Observations of Plasma Structures in the Mid-Latitude Ionosphere with the International LOFAR Telescope

Alan Wood[1], Gareth Dorrian[2] and Richard Fallows[3]

[1]School of Science and Technology, Nottingham Trent University, UK (alan.wood@ntu.ac.uk) [2]School of Electrical, Electronic and Computational Engineering, University of Birmingham, UK [3]ASTRON, the Netherlands Institute for Radio Astronomy, The Netherlands

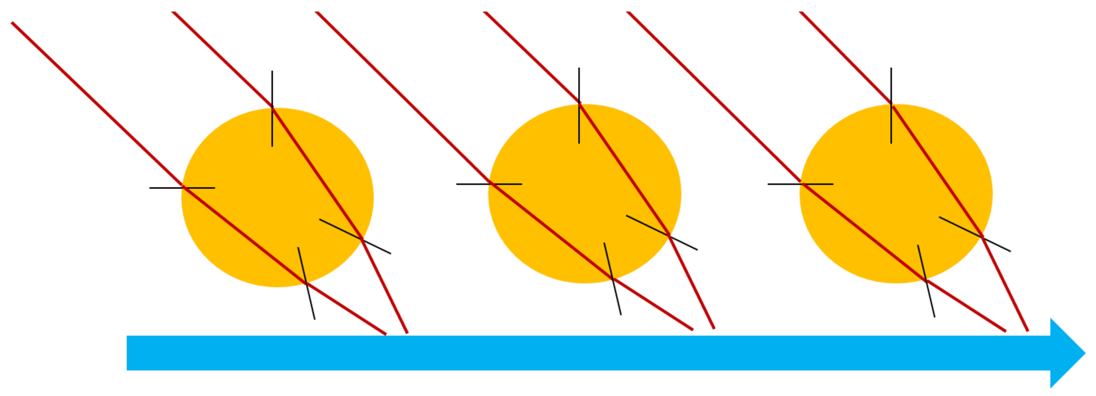
NOTTINGHAM TRENT UNIVERSITY

Abstract

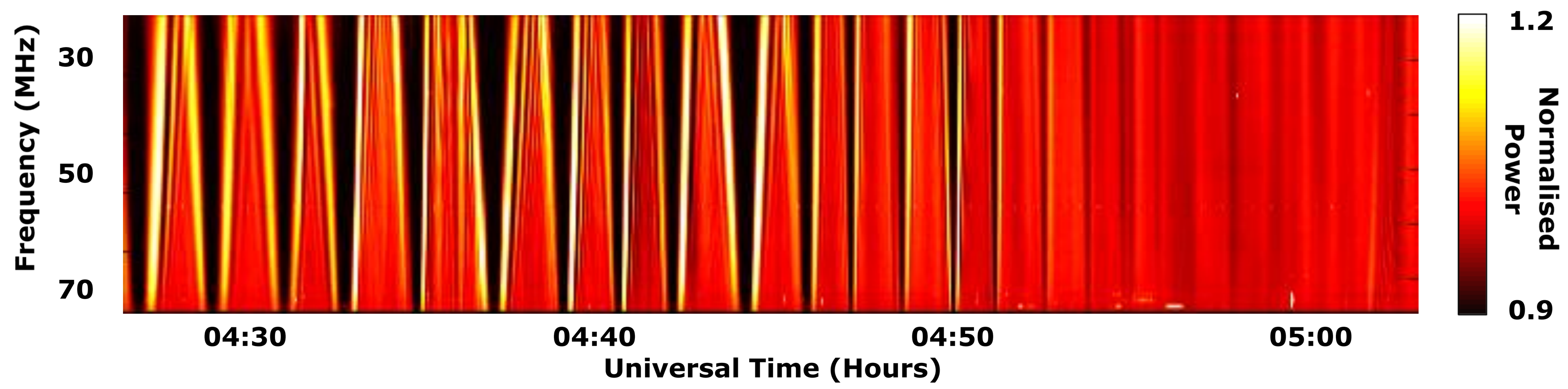
The International LOFAR (Low Frequency Array) Telescope is one of the world's leading radio telescopes, operating across the frequency band 10-250 MHz. As radio waves from astronomical sources pass through the ionosphere, they can undergo refraction and/or diffraction. The received signal can therefore be used to infer information on plasma structures in the ionosphere.

Frequency Dependent Behaviour

As radio waves from astronomical sources pass through the ionosphere, they can undergo refraction and/or diffraction. Refraction depends upon the local refractive index which varies with plasma density. Refraction also depends upon the frequency of the radio wave. Subsequent interference of the radio waves can result in a diffraction pattern, with ionospheric structures acting as a diffraction screen. If the radio source and/or the ionospheric structures are moving relative to the observer, then variations in signal intensity are observed.



