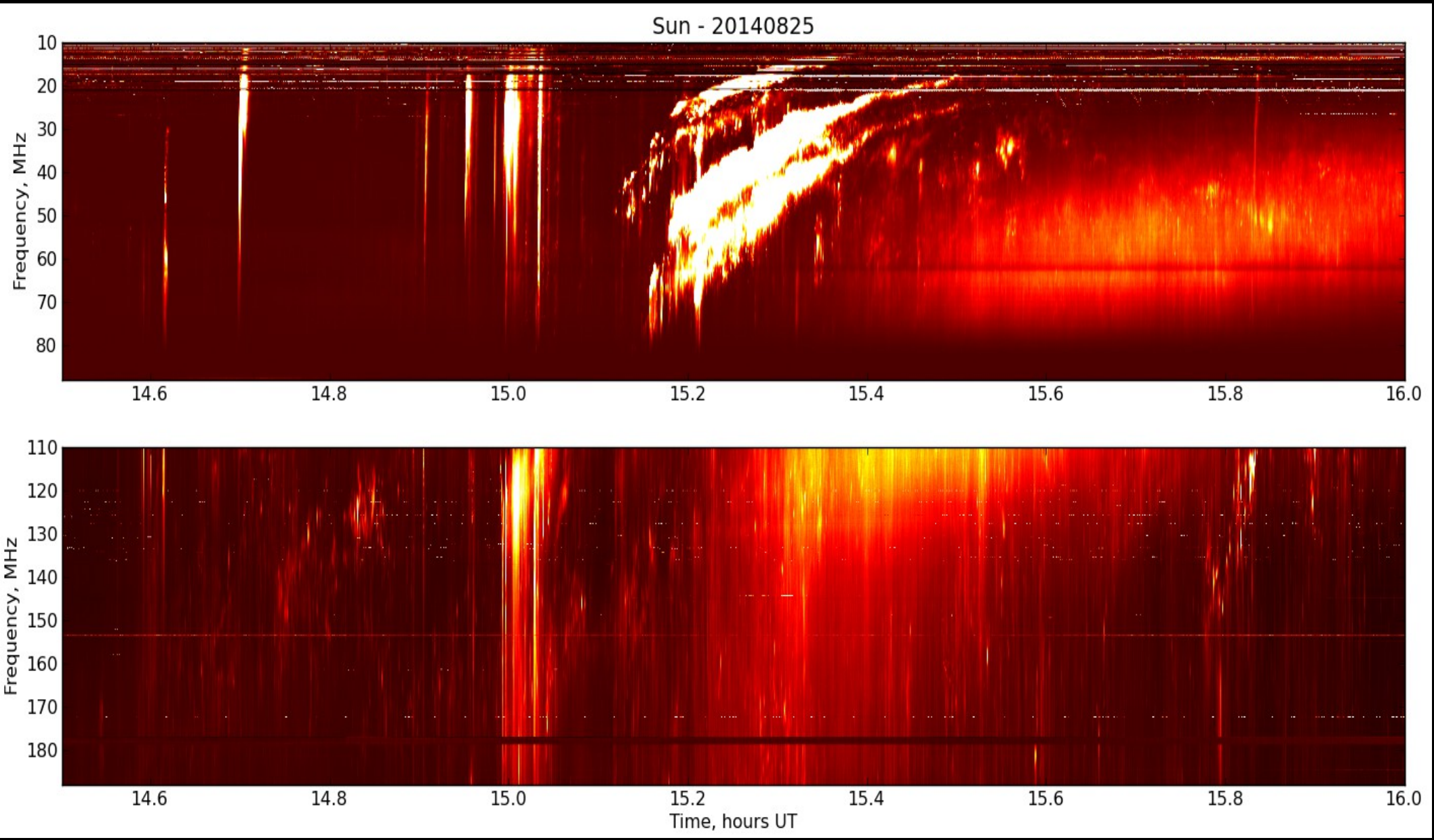
ASTRON

Netherlands Institute for Radio Astronomy

From the Sun to the Earth: Observing Space Weather with LOFAR

Richard Fallows
ASTRON

Wide bandwidth solar spectrum



Ground-based Observations: Using Radio-Wave Propagation Effects

LOFAR
ASTRON

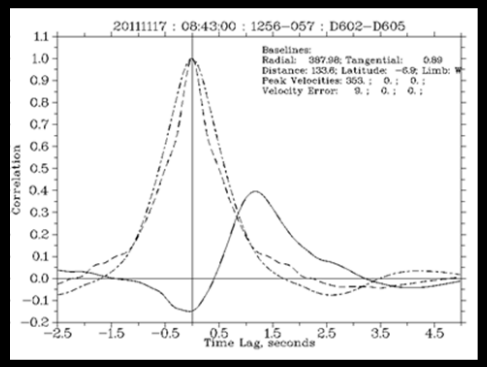
Interplanetary magnetic field

Faraday Rotation from polarised source

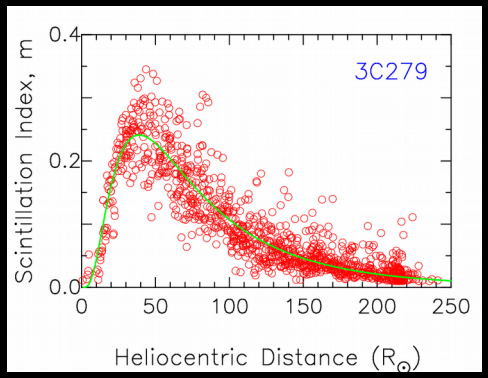
Interplanetary Scintillation from compact source

