Observing Travelling Ionospheric Disturbances with LOFAR

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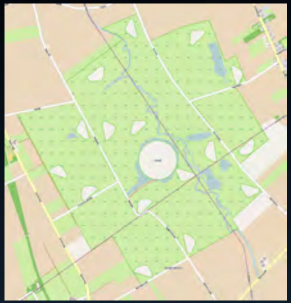
LOFAR – Europe’s Largest and Most Flexible Radio Telescope



Core of 24 stations in area with 4km diameter:
- Core station signals can be combined in the central correlator to form up to ~200 independent “tied-array” beams.

LOFAR correlator:-
- Correlates data from all or subset(s) of LOFAR stations
- Usually used for interferometric imaging
- Can also process and record single-station data.

Core of 24 stations in area with 4km diameter. 14 remote stations scattered across the NE of the Netherlands.

Fourteen operational stations across Europe:
- 6 in Germany;
- 3 in Poland;
- 1 each in France, Ireland, Lativa, Sweden, and the UK.

One new station to come:
- Italy in ~2022

Station cabinet:-
- Contains receivers, beam-former and correlator
- 96MHz of bandwidth can be split amongst up to 488 beams

“High-band” tiles:-
- Frequency range: 110-250MHz
- 4x4 array of bow-tie antennas
- Analogue beam-former points single ~20-degree wide beam

