Ionospheric Scintillation with LOFAR: Making Sense of Dynamic Spectrum Oddities

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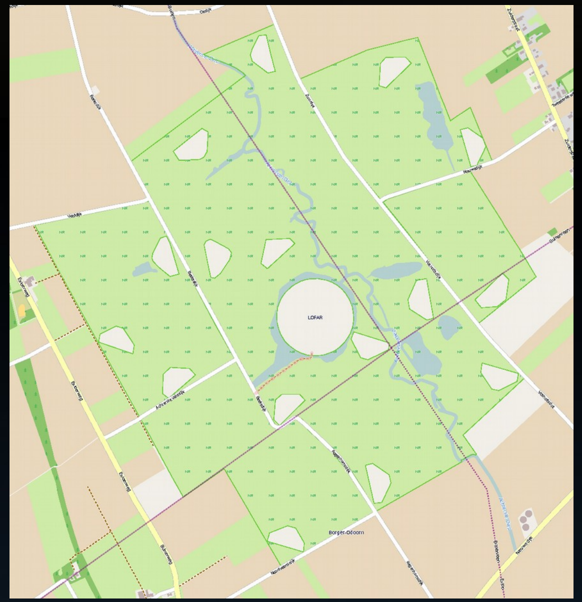
LOFAR – Europe’s Largest and Most Flexible Radio Telscope



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.

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

Two new stations to come:
- Latvia in 2019;
- Italy in ~2021

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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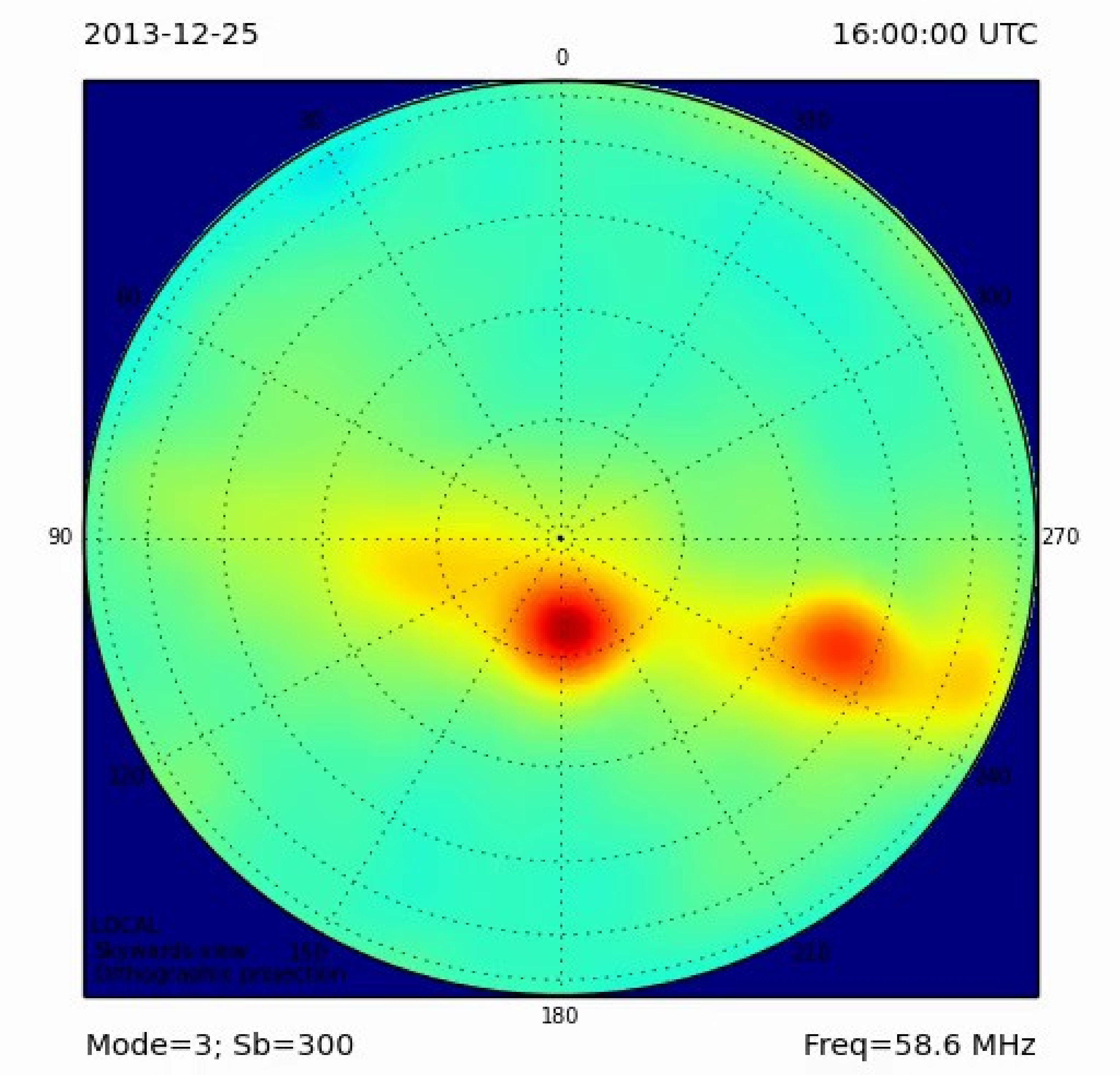
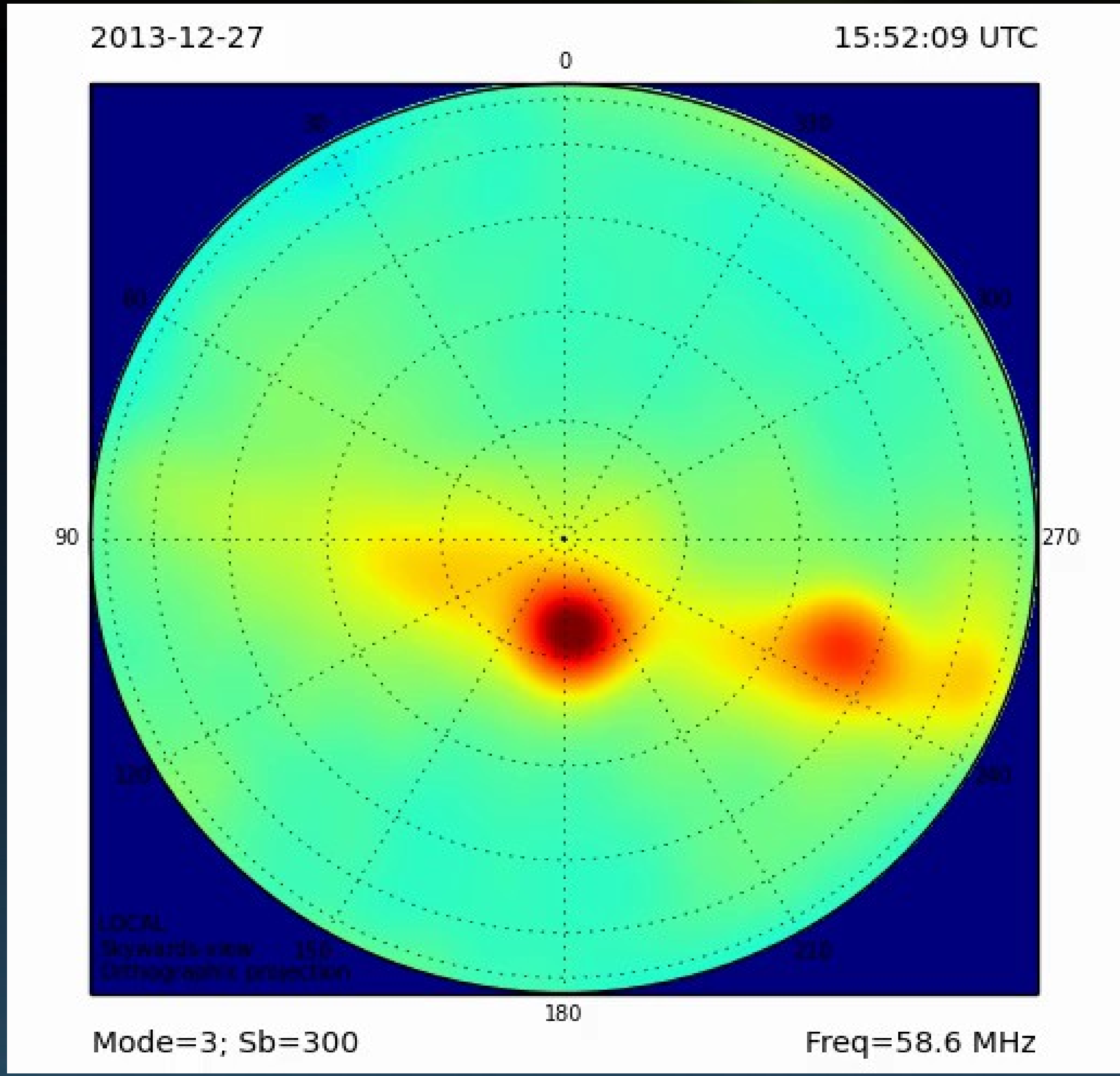
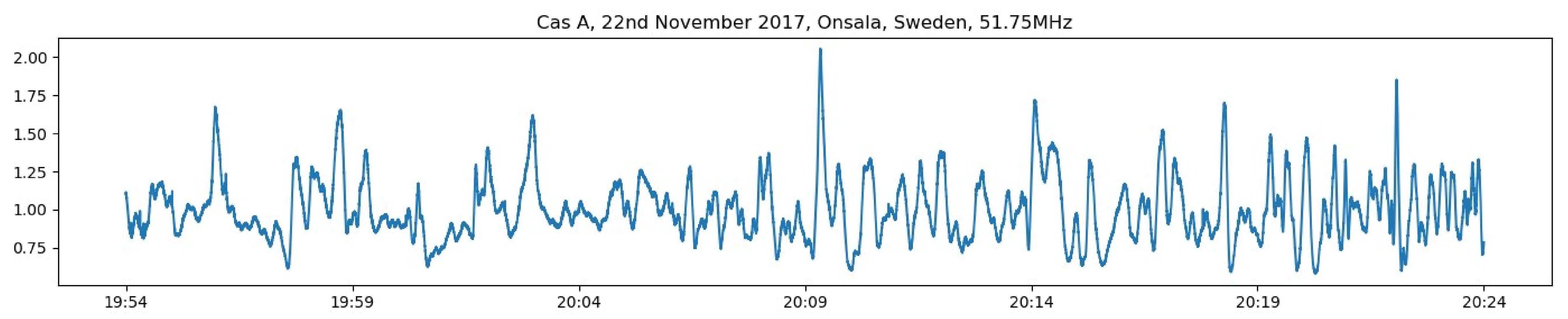