Solar wind density and velocity

Ionospheric scintillation



Cross-correlation of time series -> velocity

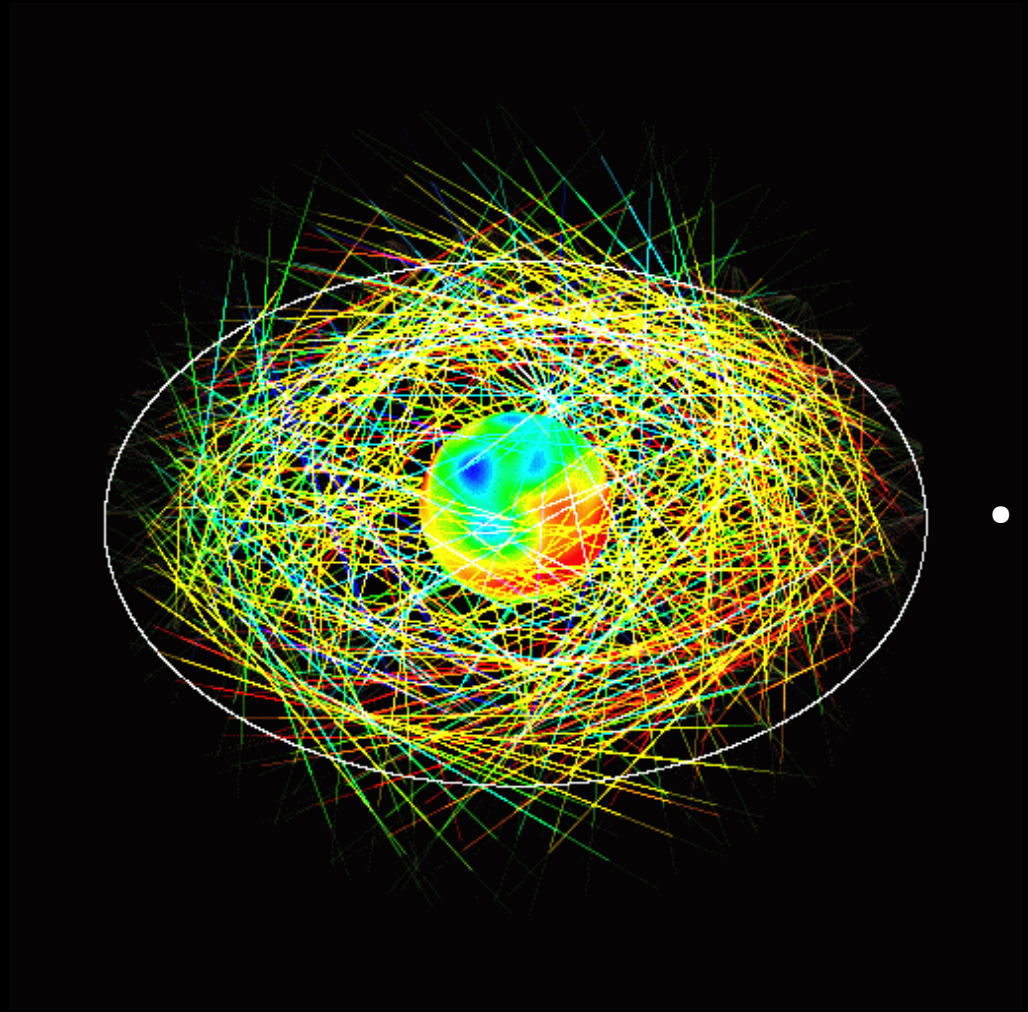


Variation in amount of scintillation -> density

The solar wind:

Getting a 3-D view of solar wind speed throughout the inner heliosphere

“Imaging” the Solar Wind with Tomography



- Many observations taken over a whole solar rotation results, in the Sun's frame of reference, in many overlapping lines of sight between antennas and radio sources.
- Tomographic inversion techniques used to create images of the solar wind in both scintillation-level (proxy for density) and solar wind speed.

Stations worldwide are necessary to continually monitor the solar wind.

Current dedicated observatories exist in India, Japan, Mexico and Russia. The European longitudes of LOFAR provide useful additional coverage.

Most are transit instruments, limiting the number of possible observations per day.

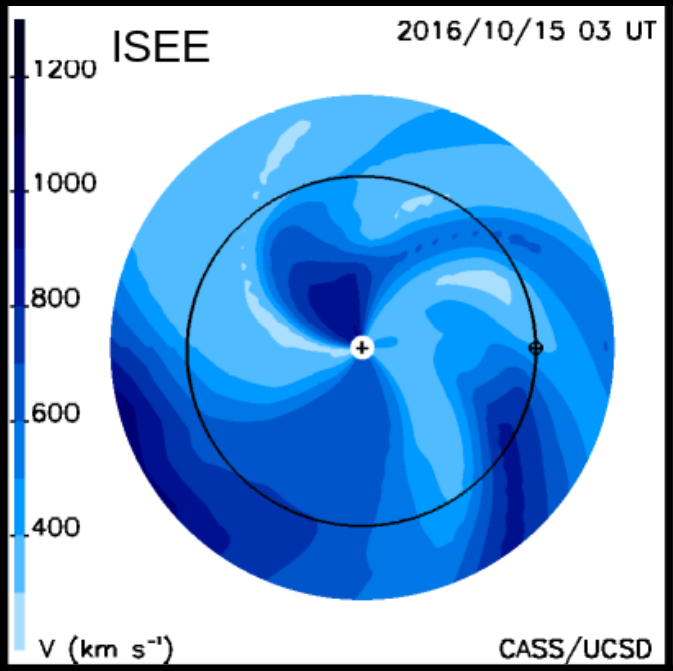
A trial campaign took place in October 2016 involving LOFAR, the MWA, and observatories worldwide to demonstrate what could be achieved.

All current dedicated observatories are single-frequency and only Japan is multi-site. This limits the physics which can be studied.

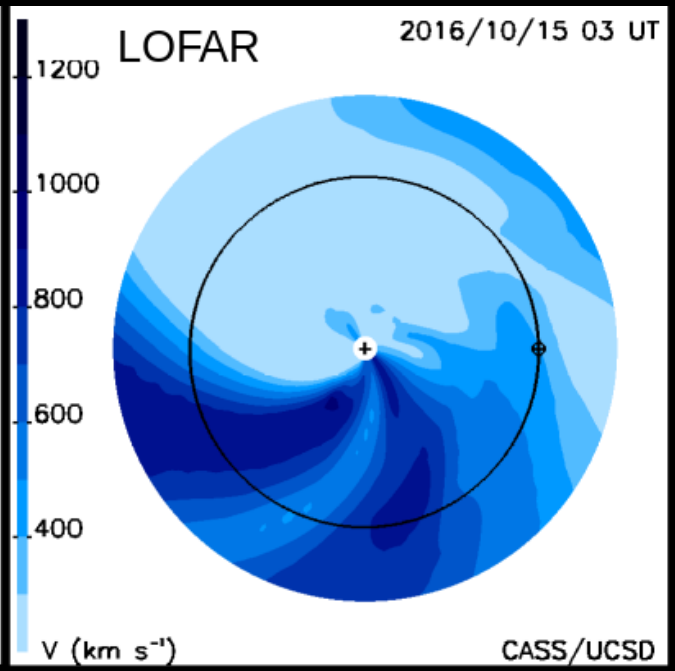
With the wide bandwidth and geographical coverage of LOFAR, we can compare the different methods of analysis currently in use and try analyses which are not possible with any dedicated instruments.