“Low-band” dipoles:-
- Frequency range: 10-90MHz
- All-sky coverage

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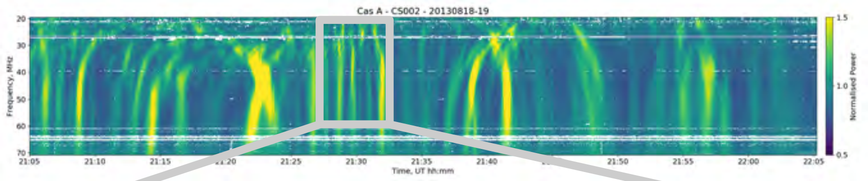
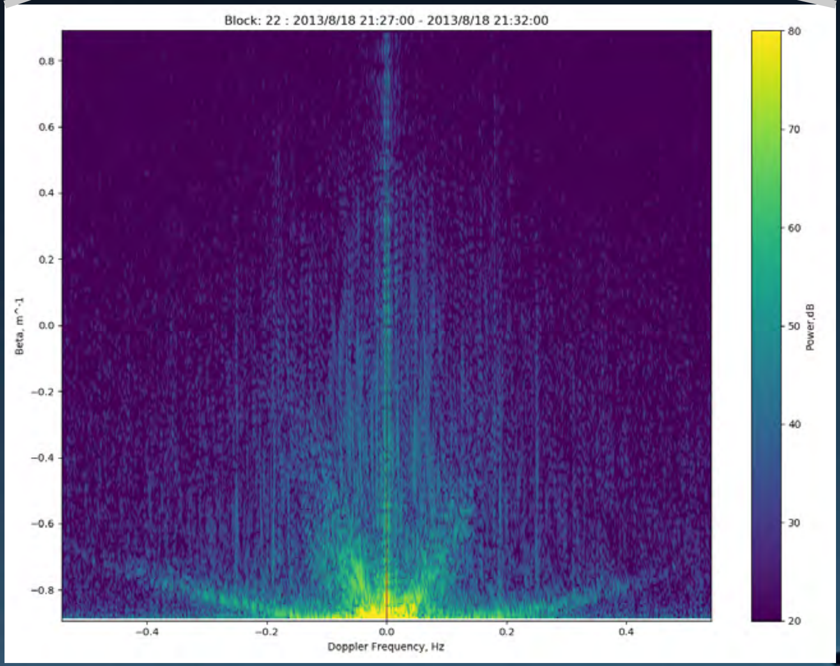
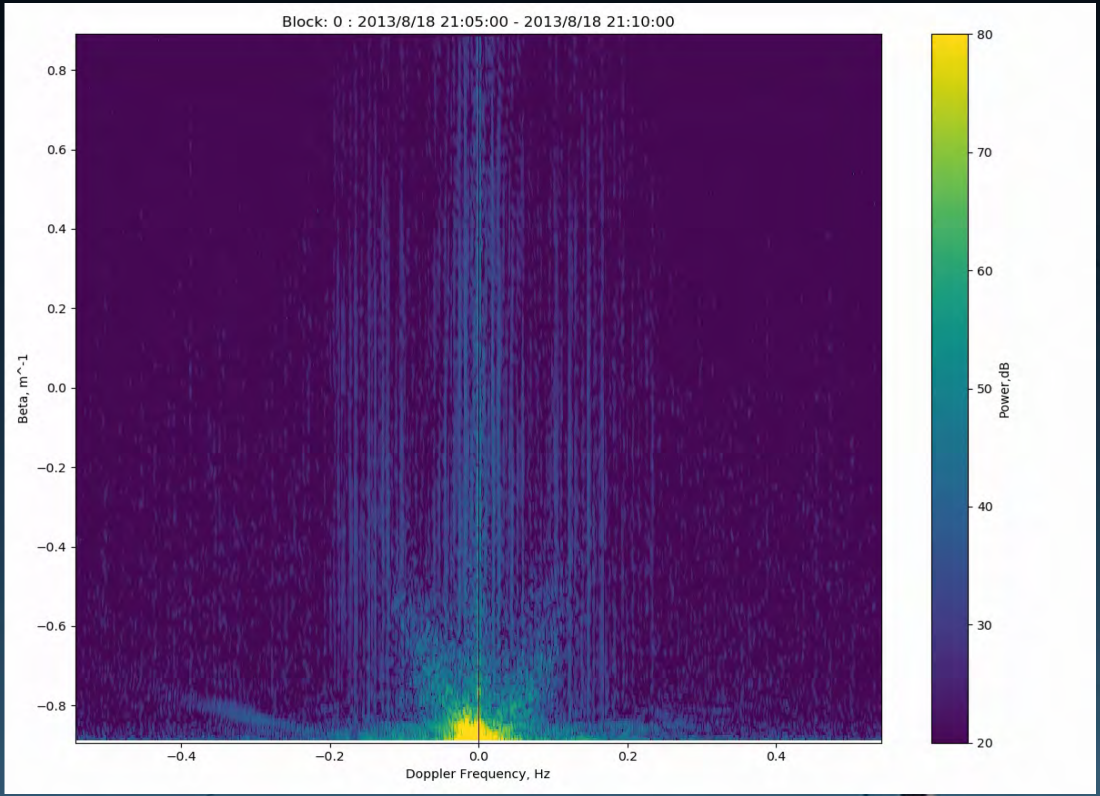
18th August 2013 – LOFAR Core – Cas A
Beamformed data recorded by each individual station

Dynamic spectrum







Delay-Doppler spectrum – 2D power spectrum of the dynamic spectrum

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Fallows et al., 2020, doi:10.1051/swsc/2020010