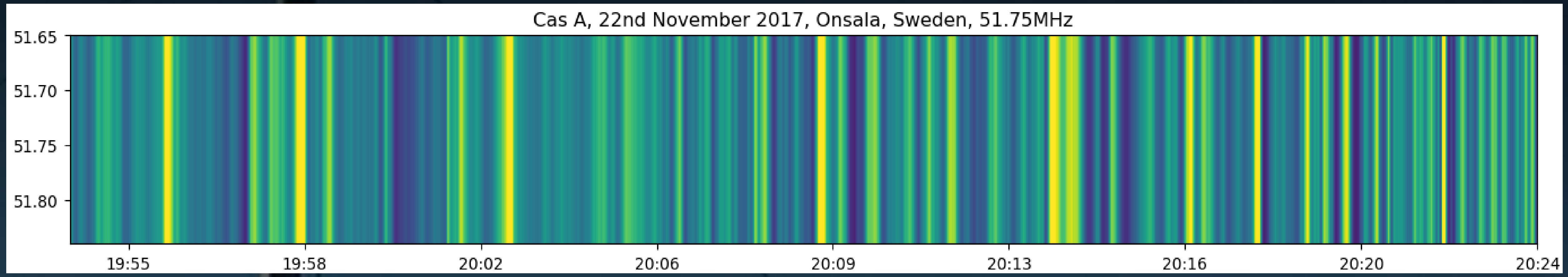
All-sky imaging, one image per second, 58.6MHz
Kilpisjärvi Atmospheric Imaging Receiver Array – northern Finland

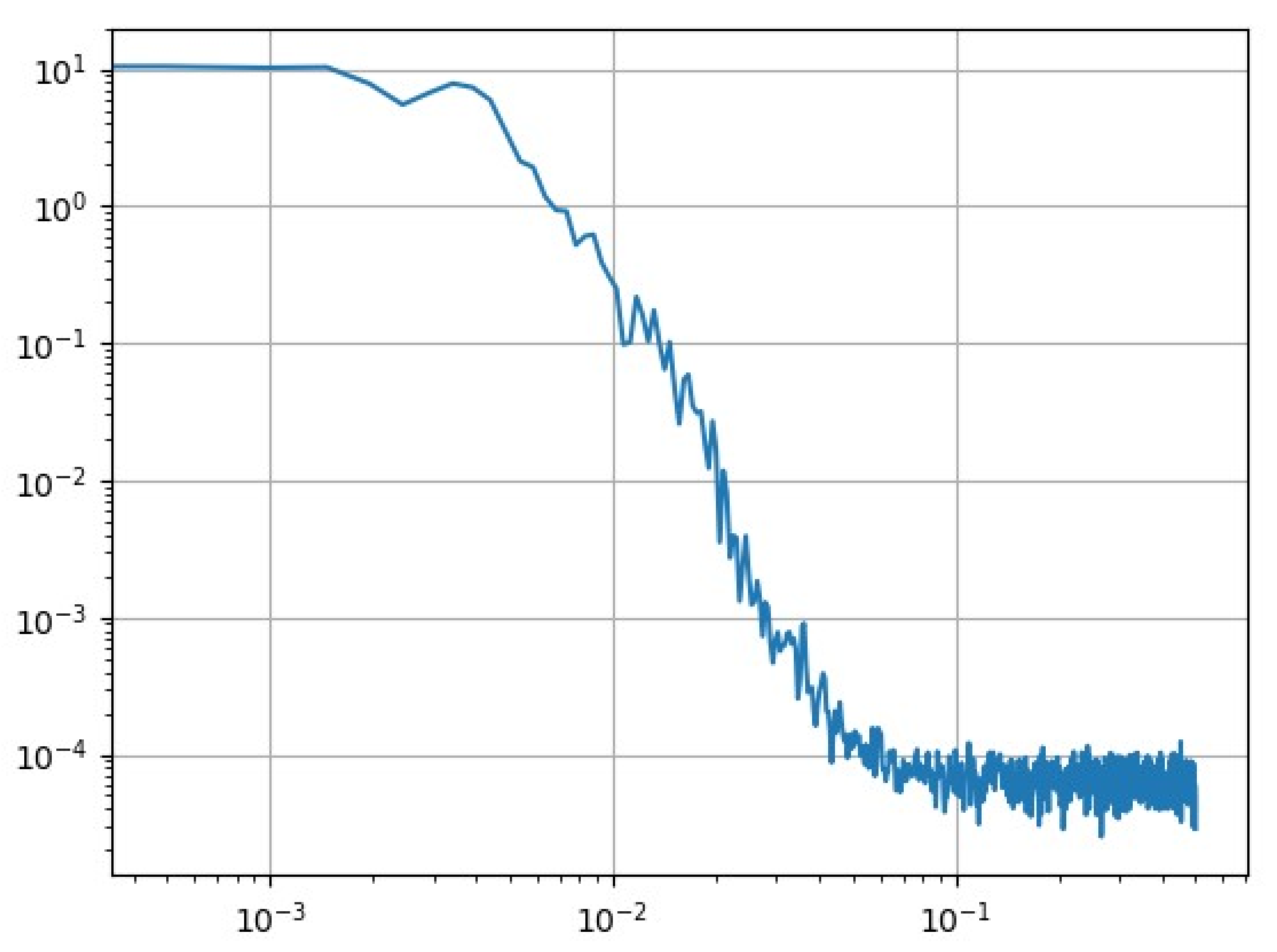
Scintillation – The "Traditional" Analysis