Tomographic Reconstruction of Solar Wind Velocity: October 2016

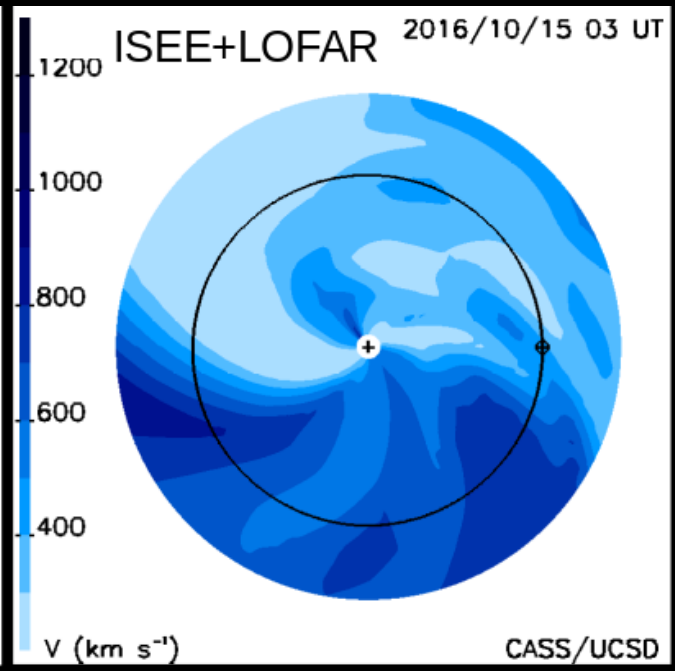
Japan



LOFAR



Combined

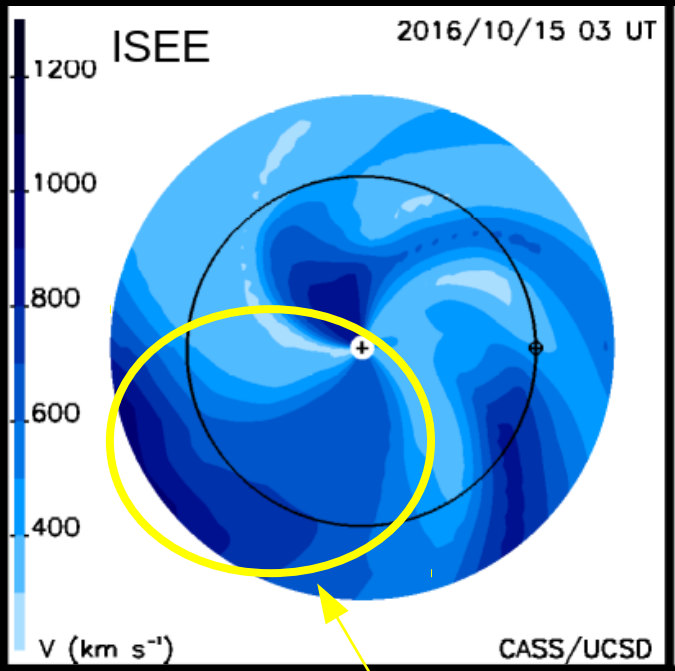


Reconstructions look good, but some key differences between ISEE and LOFAR, most likely due to spatial and temporal coverage of observations of IPS. All results **preliminary**.

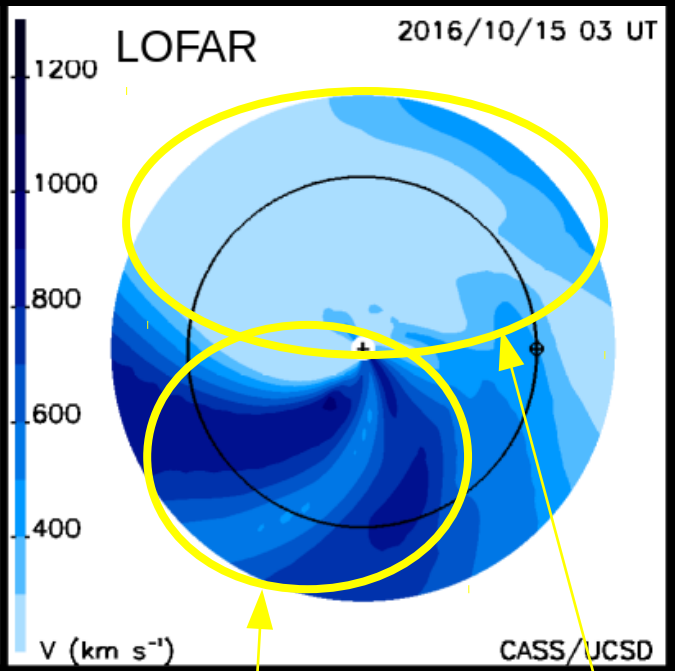
Reconstructions courtesy Bernie Jackson (UCSD) and Mario Bisi (RAL)