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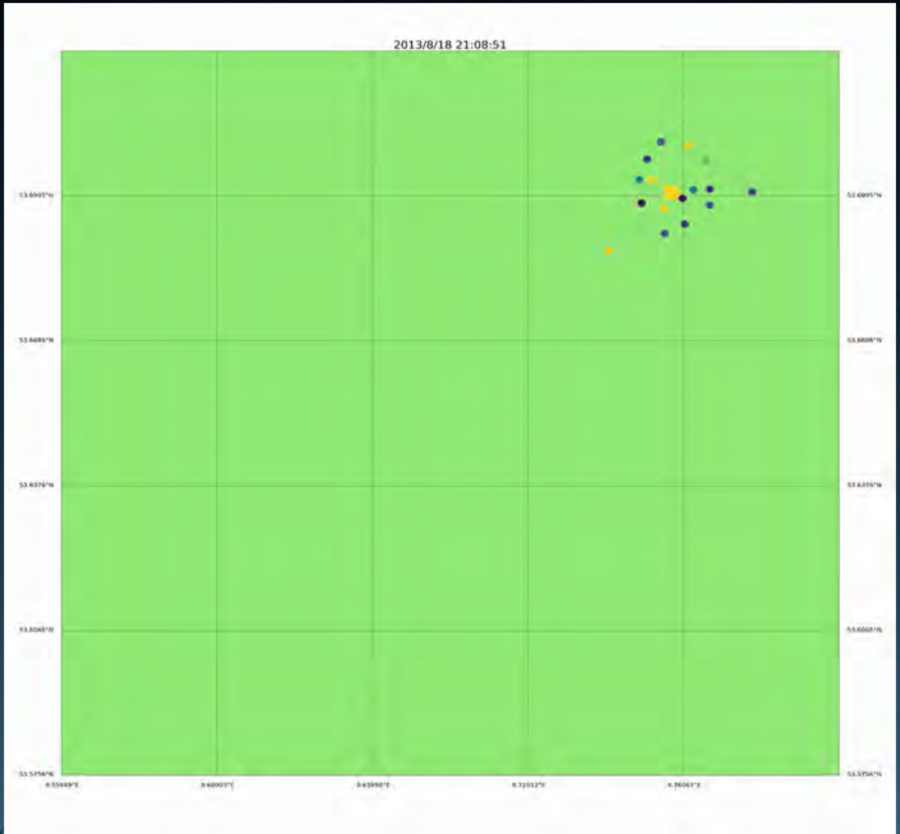
Looking Down Through the Ionosphere

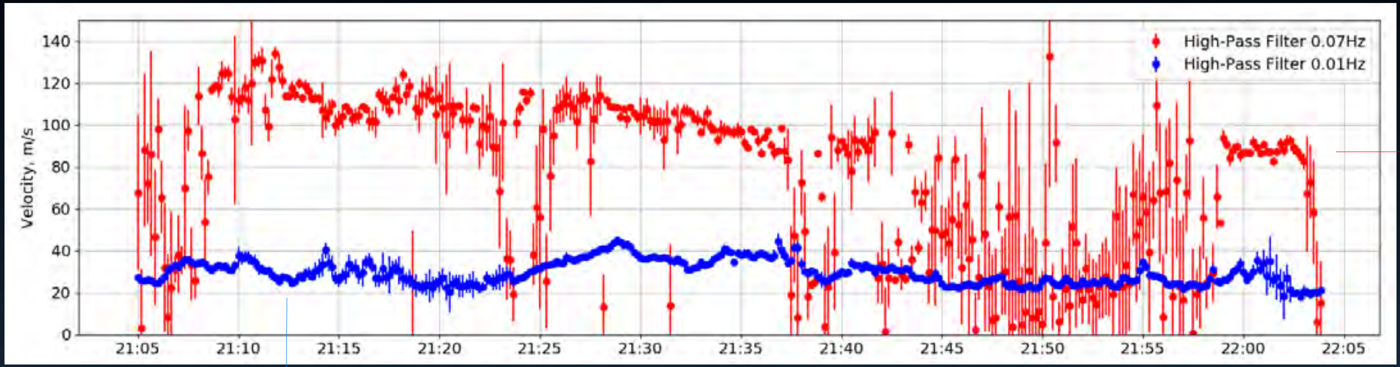
For each station and each instant of time:-
- Calculate geographic location of line of sight pierce point height of 200km
- Plot this point on a map using a colour corresponding to the intensity received by that station at that time.

This movie is for the Core stations only from the observation of Cas A taken on 18th August 2013.