Fourier Transform

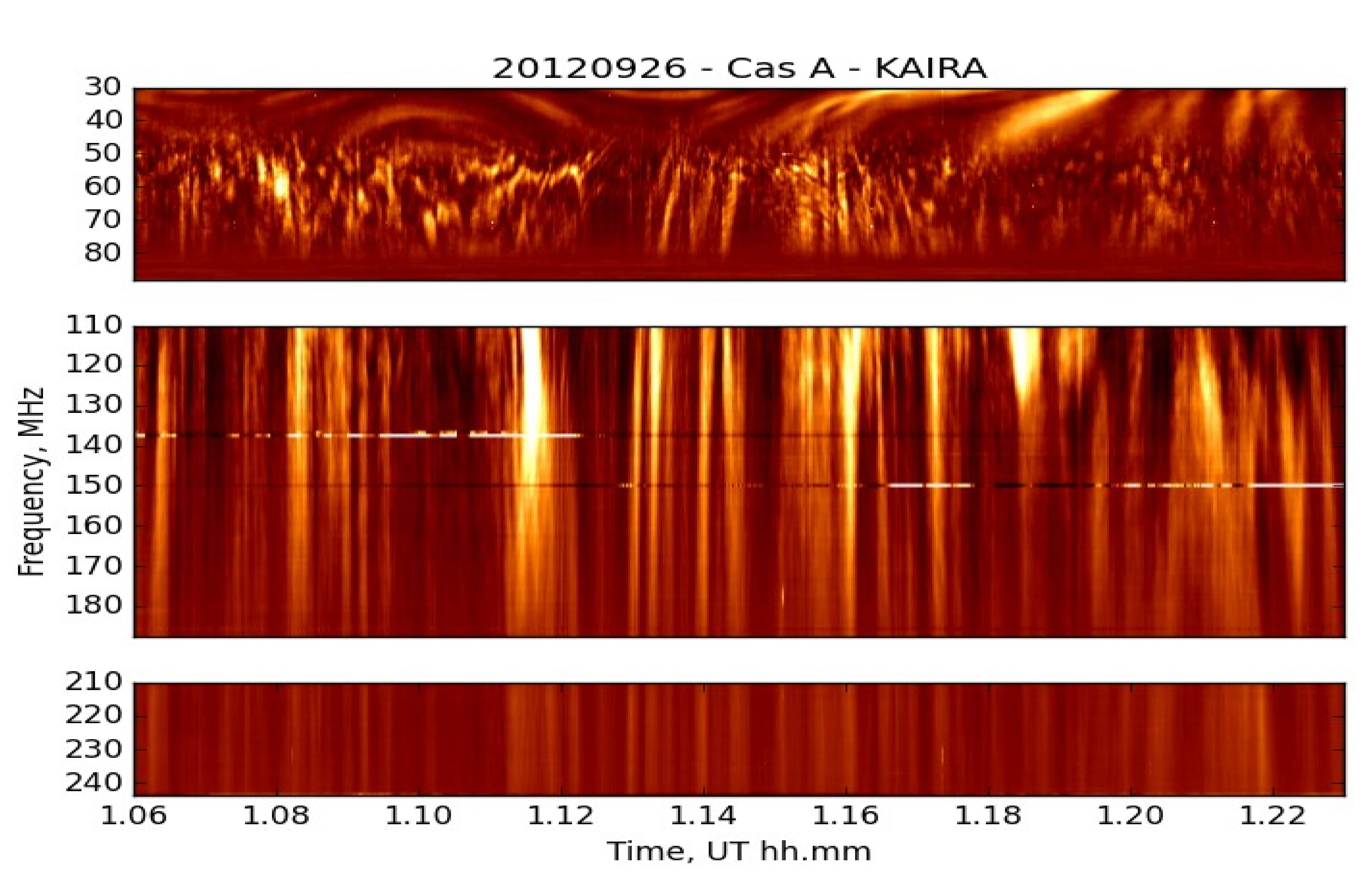
Time series in dynamic spectrum format





Power spectrum

Scintillation – Expanding the Bandwidth



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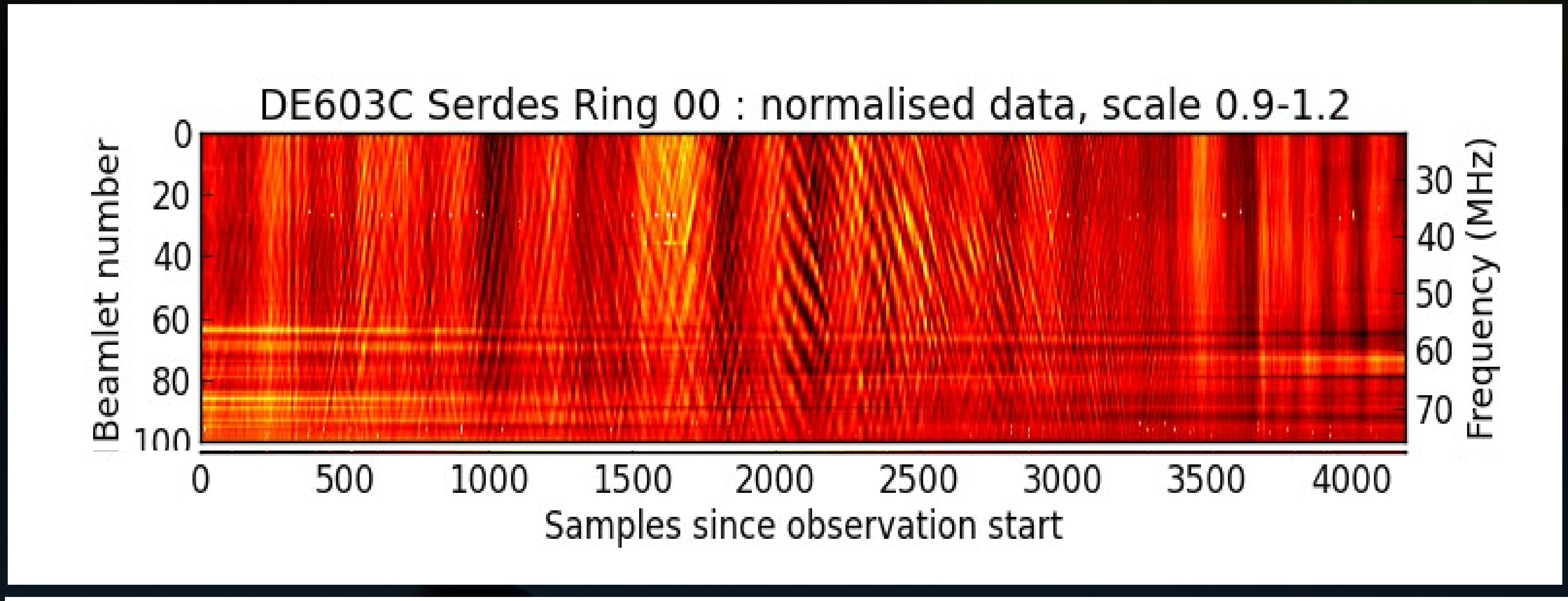
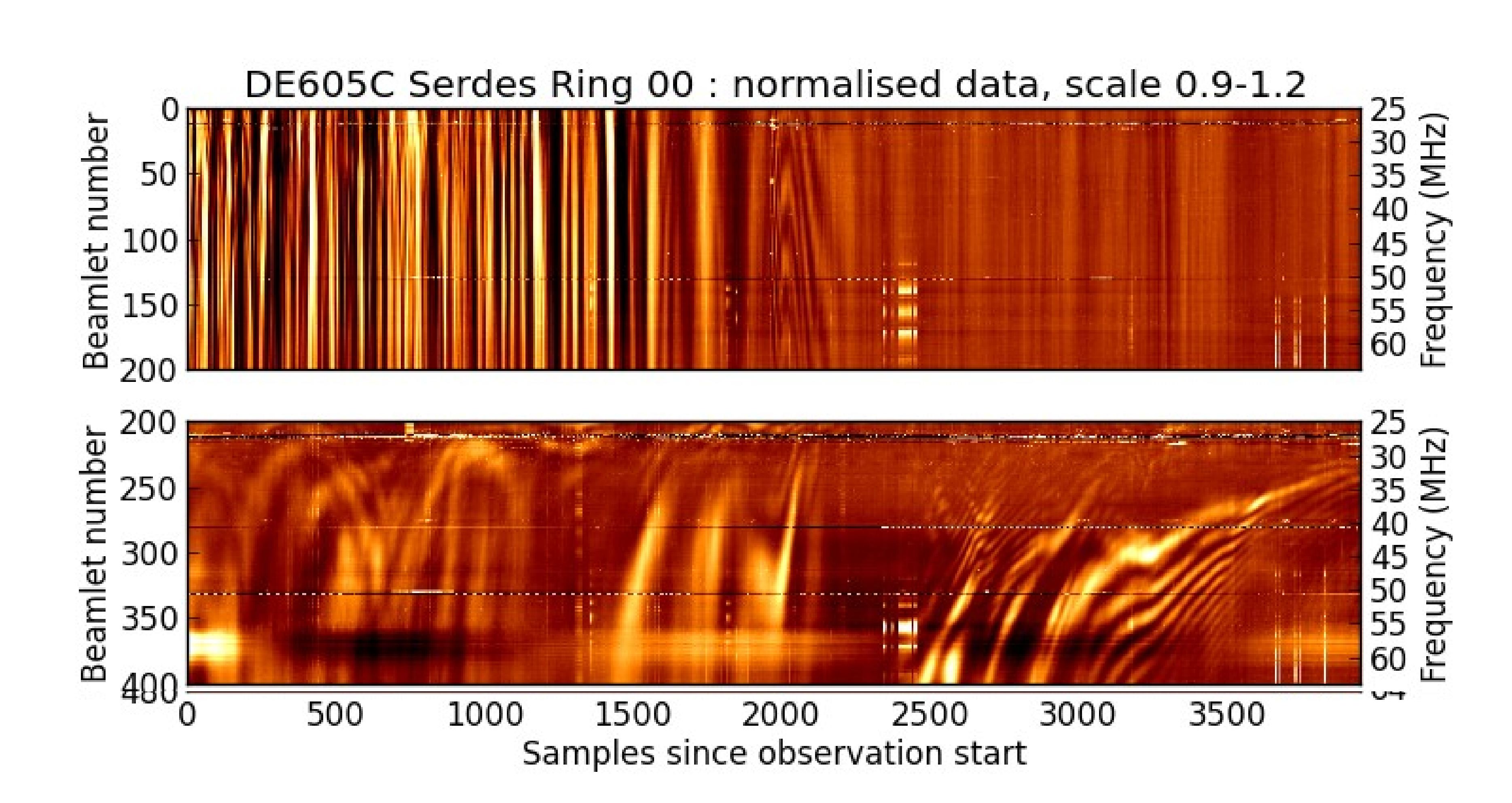
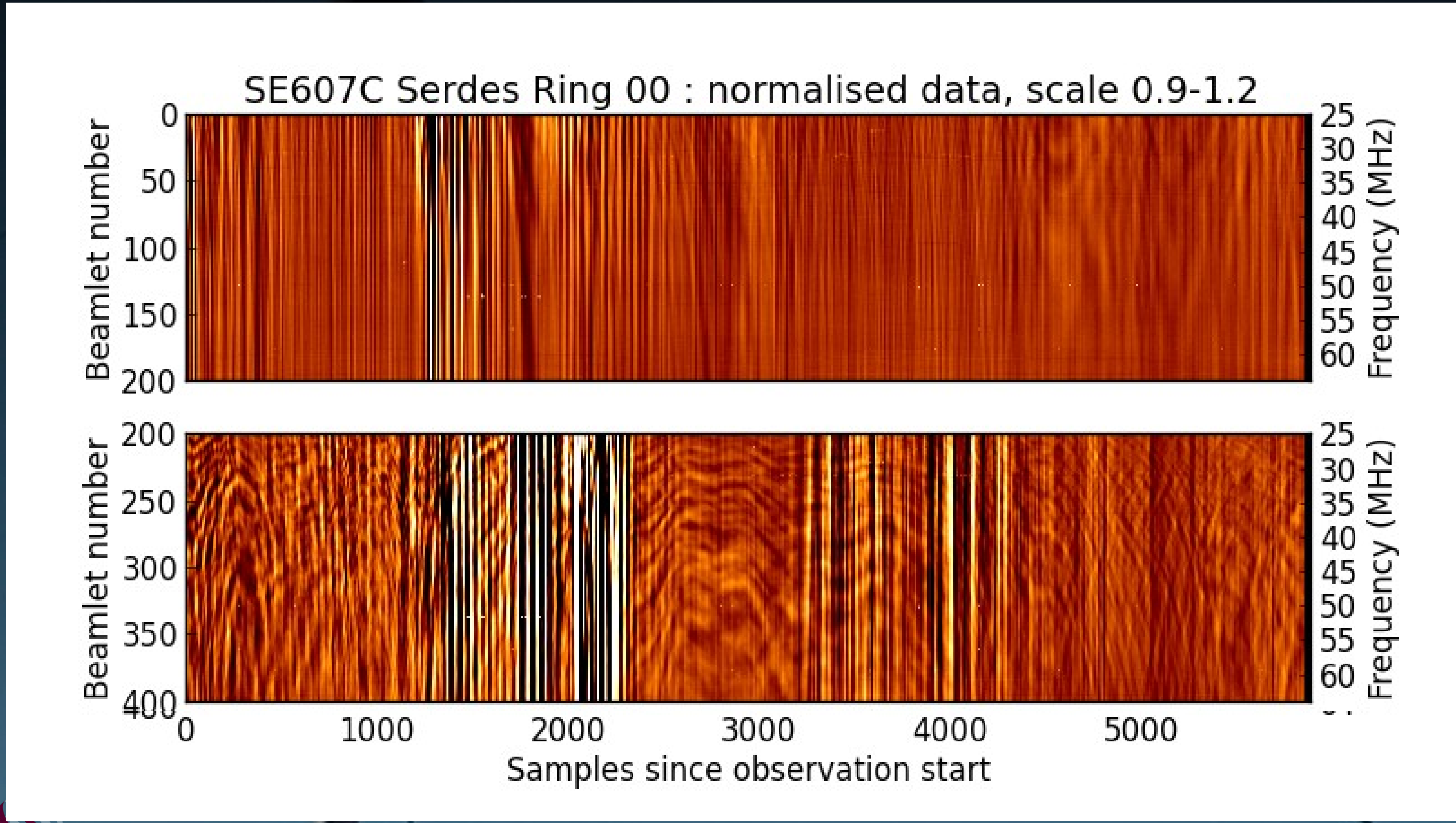
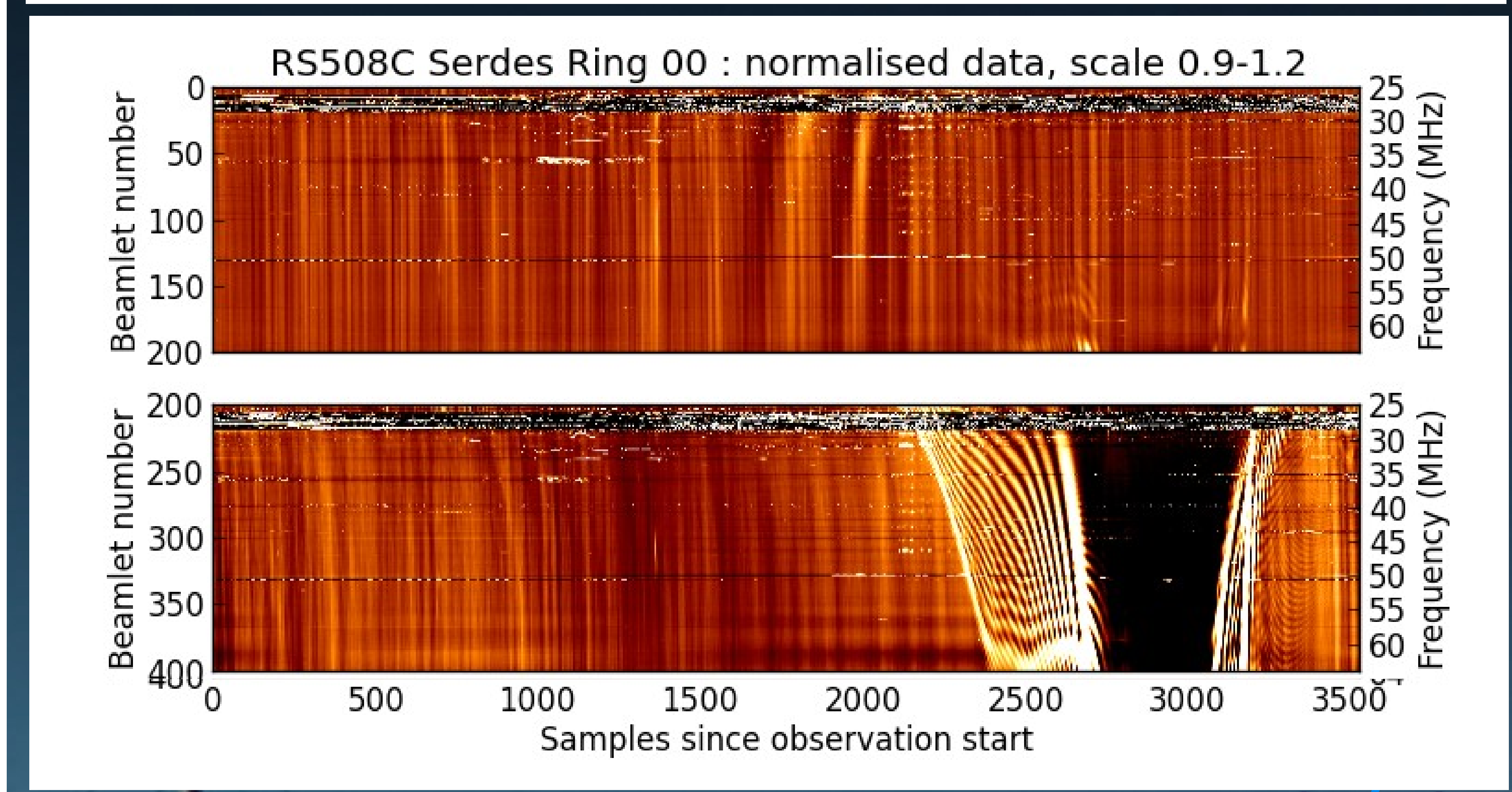
Scintillation Above LOFAR – An Expanding Collection of Oddities