Tomographic Reconstruction of Solar Wind Velocity: October 2016

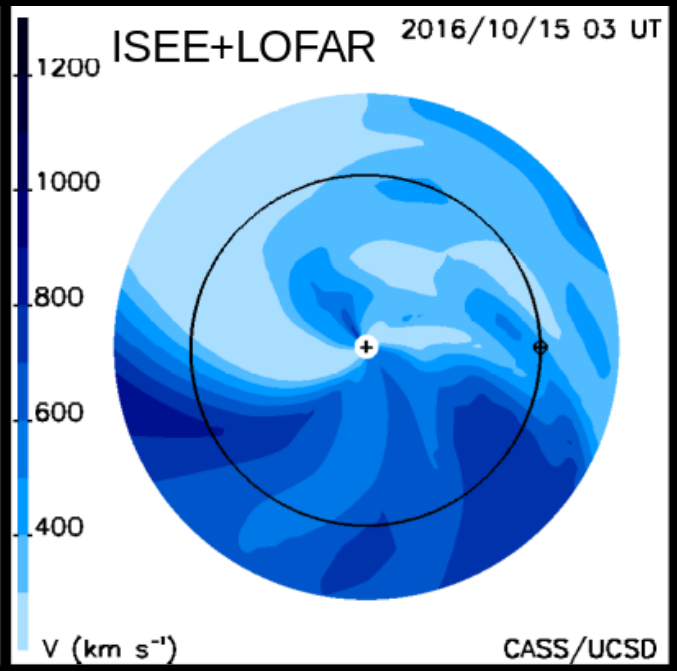
Japan



LOFAR



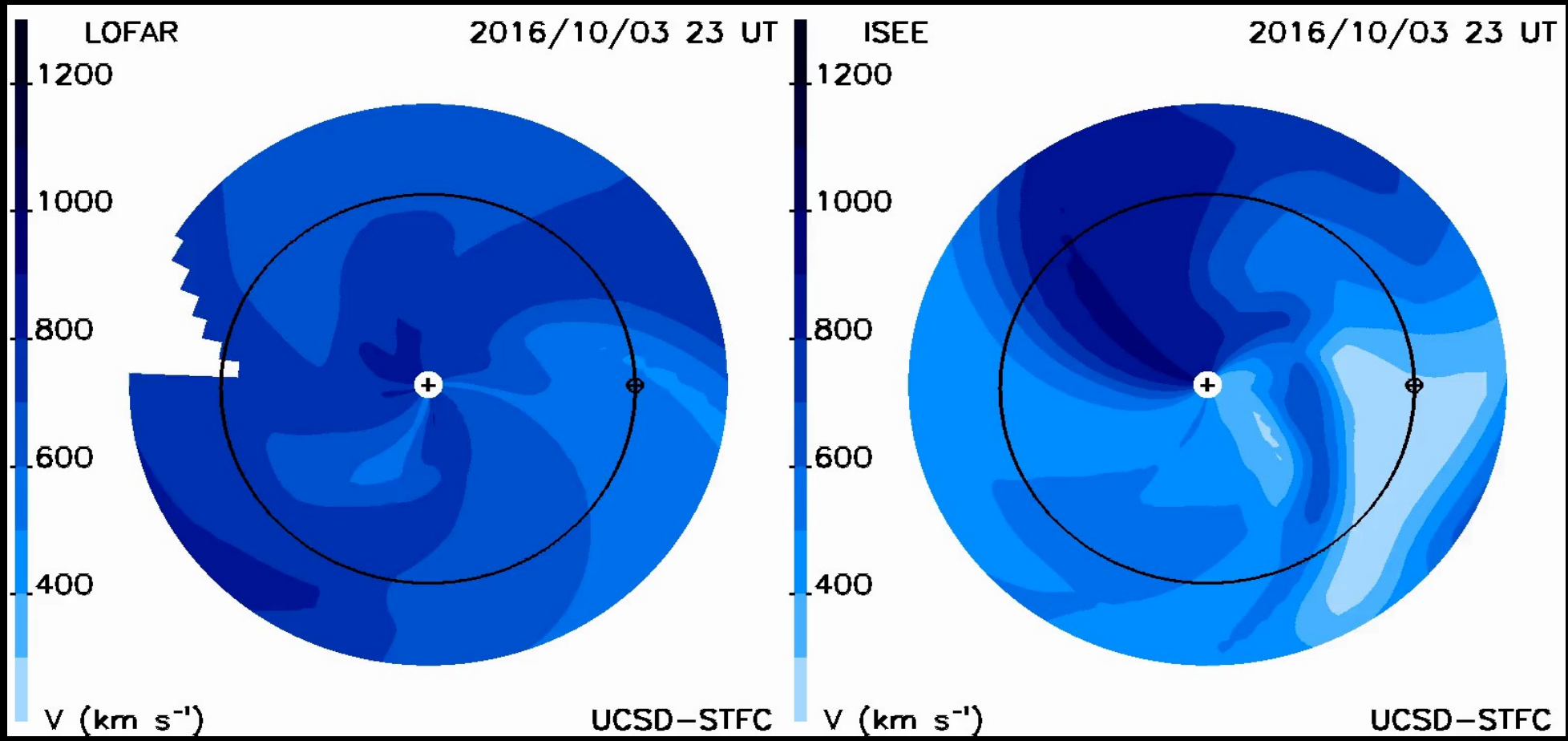
Combined



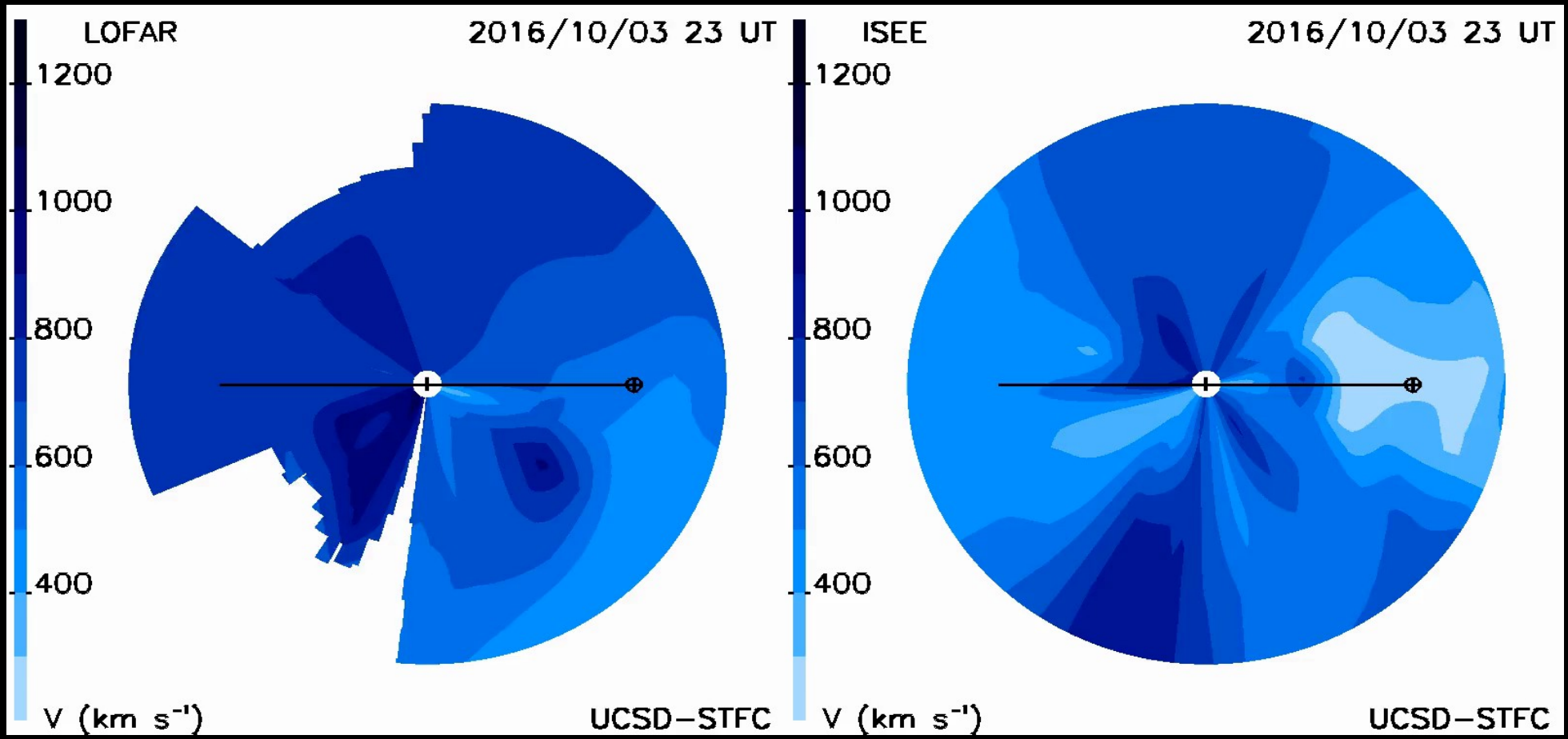
ISEE sees single, broad fast stream, where LOFAR resolves two.

