

Ionospheric calibration for ultra-low frequency radio astronomy

F. de Gasperin⁽¹⁾⁽²⁾, H. Edler⁽¹⁾

(1) Hamburger Sternwarte, Universität Hamburg, Gojenbergsweg 112, 21029, Hamburg, Germany

(2) INAF - Istituto di Radioastronomia, via P. Gobetti 101, 40129, Bologna, Italy

The ionosphere is the main driver of a series of systematic effects that limit our ability to explore the low-frequency (<1 GHz) sky with radio interferometers. Its effects become increasingly important towards lower frequencies and are particularly hard to calibrate in the low signal-to-noise ratio regime in which low-frequency telescopes operate.

In this talk I will describe the effect of ionospheric-induced systematic errors on astronomical interferometric radio observations at ultra-low frequencies (<100 MHz). I will present the current strategies in place to isolate and remove these effects from the data. Together with this I will outline the limitations and open lines of research. We show that we can isolate the ionospheric effect in LOFAR Low Band Antenna (LBA) data and that our results are compatible with satellite measurements, providing an independent way to measure the ionospheric total electron content (TEC). We show how the ionosphere also corrupts the correlated amplitudes through scintillations, and we prove that systematic errors on the phases of LOFAR LBA data can be accurately modeled as a sum of four effects: clock drifts, ionosphere first, second, and third order [1]. I will also show that we can obtain direction-dependent calibrated images by adopting a number of novel techniques to maximize the signal-to-noise ratio (see Fig. 1; [2]).

Finally, I will focus on the opportunities that will be opened by the forthcoming upgrade of LOFAR (so-called LOFAR 2.0). This upgrade of the telescope hardware will enable the possibility of observing simultaneously with both LOFAR Low Band Antenna and High Band Antenna. Such a capability will allow the use the high signal-to-noise ratio observations at high-frequency to isolate the ionospheric systematic effects more accurately and correct the lower-frequency data.

References

- [1] F. de Gasperin et al. "The effect of the ionosphere on ultra-low-frequency radio-interferometric observations" *Astronomy & Astrophysics*, 615, 2018, A1799
- [2] F. de Gasperin et al. (2020). "Reaching thermal noise at ultra-low radio frequencies: The toothbrush radio relic downstream of the shock front". *Astronomy & Astrophysics*, 642, A85

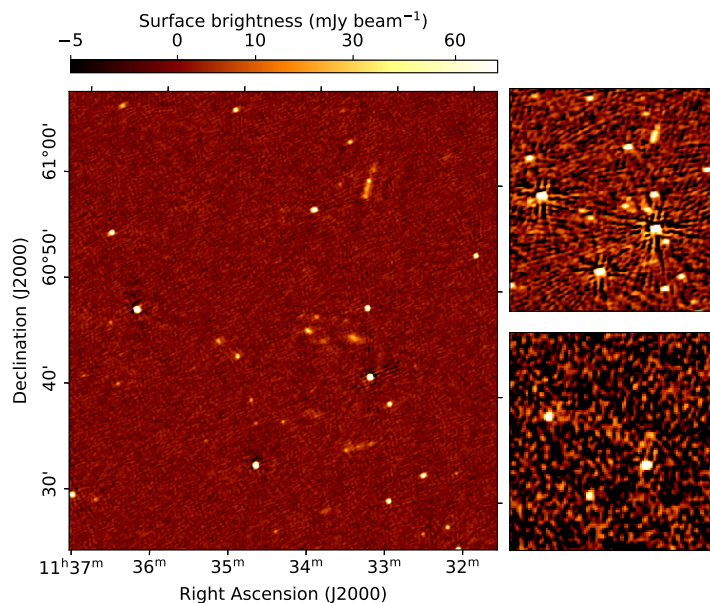


Figure 1. A region of the LOFAR LBA sky survey re-imaged following a direction-dependent calibration (rms noise: $1.3 \text{ mJy beam}^{-1}$ - beam: $15'' \times 15''$). Top right: the same field without direction-dependent calibration (rms noise: 3 mJy beam^{-1} - beam: $46'' \times 32''$). Bottom right: the same field in the VLSSr survey (rms noise: 73 mJy beam^{-1} - beam: $80'' \times 80''$).