URSI AP-RASC, Sydney, Australia, 17 – 22 August 2025

Plasma bubble in the radio astronomical image observed with the MWA

Shintaro Yoshiura*(1), Yuichi Otsuka(2), Cathryn M. Trott(3)(4), Dev Null(3)(4). Nozomu Nishitani(2), Keitaro Takahashi(5), Michi Nishioka(6), Septi Perwitasari(6), and Atsuki Shinbori(2)
(1) National Astronomical Observatory of Japan, 2-21-1 Osawa, Mitaka, Tokyo 181-8588, Japan
(2) Institute for Space-Earth Environmental Research (ISEE), Nagoya University, Nagoya, Japan
(3) International Centre for Radio Astronomy Research, Curtin University, Bentley, WA 6102, Australia
(4) ARC Centre of Excellence for All Sky Astrophysics in 3 Dimensions (ASTRO 3D), Bentley, Australia
(5) Kumamoto University, International Research Organization for Advanced Science and Technology, 2-39-1 Kurokami, Chuo-ku, Kumamoto 860-8555, Japan
(6) National Institute of Information and Communications Technology (NICT), Tokyo, Japan

1 Extended Abstract

A radio interferometer, which consists of multiple individual antennas, measures the correlation of received voltages. The correlated signal, known as visibility, is used to create high-resolution images with a large field of view. The positional information of radio sources is encoded in the phase of the visibility. However, Earth's ionosphere introduces significant delays in incoming low frequency signals at each antenna, causing phase error that shift apparent position of radio sources.

The Murchison Widefield Array, a radio interferometer located in Western Australia, has been observing low frequency radio signals for various scientific studies [1]. By comparing the apparent positions of radio sources with their catalogued positions, the distribution of ionospheric distortions has been investigated (e.g. [2]).

Global Navigation Satellite Systems (GNSS) provide measurements of the global total electron content (TEC). The Rate Of TEC change Index (ROTI) is used to detect ionospheric density irregularity. On December 1, 2023, a region with high ROTI propagated from equatorial region to Western Australia. This indicates that the generation and propagation of a plasma bubble which is a localized depletion of electron density in the ionosphere during the magnetic storm on that date [3]. At the time, the MWA was in operation, measuring the redshifted 21-cm line emitted by neutral hydrogen atoms in the distant universe. In [4], we investigated the GNSS and MWA data to study the ionospheric distortion in the radio images.

As the MWA has a wide field of view (approximately 20 x 20 degrees), a lots of radio sources are available for simultaneously measuring the position offset. When the high ROTI region reached the MWA site, we observed a propagating duct-like region where radio sources were wiped out. This duct-like structure had an estimated size of approximately 50 km x more than 100 km and a velocity of $\sim$ 100 m/s. We also found that a bright radio source appeared to split into multiple components within the duct-like structure. These split components exhibited high time variation in the flux and position. This scintillation may have been caused by small scale structure in the ionosphere. The size, velocity and small scale features of the duct-like structure suggest that it was associated with a plasma bubble.

References

[1] Tingay, S. J., Goeke, R., Bowman, J. D., et al. "The murchison widefield array: The square kilometre array precursor at low radio frequencies", 2013, PASA, 30, e007

[2] Loi, S. T., Murphy, T., Cairns, I. H., et al. "Real-time imaging of density ducts between the plasmasphere and ionosphere", 2015, GRL, 42, 3707

[3] Sun, W., Li, G., Zhang, S.-R., et al. "Regional Ionospheric Super Bubble Induced by Significant Upward Plasma Drift During the 1 December 2023 Geomagnetic Storm", 2024, Journal of Geophysical Research (Space Physics), 129, e2024JA032430

[4] S. Yoshiura et al, "Strong ionospheric activity at the MWA site associated with plasma bubble measured by GNSS", 2024, submitted.