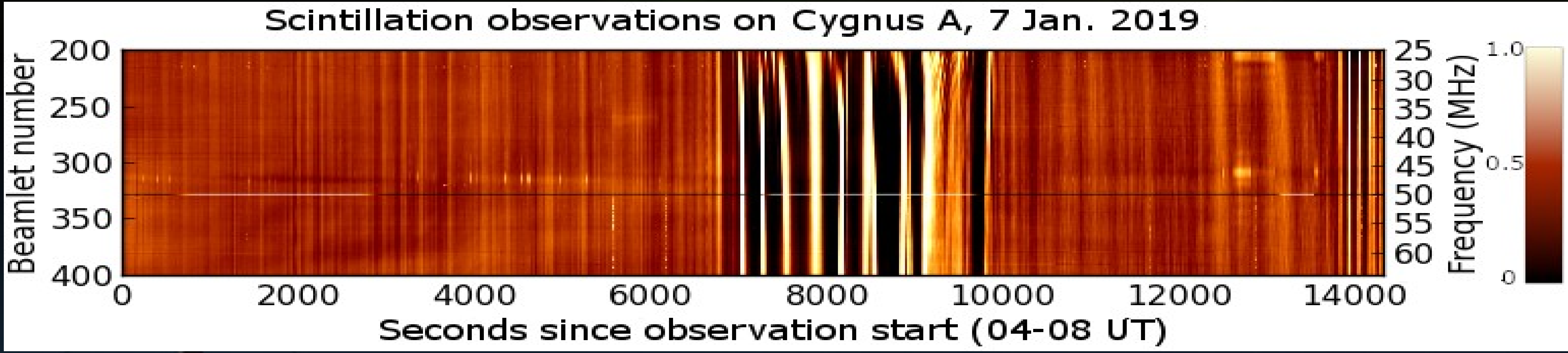








Rapid Onset and Dissipation



"Both the Kp and Dst indices at this time indicated that conditions were quiet and that the 3-hour resolution of the Kp index would be inadequate as a predictor of this event. ... There was also very little solar activity at this time. It is demonstrated that the scintillating feature may be related to local sunrise in the F2-region ionosphere, at an altitude of approximately 350 km. Such rapid changes in scintillation conditions are indicative of sharply defined boundaries between ionospheric plasma structures and the surrounding ionosphere."