No source coverage with LOFAR due to system issues.

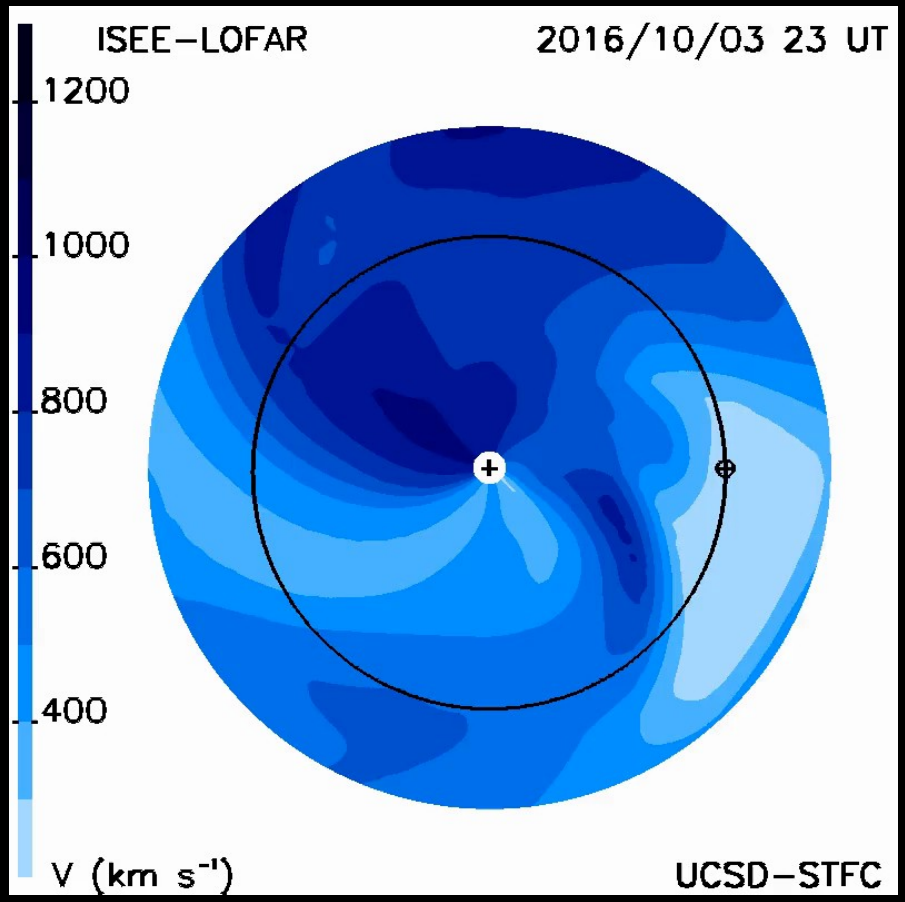
Solar Wind Velocity in the Ecliptic Plane



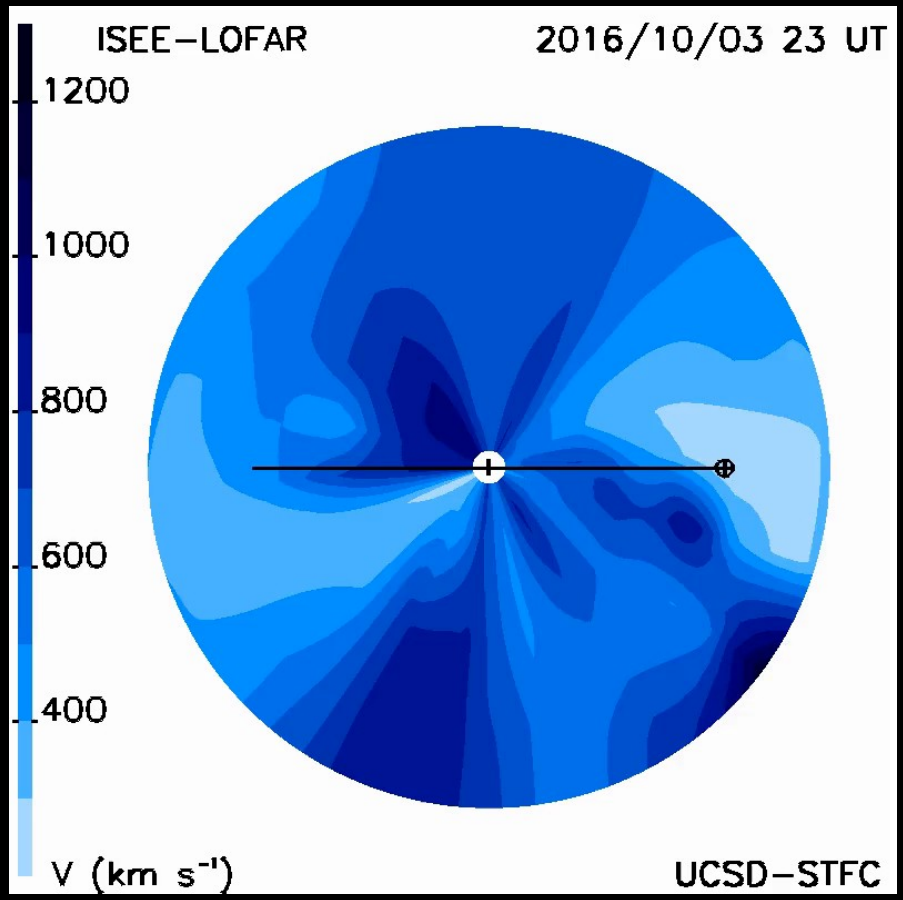
Solar Wind Velocity in the Meridional Plane: Sky View