LOFAR station PL612C (53.4 °N; 21.6 °E) observation of Cygnus A on 30th January 2018



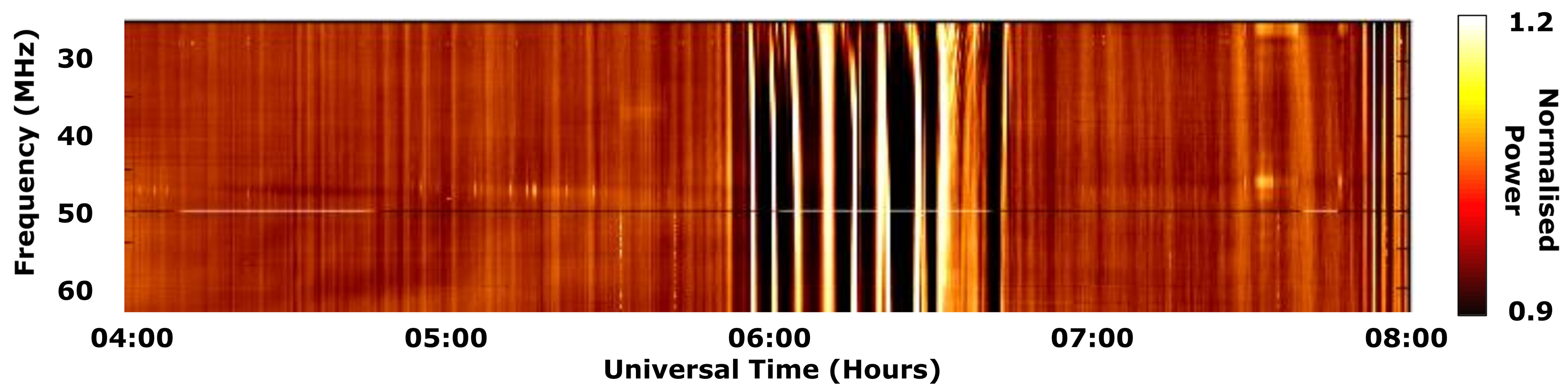
Under the weak scattering approximation the effects of scattered waves upon each other are neglected. The variations in the intensity of the received signal are caused by irregularities with a spatial scale size ranging from the Fresnel dimension to an order of magnitude below this value. The Fresnel length D_F is related to the wavelength of the radio source λ and the distance from the receiver to the scattering region L:

$$D_F = \sqrt{2 \cdot \lambda \cdot L}$$

If the distance to the scattering region is known then the spatial scale of the ionospheric structures can be inferred.

Rapid Onset & Dissipation

LOFAR station IE613C (53.1 °N; 7.9 °W) observation of Cygnus A on 7th January 2019



Rapid onset and dissipation of ionospheric structures can be inferred from rapid changes to intensity of a received signal. The time taken for the signal power to increase from the background value to the first peak in this observation was approximately 60 seconds. The spikes themselves have lifetimes ranging from 10s to 100s of seconds.

It is interesting to note that this observation does not show frequency dependent behaviour. The origin of the ionospheric structures causing these variations is not known. The signal passes through the F-region above the solar terminator, so the event onset may be related to sunrise.

Deep Fading of Signal

Deep fading of the received signal can be observed. Sporadic-E is a consequence of variations in the neutral wind speed with altitude in the presence of the geomagnetic field, resulting in plasma accumulating in a thin layer. This can cause incident radio waves to be strongly refracted, affecting the strength of the received signal. The deep fading of the received signal could be due to such a phenomena.

LOFAR station RS508 (53.2 °N; 7.0 °E) observation of Cygnus A on 14th July 2018

Discussion

The International LOFAR telescope allows ionospheric structures to be inferred at a high temporal and frequency resolution. LOFAR comprises stations across central and western Europe. There is a dense network of stations in the LOFAR core, close to Göttingen in the Netherlands, giving high spatial resolution in this region. Stations located across Europe allow observations across a wider spatial scale. Collectively LOFAR enables studies of the morphology and evolution of ionospheric structures.

Fallows et al. (2020) showcases the impressive capabilities of this instrument and also gives a comprehensive overview of methods for data analysis and interpretation.

Reference

Fallows, R. A., Forte, B., Astin, I. Allbrook, T., Arnold, A., Wood, A., Dorrian, G., Rothkaehl, H. Matyjasiak, B., Krankowski, A. et al., A LOFAR Observation of Ionospheric Scintillation from Simultaneous Medium- and Large-scale Travelling Ionospheric Disturbances, J. Space Weather Space Clim., 2020. doi.org/10.1051/swsc/2020010.

Acknowledgements: *The Low Frequency Array was designed and constructed by ASTRON, and has facilities in several countries that are collectively operated by the International LOFAR Telescope (ILT) foundation under a joint scientific policy.*