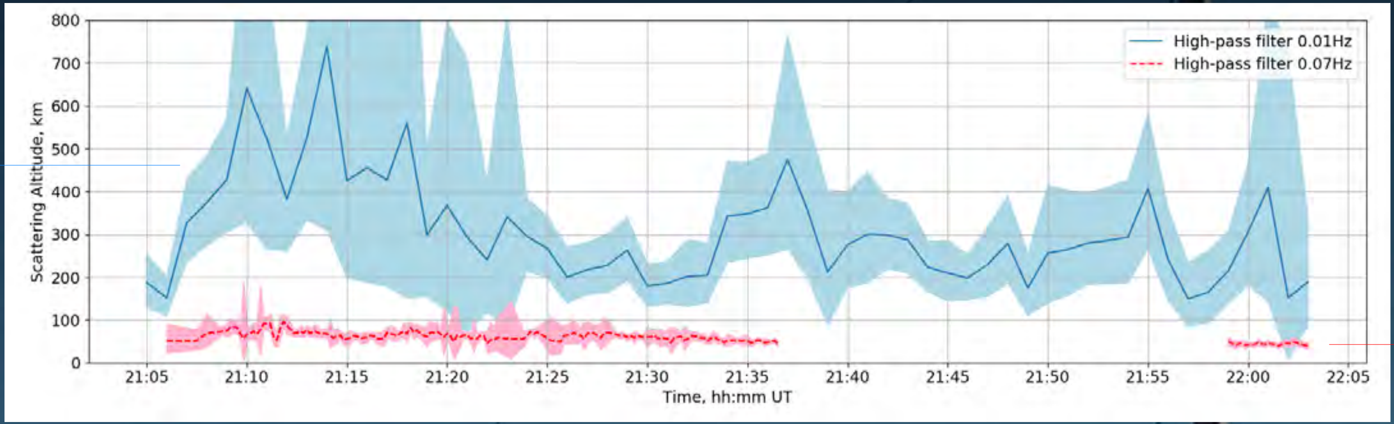
Fallows et al., 2020, doi:10.1051/swsc/2020010

Velocities and Altitudes of the Scattering Medium



Shallow arc in Delay-Doppler spectrum: Faster velocity NE to SW, associated with the D-region.

Steep arc in Delay-Doppler spectrum: Slower velocity NW to SE, associated with the F-region or higher.



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Fallows et al., 2020, doi:10.1051/swsc/2020010

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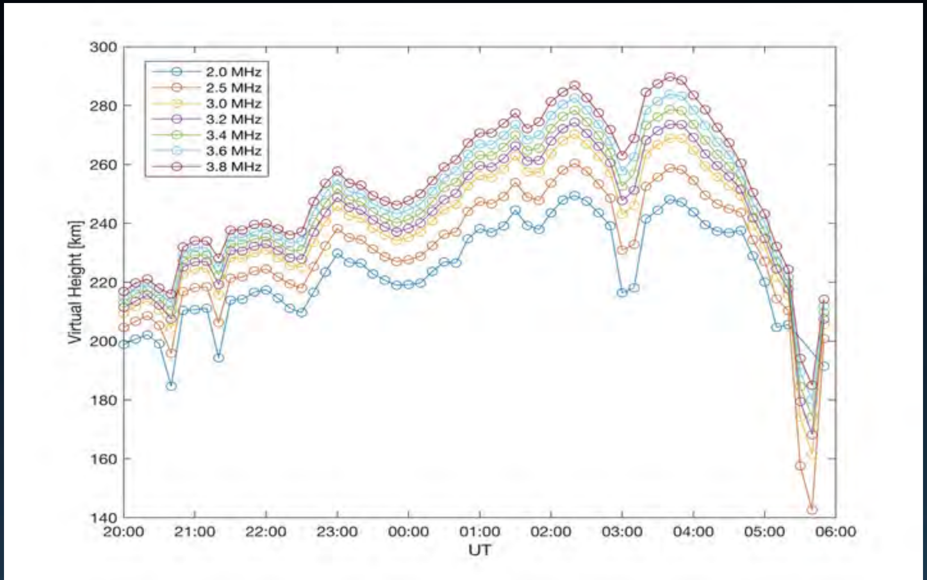
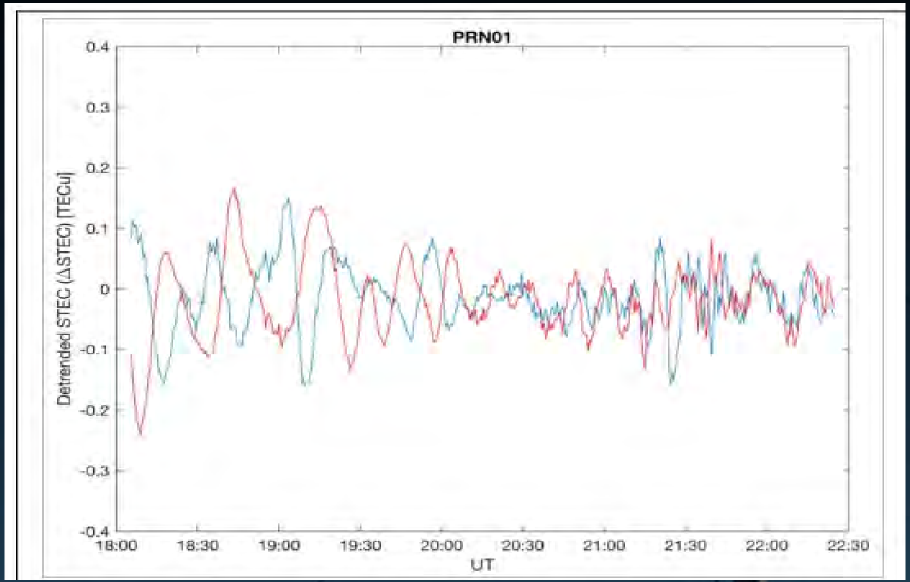
Supporting Data from Ionosonde and GNSS – 18-19 August 2013