Combined View



Ecliptic plane



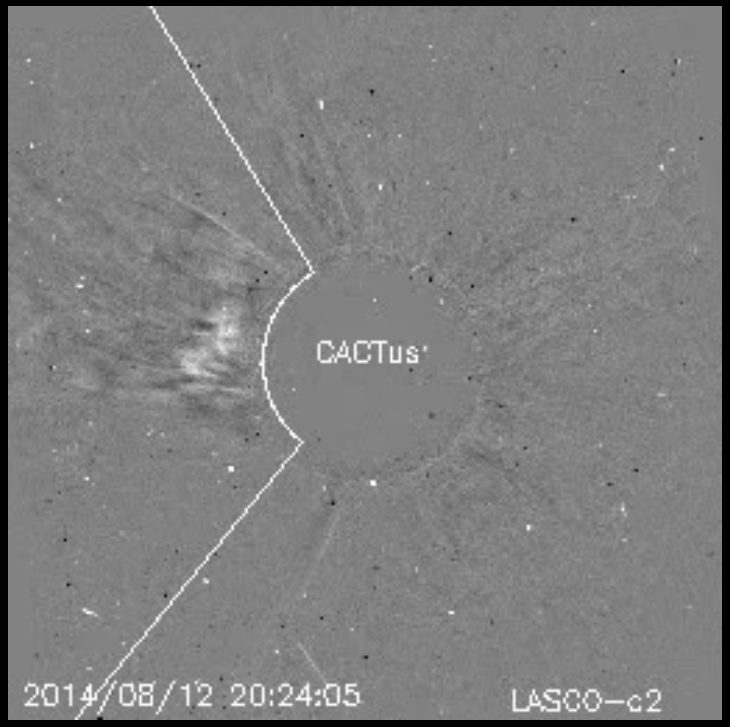
Meridional plane

Coronal Mass Ejections:

Searching for the “holy grail” of space weather, measurement of the interplanetary magnetic field

CME 12th August 2014: Attempt at Faraday Rotation Measurement

PSR J1022+1001
Elongation: 13 degs
Latitude: -1.8 degs

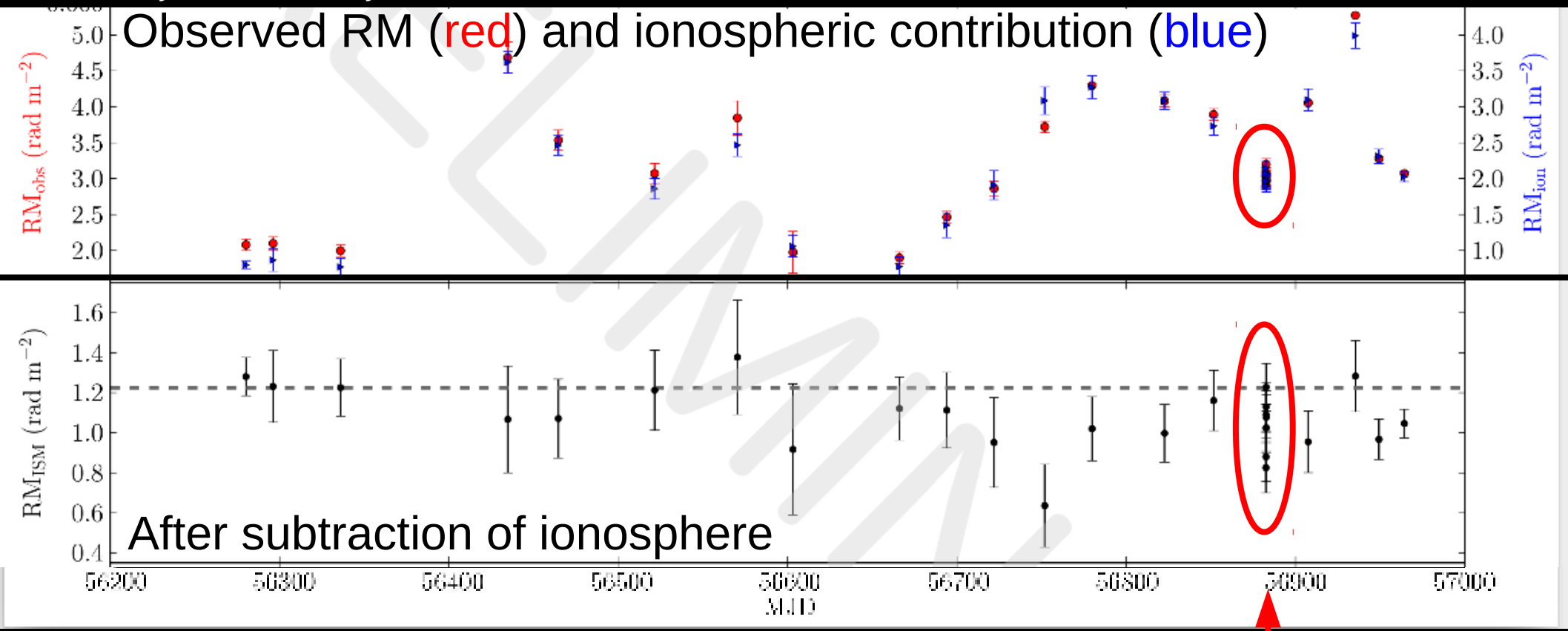


Pulsar observed in ten-minute chunks from 13:00 to 16:30 UT on 13th August 2014

Not to scale...

