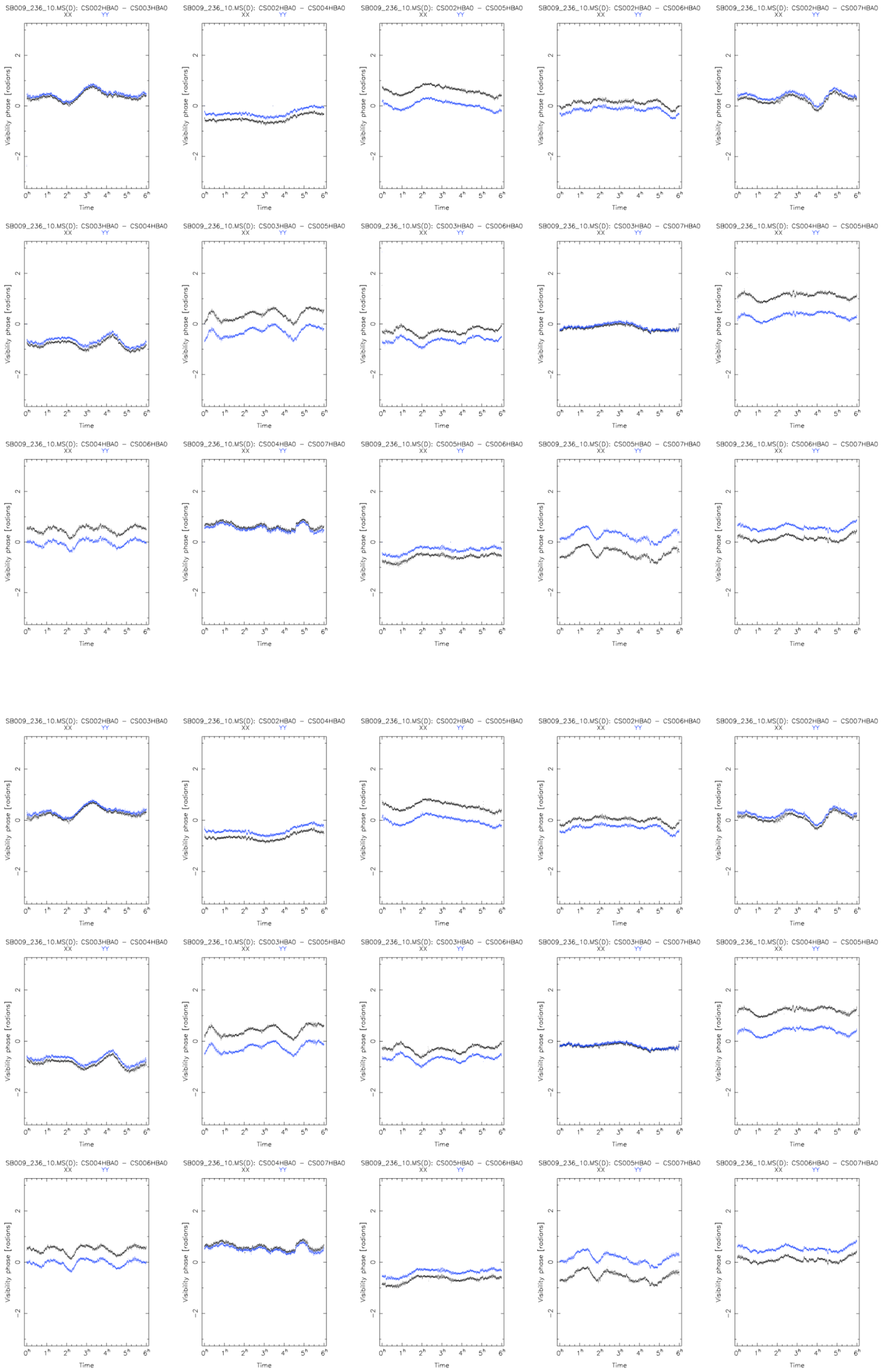

Figure 1: *Montage of the visibility phase on 15 baselines between the six stations (HBA0 sub-station) of the superterp in the core of LOFAR. The observation was centered on the source 3C196 (~ 90 Jy) and lasted 6 hours around meridian transit. The data were averaged over 10s and a full subband (180 kHz) centered at 117 MHz. The black and blue lines refer to the parallel-handed cross-correlations. Top panel: data for 28 January 2011. Bottom panel: data for 25 February 2011. Note the high quality of the data and the excellent stability of the phases over a period of 4 weeks.*

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