- Dorrian et al., in prep., 2019

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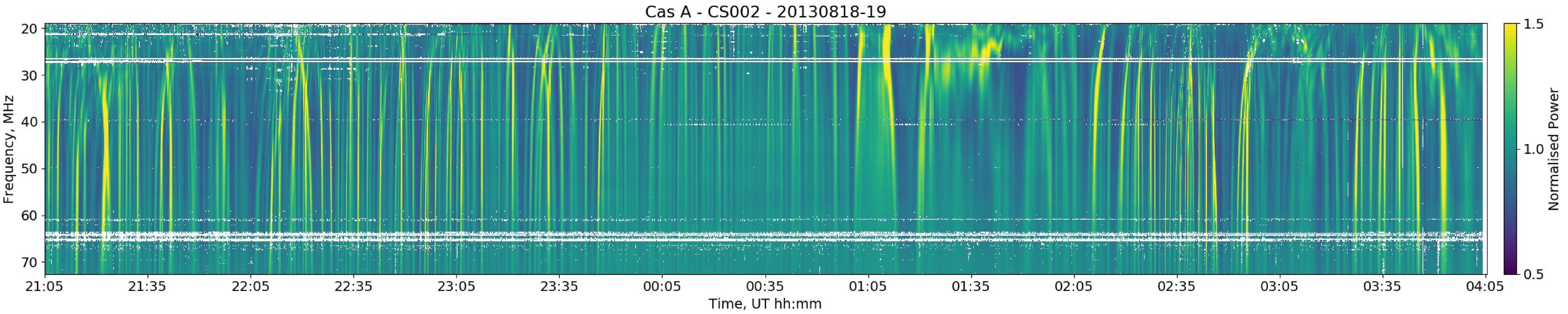
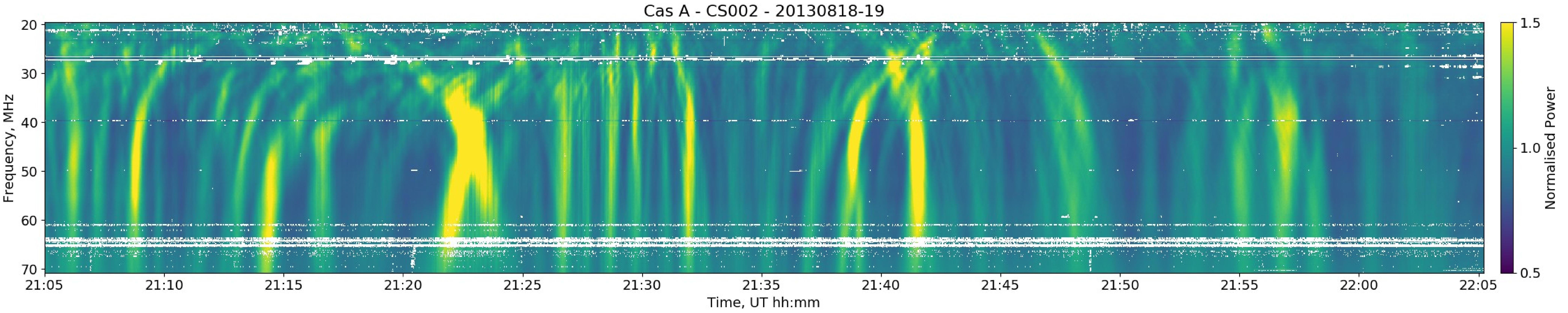
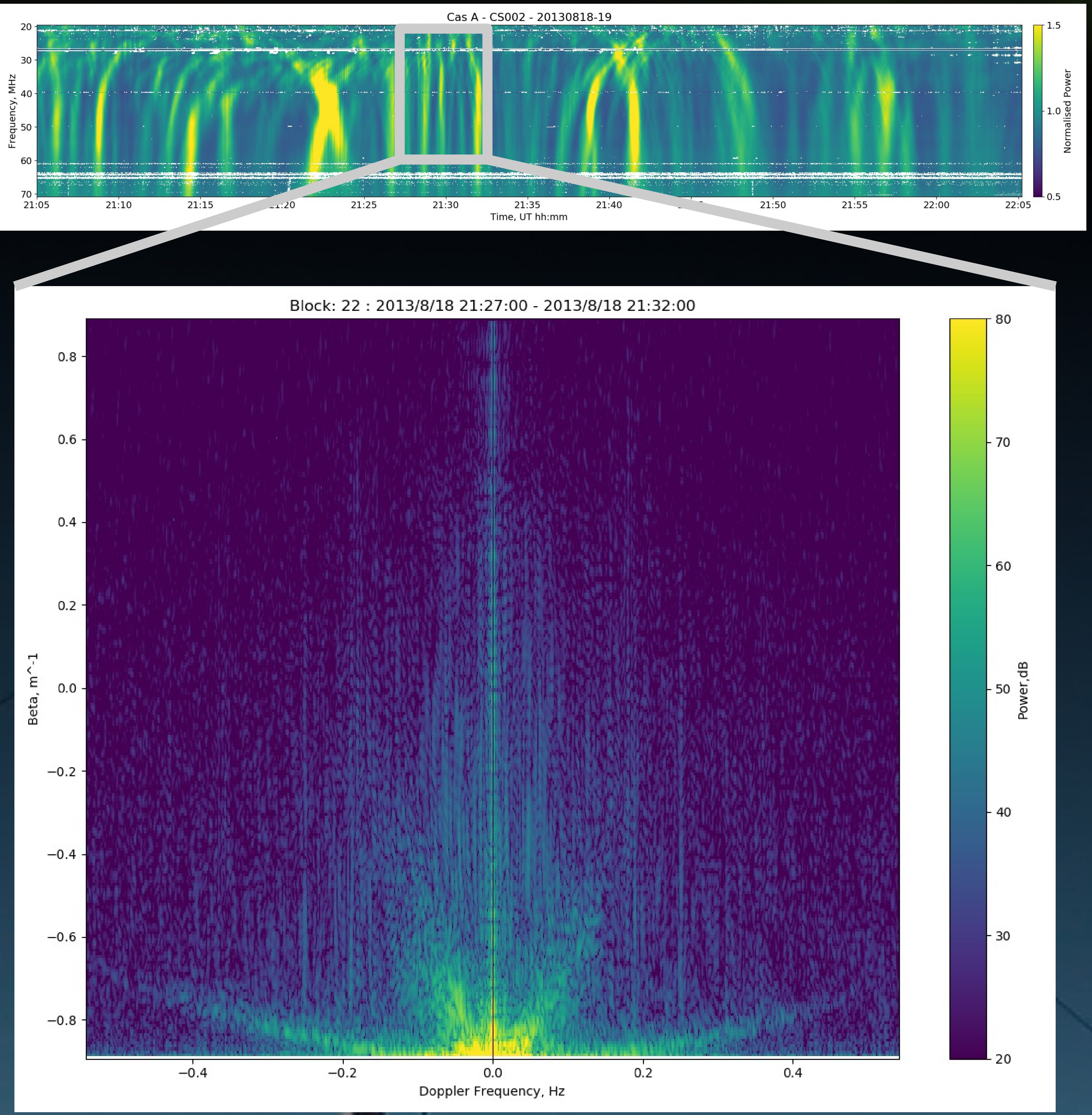
18th August 2013 – LOFAR Core – Cas A