Interstellar Medium Variations

Plot courtesy Charlotte Sobey

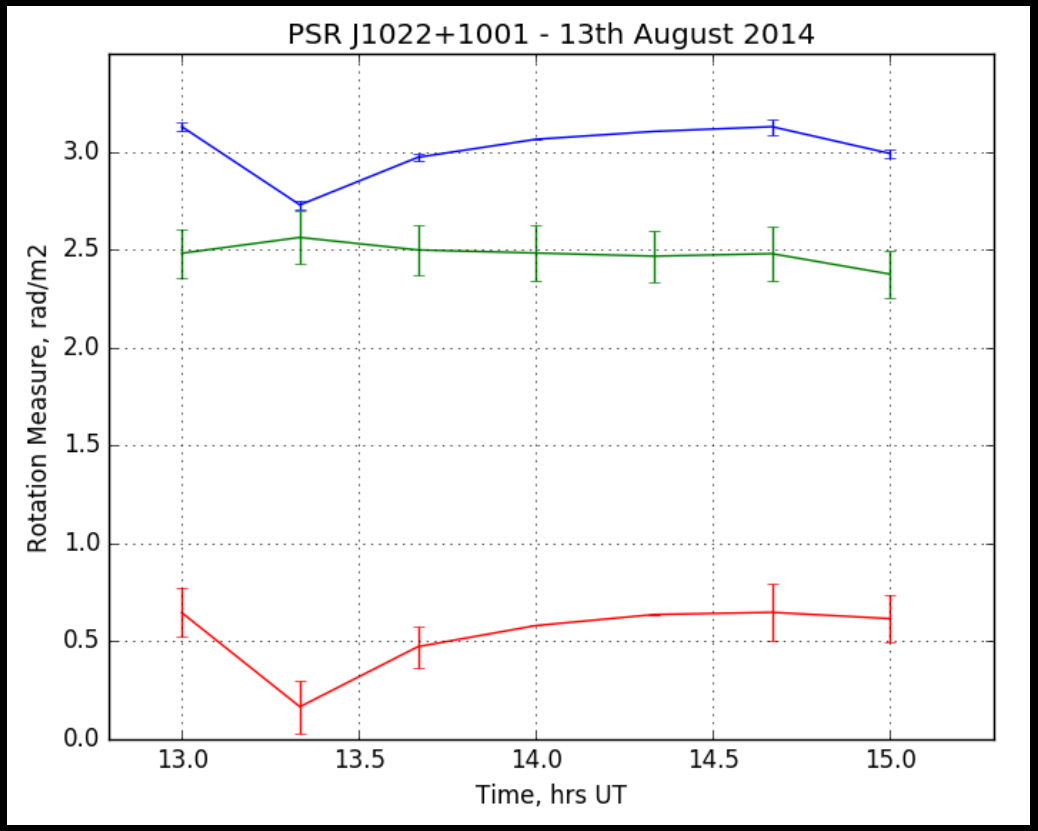


800 days

Day of interest

Ionospheric contribution estimated using Total Electron Content (TEC) maps produced from GPS satellite data.

RM Calculations – Current Estimates



Measured RM (ISM subtracted)

Calculated Ionospheric RM

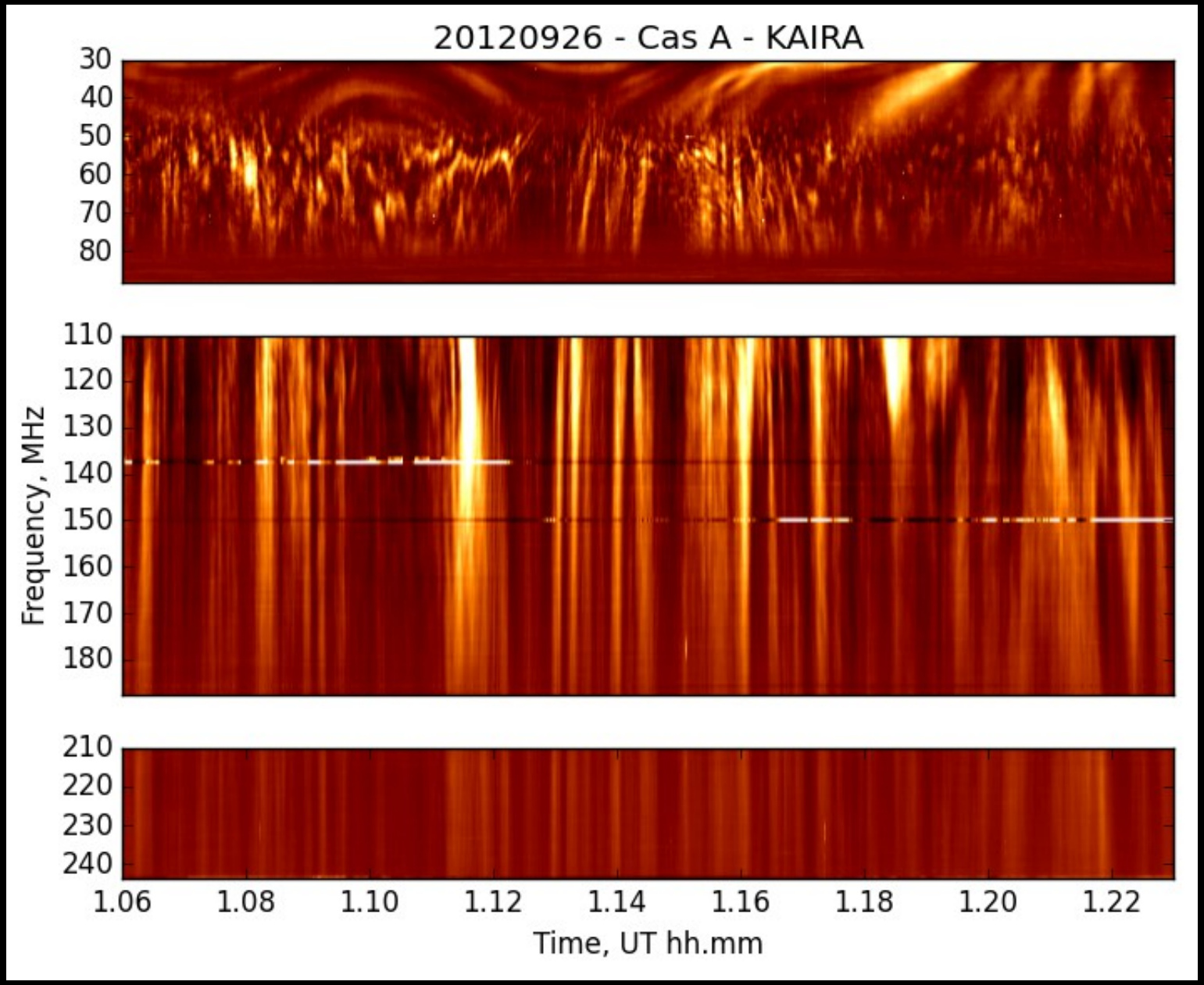
RM difference

Modelling and number checking efforts underway indicate that the resulting difference in RM, assumed to be due to the heliosphere, is in the ballpark for that expected from the passage of this CME.

The mid-latitude ionosphere:

Quiet and uninteresting? Think again.

