32nd URSI GASS, Montreal, 19-26 August 2017

Effects of Ionosphere and Troposphere on Sensitive Radio Observations from 70 MHz to 24 GHz.

Abhirup Datta[(1),(2)], Sumanjit Chakraborty[(1)]
(1)Centre of Astronomy, Indian Institute of Technology Indore, Simrol Campus, Indore-452020, Madhya Pradesh, India.
(2)Center of Astrophysics & Space Astronomy, Dept. of Astrophysical and Planetary Sciences, Univ. of Colorado Boulder, Boulder, CO 80309, USA

1. Extended Abstract

Any electromagnetic signal coming from outside the Earth's atmosphere will get affected by the Ionosphere at centimeter and meter wavelengths while the same will get affected by the Troposphere between centimeter and millimeter wavelengths. In this work, we explore a uniform formalism to understand the highest radio frequencies where ionosphere poses a challenge for sensitive radio observations with upcoming telescopes like the SKA (Square Kilometer Array). We also investigate the lowest radio frequencies where Tropospheric effects are still significant for SKA-like observing capabilities.

One of the major challenges of low frequency (< 1.4GHz) radio astronomical observations is the effect of Earth's ionosphere. The three dimensional ionosphere introduces phase corruption in any signal coming from the outer cosmos and getting measured by Earth-based radio telescope. In order to make sensitive observations at low radio frequencies it is extremely critical to properly calibrate out the ionospheric corruption from the measured signal. Radio interferometers are extremely sensitive to ionosphere-induced path length differences. For calibration purposes, the necessary antenna-based, time- and direction-dependent phase corrections can typically only be determined to sufficient accuracy using self-calibration or field-based calibration techniques from the interferometry data itself. Moreover, there is a requirement of high time resolution (~ 10 seconds) ionospheric calibration in order to remove potential ionospheric corruption from interferometric data-sets at 200 MHz. The given array geometry and distribution of calibrator sources across the field-of-view generally leads to a dense instantaneous sampling of the spatially variable ionosphere electron density. This sampling can be much finer than that achieved by a dense grid of GPS receivers dedicated to study ionosphere over a local area. This opens up a synergy to not only study ionosphere to remove any resultant corruption from the interferometric observations but also to compliment ionospheric research on much smaller spatial scales than possible with dense grid of GNSS receivers alone. It should also be noted that the sensitivity of a radio interferometer towards any change in the electron density content of the ionosphere is much higher than that of the current state-of-the-art GNSS receivers. Even if we assume the phase stability of a radio interferometer like the SKA (Square Kilometer Array) to be ~10 degrees, the sensitivity of the SKA between 70-1420 MHz is in the order of a ~ 1-10 mTEC which is about an order of magnitude better than GPS-based experiments. Several ionospheric studies have made use of radio interferometry which has even lead to the discovery of a new type of traveling ionospheric disturbance (TIDs).

For a single radiometer, ionospheric effects are also pronounced through refraction, absorption and emission. All-sky averaged cosmological signals get corrupted due to these effects of ionosphere on low-frequency radio waves. It has been demonstrated the need for sensitive ionospheric calibration in order to proceed for deeper radio observations with single antenna. Electron density fluctuations in the ionosphere are affected by the nature of the solar disturbances. The solar activity follows variabilities at different temporal scales. The variability in the dynamical system of the ionosphere is a direct consequence of the forcing action by the solar radiation. It is well known that the various solar activities such as solar radio bursts and even sun-spot index display "$1/f$" (flicker noise) characteristics as a function of time. Presence of such corruption term in the single antenna measurement makes it necessary to perform high time resolution calibration for the ionosphere. This makes a strong requirement on signal-to-noise in order to perform a fruitful ionospheric calibration.

Similar issues exist with the effect of troposphere on radio signals received between centimeter and milli-meter wavelengths. Requirement of tropospheric calibration will influence the sensitive high frequency observations with radio interferometers like the SKA.

In this study, we present a uniform study on the effects of both ionosphere and troposphere on radio observations from 70 MHz – 24 GHz. This study will present relative importance of each of the effects at each frequency bands across this huge range of frequencies. The context of this study is future SKA observations but it is not limited to only SKA and can interpreted for other similar telescopes as well.

2. References

1. Datta, Abhirup, et al. "The Effects of the Ionosphere on Ground-based Detection of the Global 21 cm Signal from the Cosmic Dawn and the Dark Ages." *The Astrophysical Journal* 831.1 (2016): 6.
2. Erickson, W. C., et al. "Ionospheric corrections for VLA observations using Local GPS data." *Astronomy & Astrophysics* 366.3 (2001): 1071-1080.
3. Helmboldt, J. F., et al. "A new technique for spectral analysis of ionospheric TEC fluctuations observed with the Very Large Array VHF system: From QP echoes to MSTIDs." *Radio Science* 47.4 (2012).
4. Intema, H. T., et al. "Ionospheric calibration of low frequency radio interferometric observations using the peeling scheme-I. Method description and first results." *Astronomy & Astrophysics* 501.3 (2009): 1185-1205.
5. Paragi, Zsolt, et al. "Very Long baseline Interferometry with the SKA." *arXiv preprint arXiv:1412.5971* (2014).
6. Tingay, Steven. "Propagation effects (tropospheric and ionospheric phase calibration)." *Proceedings of the First MCCT-SKADS Training School*. Vol. 1. 2007.
7. Wijnholds, Stefan J., et al. "Calibration challenges for future radio telescopes." *IEEE Signal Processing Magazine* 27.1 (2010).