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Probing ionospheric structures using Giant Meterwave Radio Telescope at sub-GHz frequencies

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Radio Interferometer is an array of elements that are working together simultaneously to measure the time-averaged correlation of the complex electric fields to provide images of astronomical sources with unmatched resolving power. The effect of the ionosphere limits our ability to explore the sky at sub-GHz frequencies by introducing an extra phase term, which is particularly hard to calibrate in the low signal-to-noise ratio (S/N) regime. Interferometers like Very Large Array (VLA), LOw-Frequency ARray (LOFAR), Murchison Widefield Array(MWA), Giant Meterwave Radio Telescope (GMRT), and future instruments such as Square Kilometer Array (SKA) are all affected by this in the same way.

Here, our motivation is to study the Equatorial Ionization Anomaly (EIA) region which has prominent plasma turbulence effect. In this region, which extends upto $\pm 20^\circ$ magnetic latitudes, Earth's ionosphere continues to vary at dawn and has unanticipated changes during nighttime. These activities in the EIA region can often lead to disruption in communication and navigation such as GPS. Various telescopes like LOFAR($\sim 53^\circ$ N), MWA($\sim 26^\circ$S), VLA($\sim 34^\circ$ N), have also studied the ionosphere. But due to their location constraints, their studies were limited to their local ionospheric region. The location and configuration of the GMRT($\sim 19^\circ$ N) array are well suited to study geophysically sensitive regions between the northern crest of the EIA and the magnetic equator because this region comes under the highest concentration of electron-ion density. We have taken the data from GMRT, which is an excellent candidate due to its positional advantage, to study this EIA region. The source for our study also belongs to this EIA region during the observation run.

The observational data has been taken from a bright radio galaxy ($3C68.2$) at the sub-GHz frequencies to demonstrate the capability of GMRT to detect small-scale ionospheric variability around the EIA region. Phase correction from the calibration has been obtained using standard Common Astronomy Software Applications (CASA). Several steps have been performed to extract ionospheric information from the phase data. The observed ionospheric phase for the pair of antennas is found to be proportional to the difference in the total electron content(TEC), which is called the differential phase observed along the line of sight. As the phase contains several effects, the ionospheric effect being one of largest at lower frequencies irrespective of the instrumental effects. The instrumental noise, which have been removed using dual-band data. After obtaining the ionospheric differential TEC data, geometrical corrections have been performed to make the observed TEC gradient comparable to vertical TEC gradients as closely as possible. Then the data has been fitted with the proposed model to explain the small-scale variation.

Our study reveals for the first time, that the GMRT is capable of measuring differential TEC between two antenna elements with precision about the order of a few mTECU, which is more sensitive than current GPS-based TEC measurements. Furthermore, measurement of the TEC gradient has been computed for the GMRT array, and small scale fluctuations in the 2-D TEC values have been observed. These fluctuations are useful for measuring micro-scale variation in the ionospheric plasma. From the obtained results it is evident that a sensitive instrument like GMRT can be a perfect probe for ionospheric fluctuations.

References

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