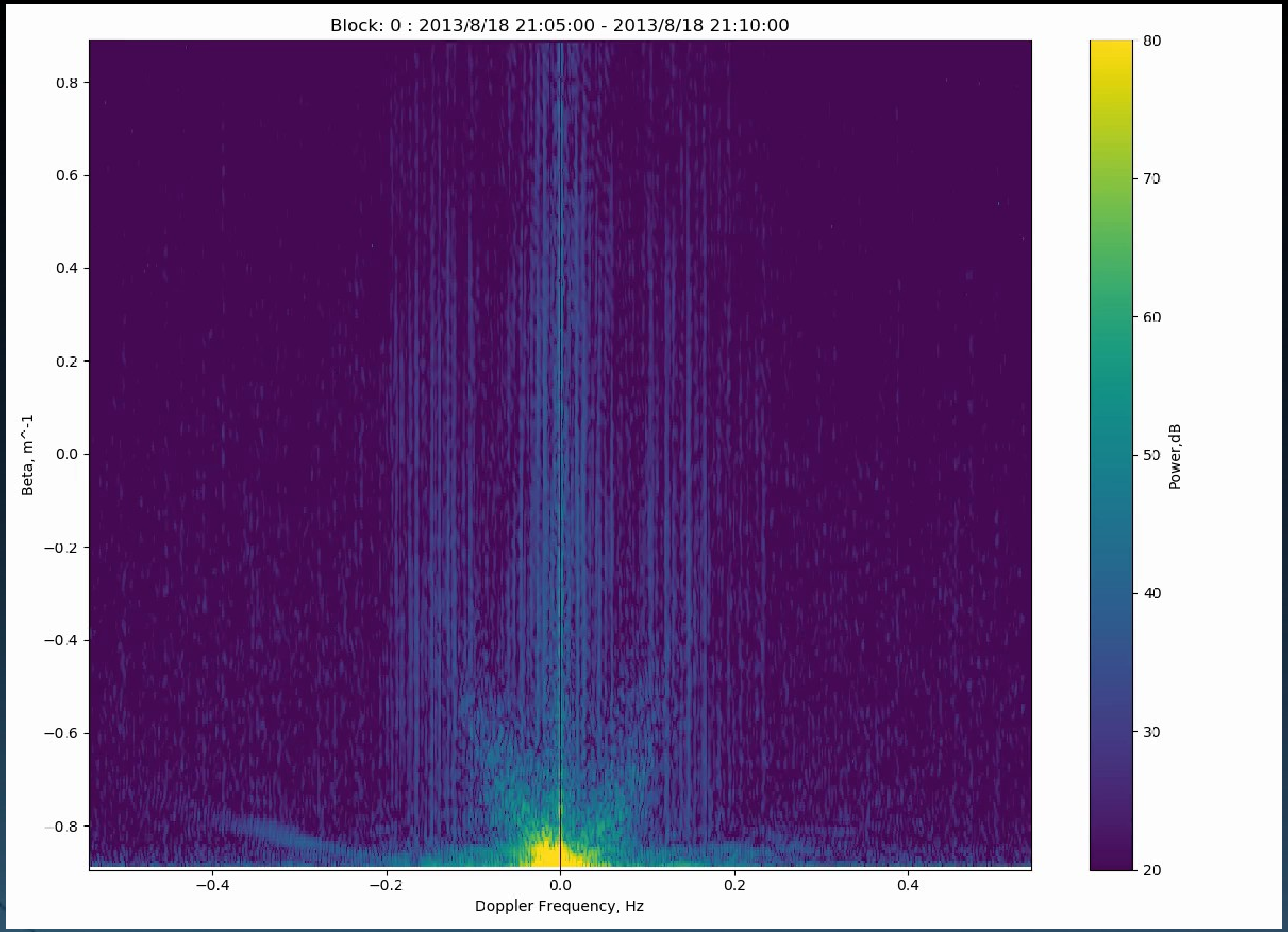




Fallows et al., in prep., 2019

18th August 2013 – LOFAR Core – Cas A





Fallows et al., in prep., 2019

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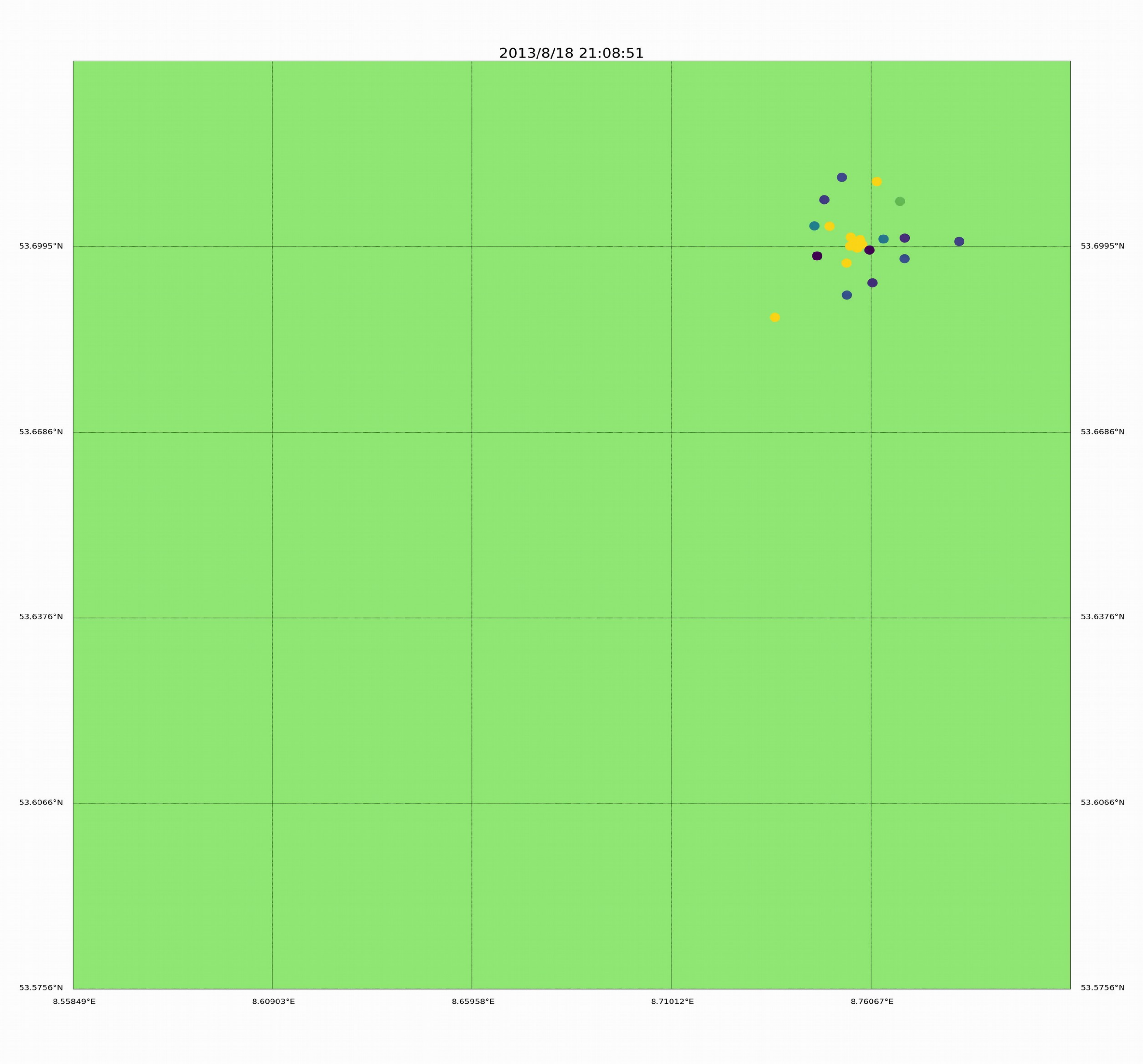
Looking Down Through the Ionosphere

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.



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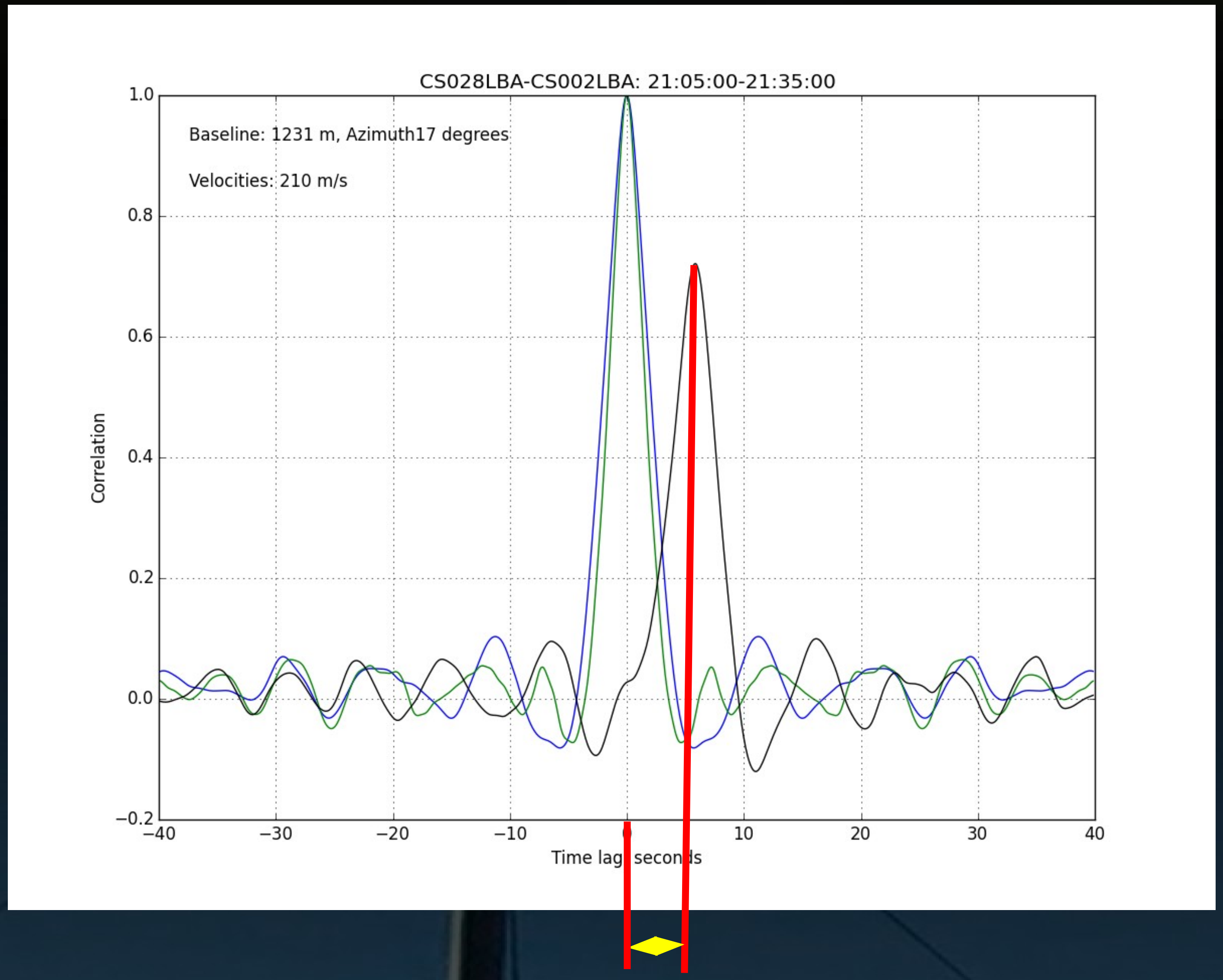
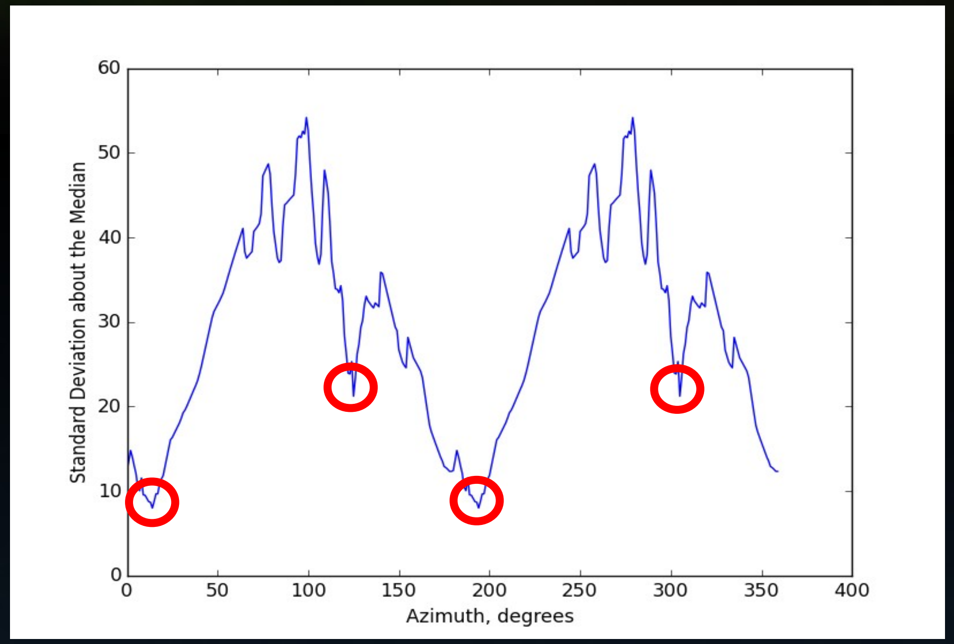
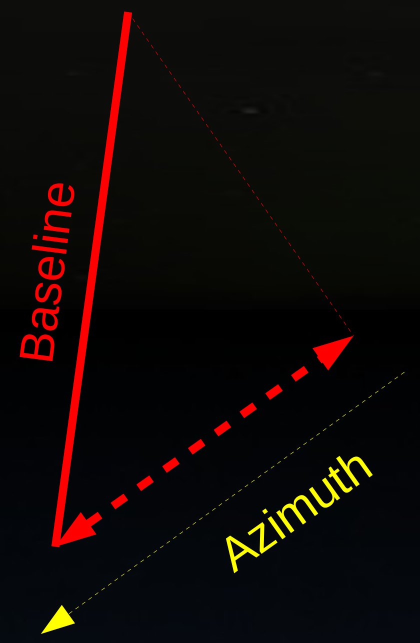
Estimating Velocity(s)