Multiple traces from the ionosonde in Chilton (UK) recorded between 20:00 18 August 2013 and 06:00 19 August 2013.

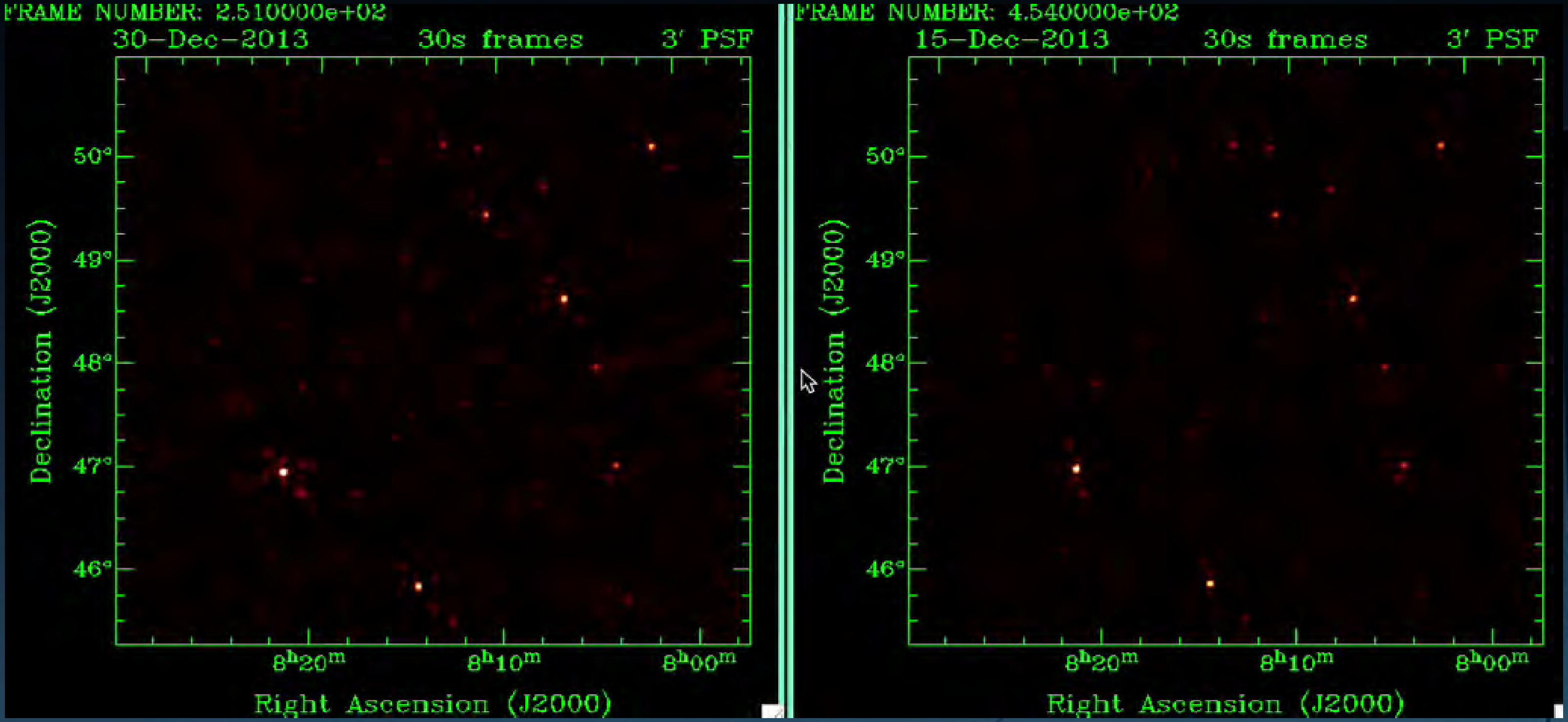


GPS satellite PRN01 as observed on 18 August 2013 from Chilbolton (CHI0, blue line) and Hailsham (HERT, red line), both in UK, with baseline oriented from NW to SE.

Analysis of ionosonde and GPS data by Biagio Forte, Ivan Astin, Thomas Allbrook, Alexander Arnold, University of Bath, indicated the likely presence of two medium-scale TIDs, travelling in perpendicular directions.