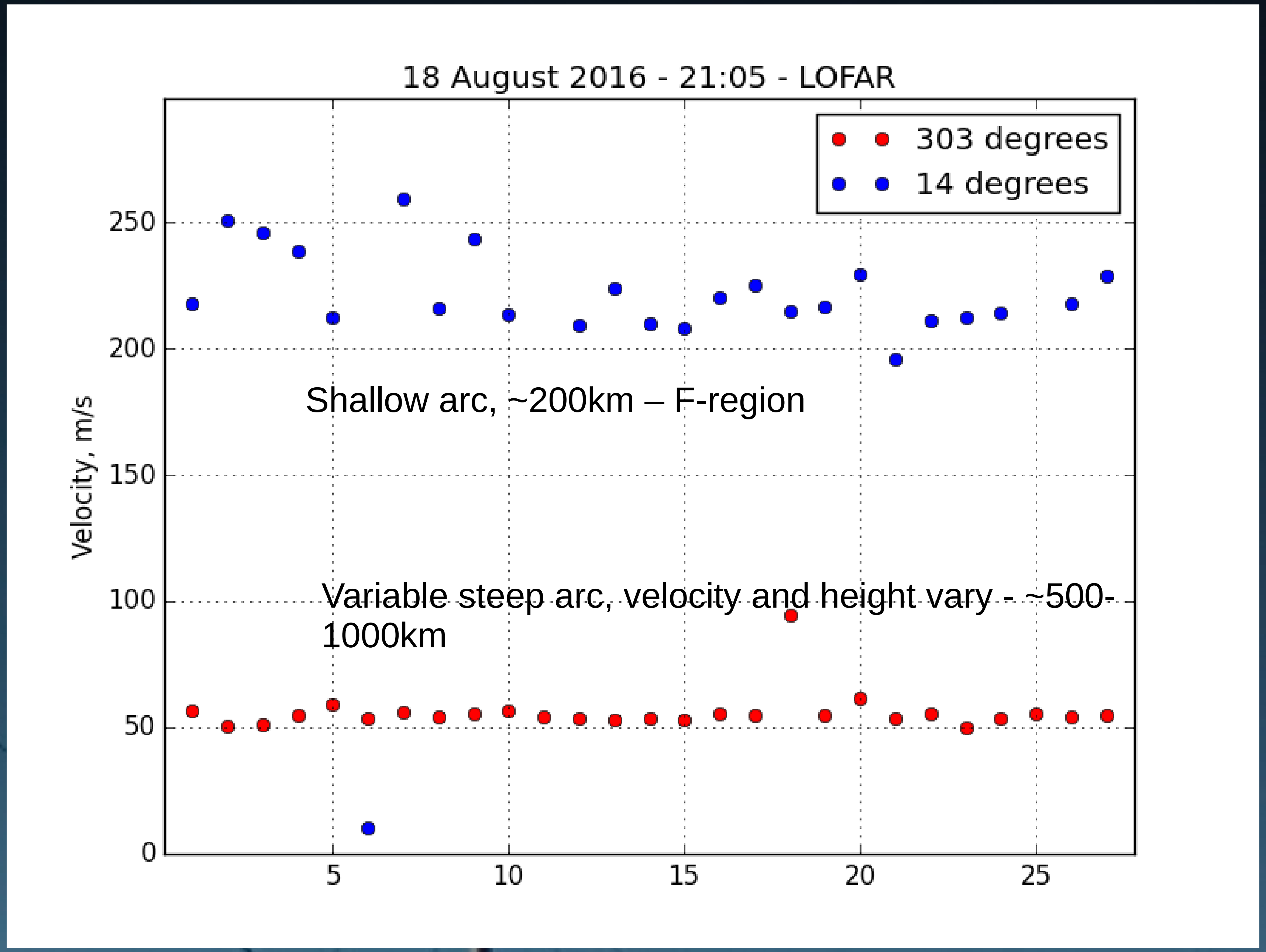
Cross-correlate time series' for every baseline in the core and find the time lags of the cross-correlation function peaks.



Calculate standard deviations of resulting velocities: Minima represent likely directions of ionospheric velocities.



For every azimuth, calculate velocities using component of the baseline aligned with the azimuth.



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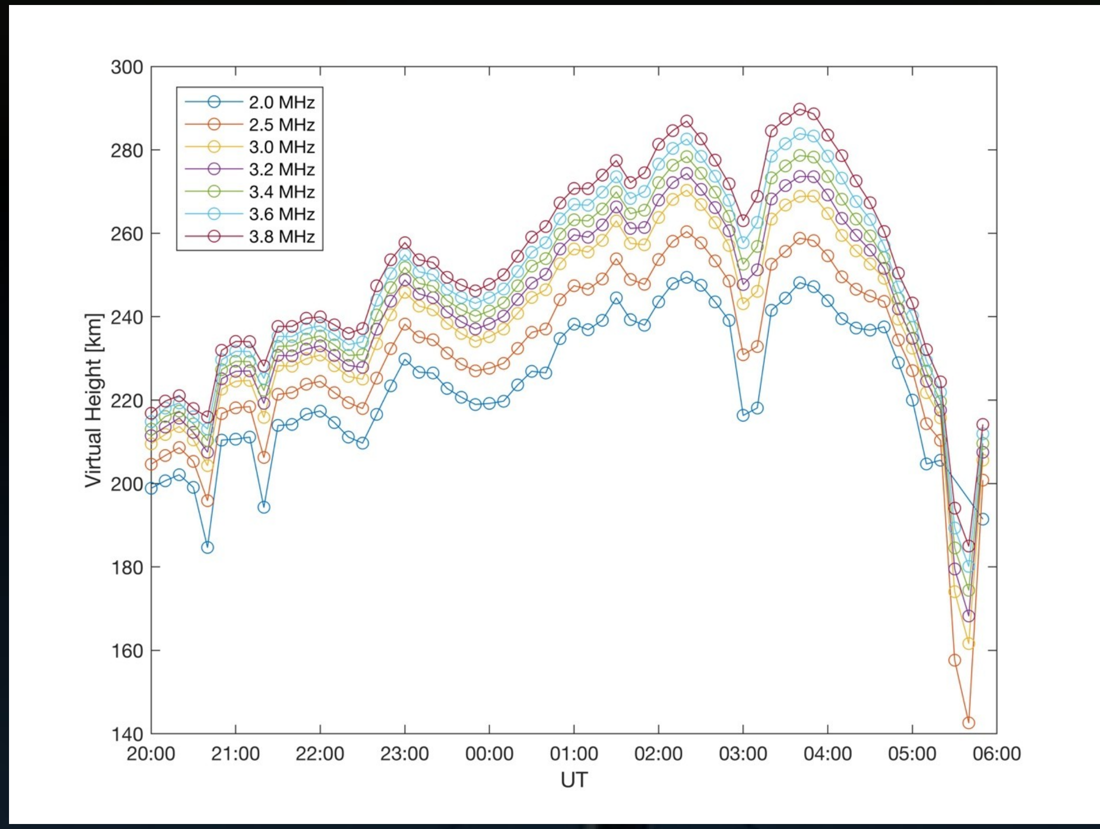
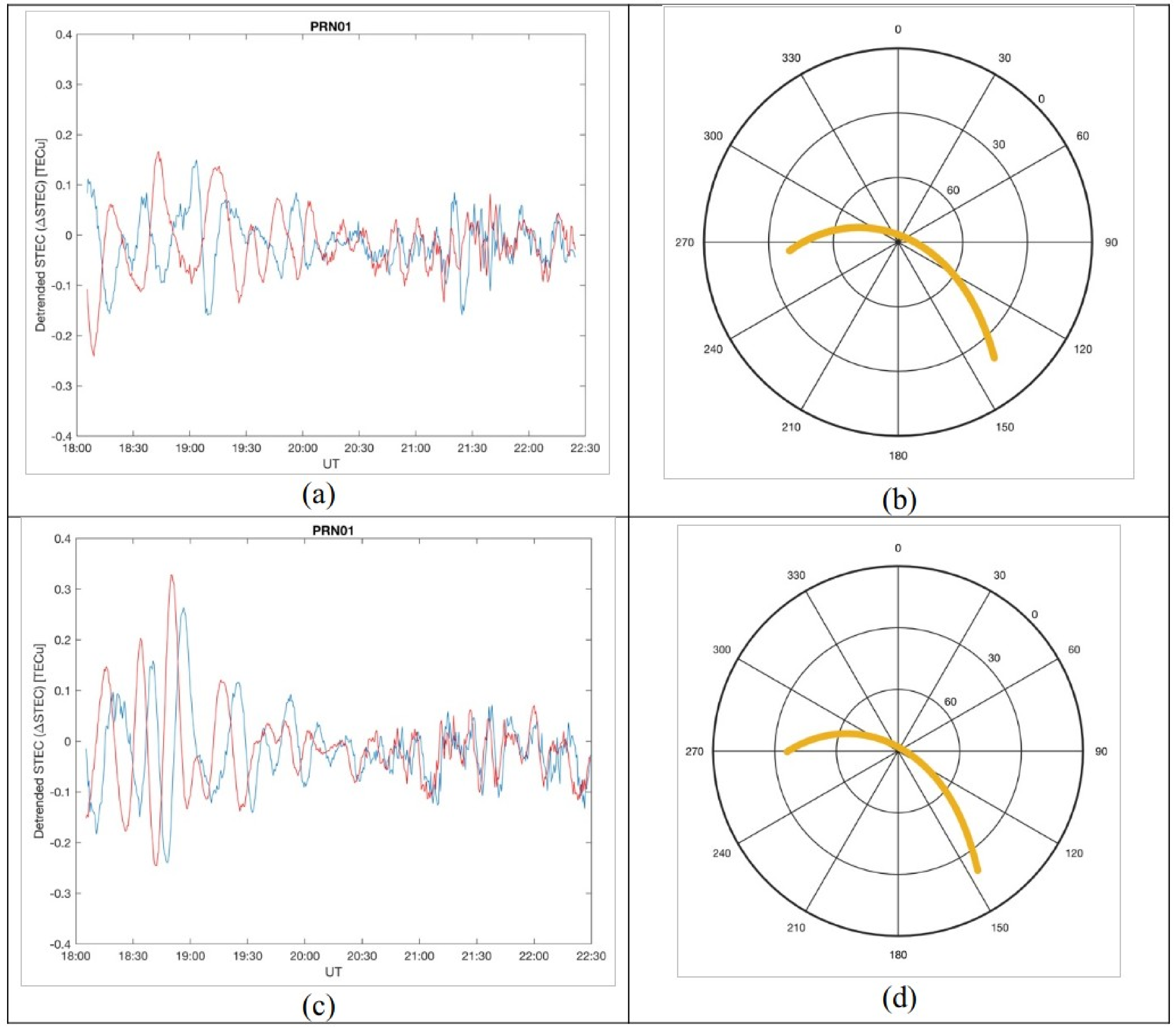
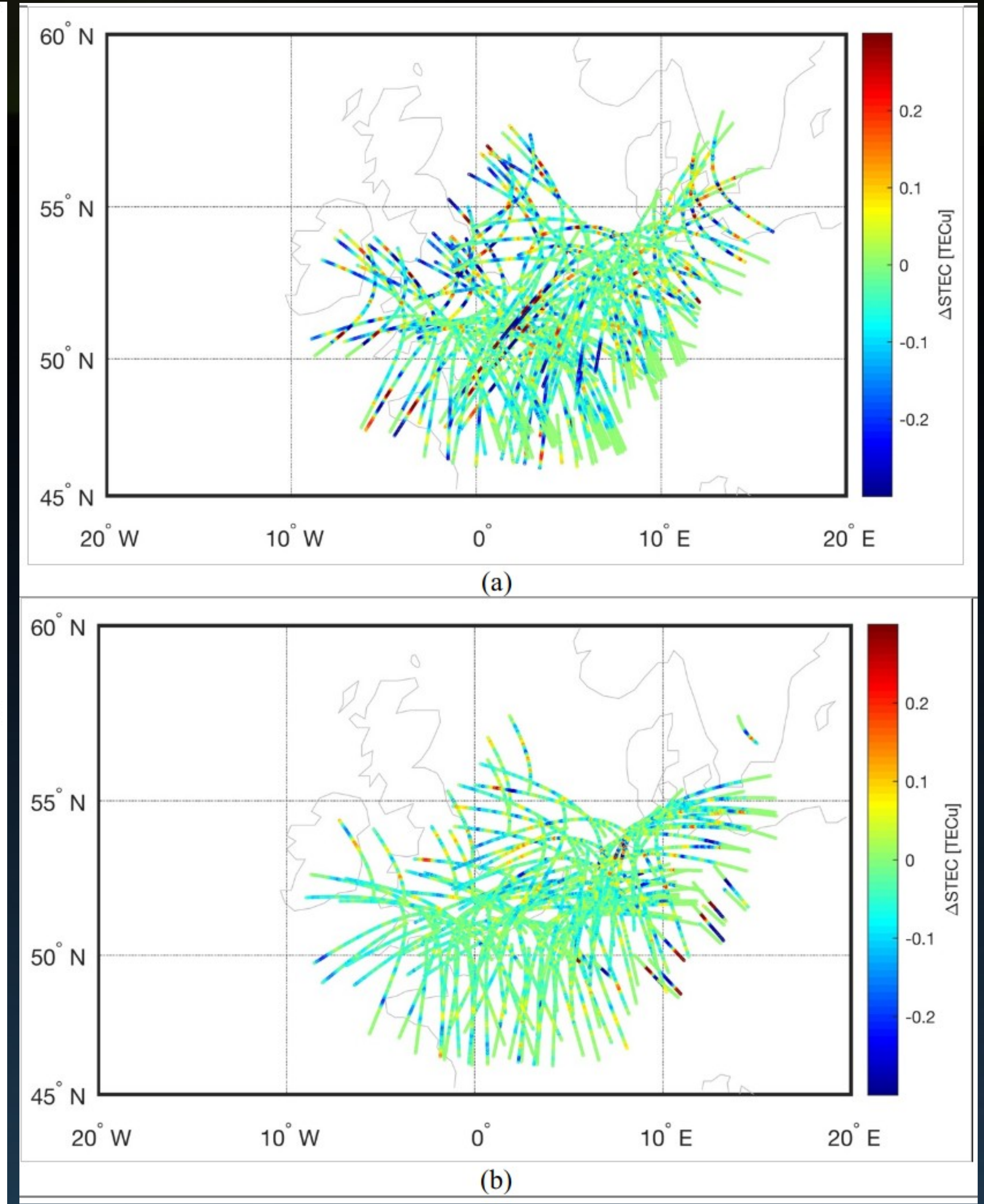
Supporting Data from Ionosonde and GNSS – 18-19 August 2013