Fallows et al., 2020, doi:10.1051/swsc/2020010

Refractive Effects in Imaging



This movie consists of 30s snapshot images at ~150MHz from data taken of the same field on a “quiet” and a “disturbed” night. Waves of plasma traversing the field during the disturbed night can be imagined from the shifting positions of the radio sources in the field.

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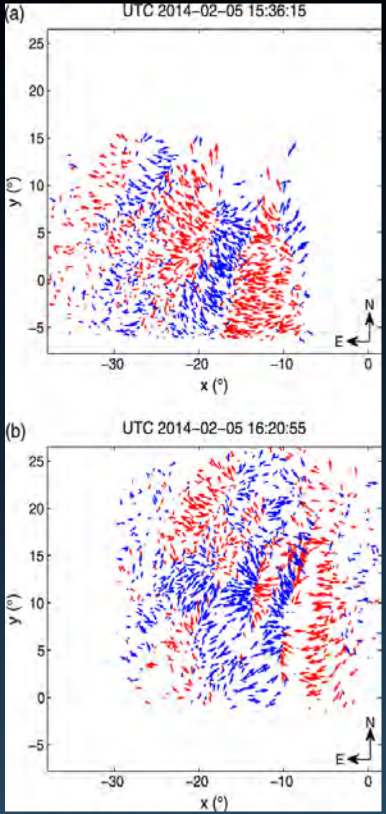
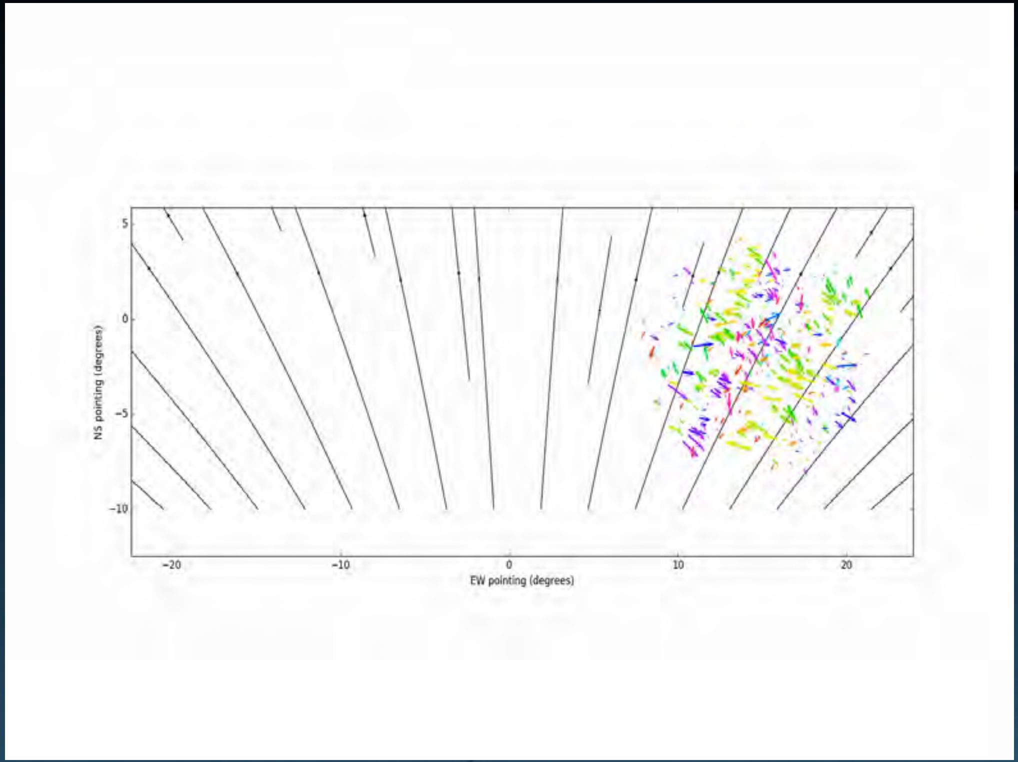
Refractive Effects in Imaging



MWA observation of position shifts (Loi et al., 2015, doi:10.1002/2015RS005711)



Apparent position shifts of radio sources in the field of view show strong alignment with the magnetic field. Colour code indicates position shift direction east/west, and arrow length a highly exagerated magnitude of the shift. This structure is apparent in ~50% of LOFAR observations. Movie credit: Maaijke Mevius.

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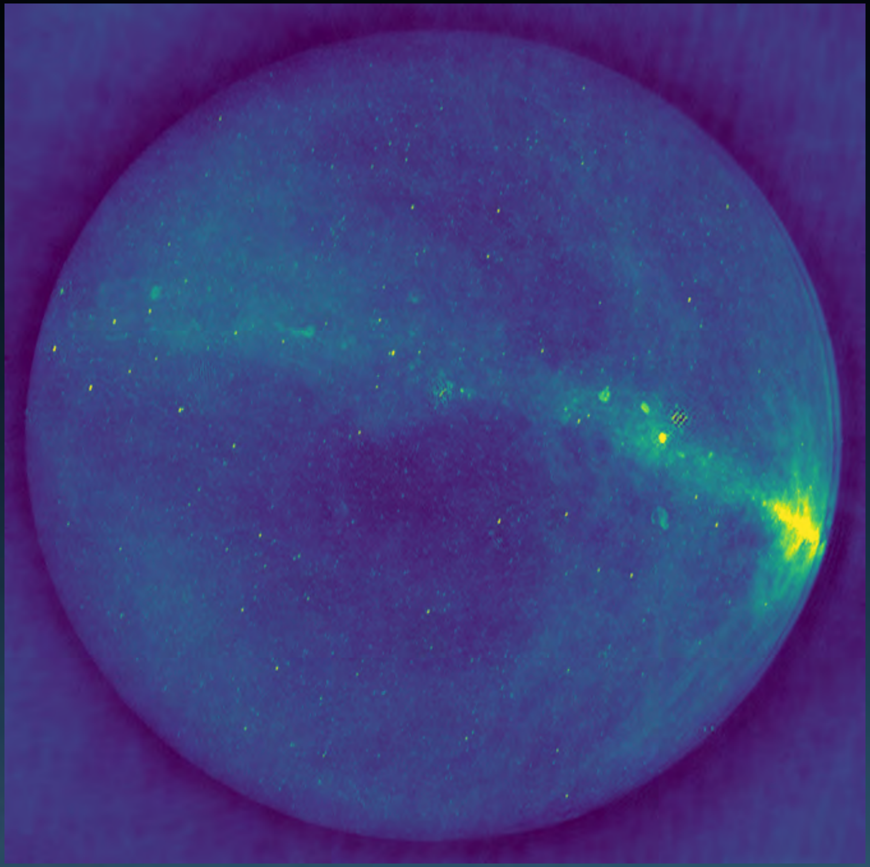
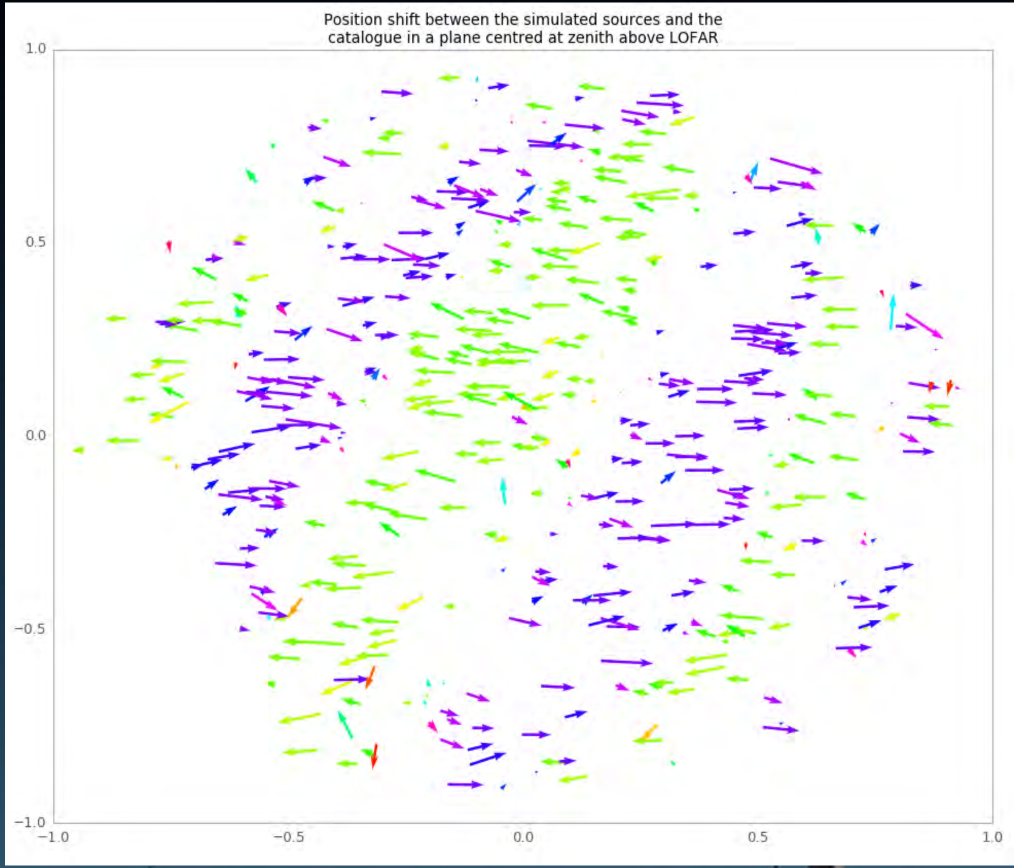
AARTFAAC – Snapshot All-Sky Imaging





AARTFAAC correlates signals from the LBAs of the inner 12 stations of the LOFAR core to create high-resolution images of the whole visible sky once a second. A raw image is shown on the left, from which all radio sources are identified and positions and fluxes measured. Right is a simulated image of position shifts resulting from a medium-scale TID. Simulation: Maaijke Mevius and Ariana Saba.

The effect of the ionosphere is inherent in LOFAR data, and the wide field of view (and all-sky capabilities particularly) offer the possibility to effectively image TIDs and other structure.

These imaging capabilities are not unique to LOFAR, but are also possible (and performed) with the MWA, and possible with all-sky imaging instruments such as the LWA and the Owens Valley LWA, providing viewpoints from very different locations worldwide.