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



Examples of satellite-station pairs. (a) 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; (b) azimuth/elevation plot for PRN01 as observed from Chilbolton. (c) PRN01 as observed on 18 August 2013 from Dentergem (DENT, blue line) and Bruxelles (BRUX, red line), both in Belgium, with baseline oriented from NW to SE; (b) azimuth/elevation plot for PRN01 as observed from Dentergem.



Geographical distribution of all TEC perturbations between 18:00-24:00 UT on 18 August 2013 (a) and 00:00-06:00 UT on 19 August 2013 (b).

Plots and details from Biagio Forte, Ivan Astin, Thomas Allbrook, Alexander Arnold, University of Bath

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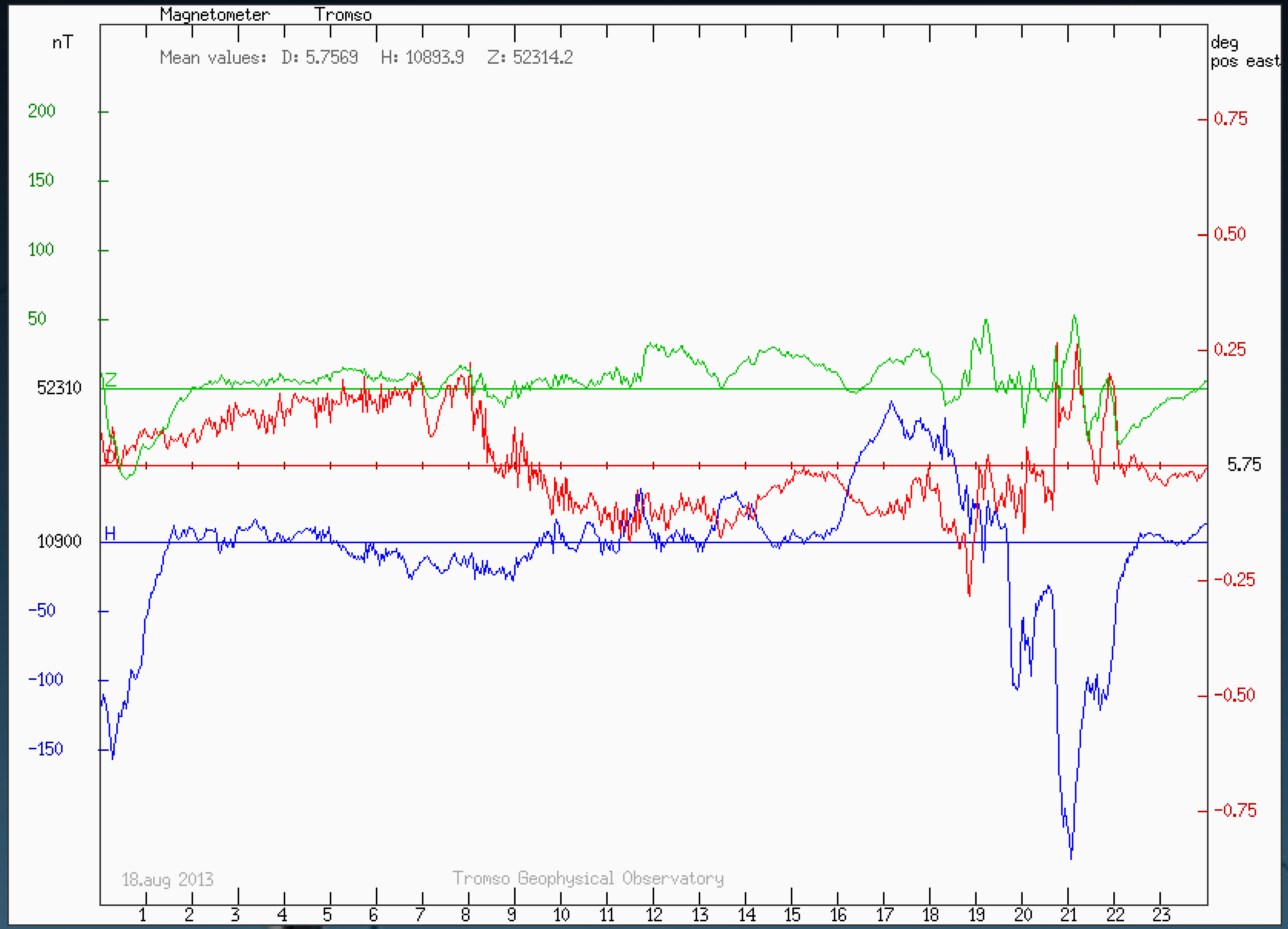
Supporting Data from Ionosonde and GNSS – 18-19 August 2013

The ionosonde and GNSS data indicate the presence of Medium-Scale Travelling Ionospheric Disturbances with components in a NW-SE direction and NE-SW direction. Two spatial scales are likely to be present at 100-200km and 20-40km. These TIDs would trigger instability mechanisms giving rise to the scintillation seen.



Magnetometer data indicate that there was a minor geomagnetic substorm immediately prior to the start of the LOFAR observation, probably triggered by a high-speed solar wind stream. This may well be the source of the TIDs seen.

Broadband dynamic spectra show structure in the scintillation pattern which would be invisible to single-frequency time series measurements.

This should enable much-more comprehensive modelling of scintillation to be carried out, especially in the ionosphere where supporting data can be obtained from a wide range of instrumentation. However, the task remains complex and knowledge of radio source structure is likely needed in addition to density structure in the line of sight to fully model the scintillation pattern.