Wide Bandwidth: a full view of scintillation

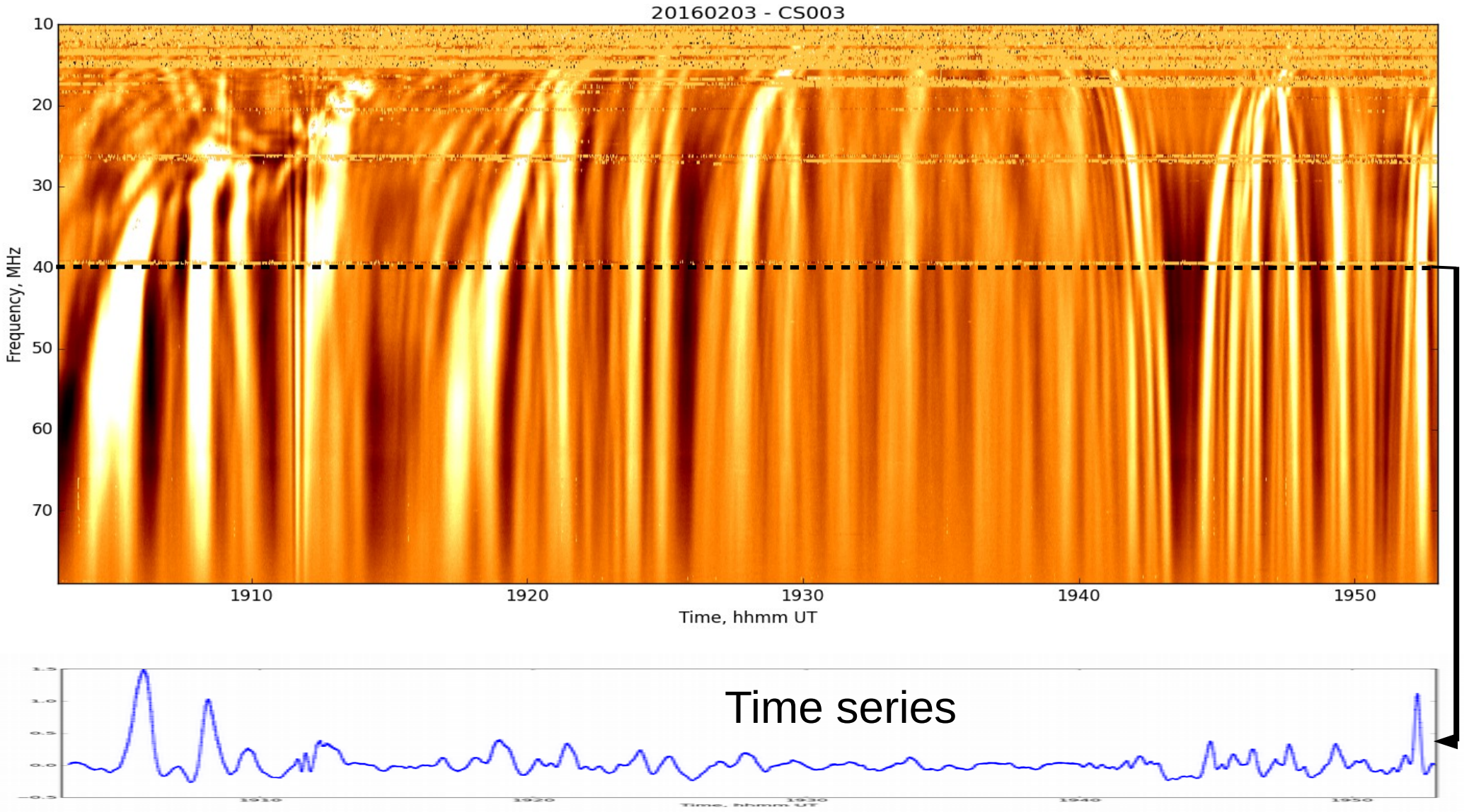


Refraction

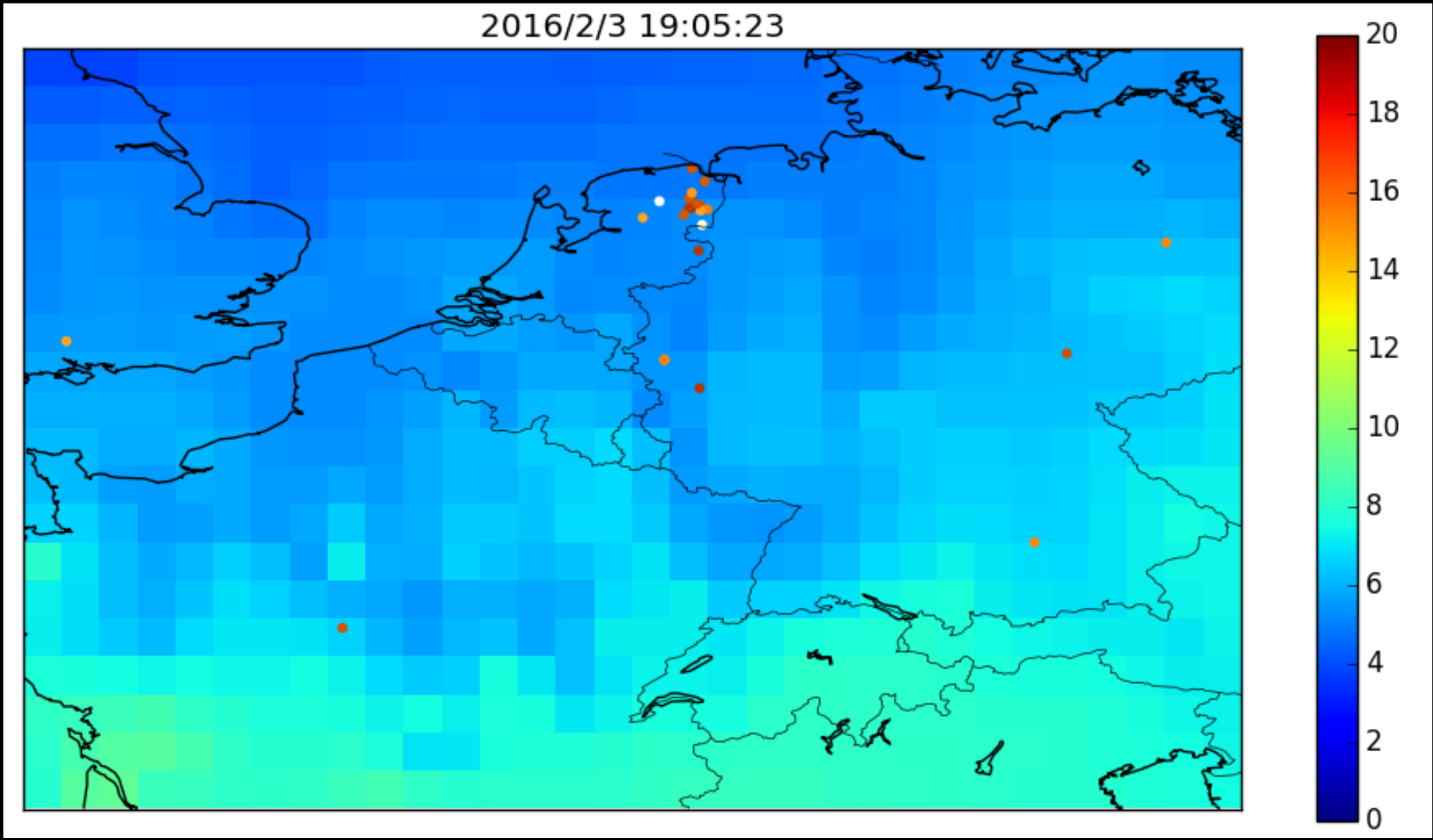
"Strong" scattering

"Weak" scattering

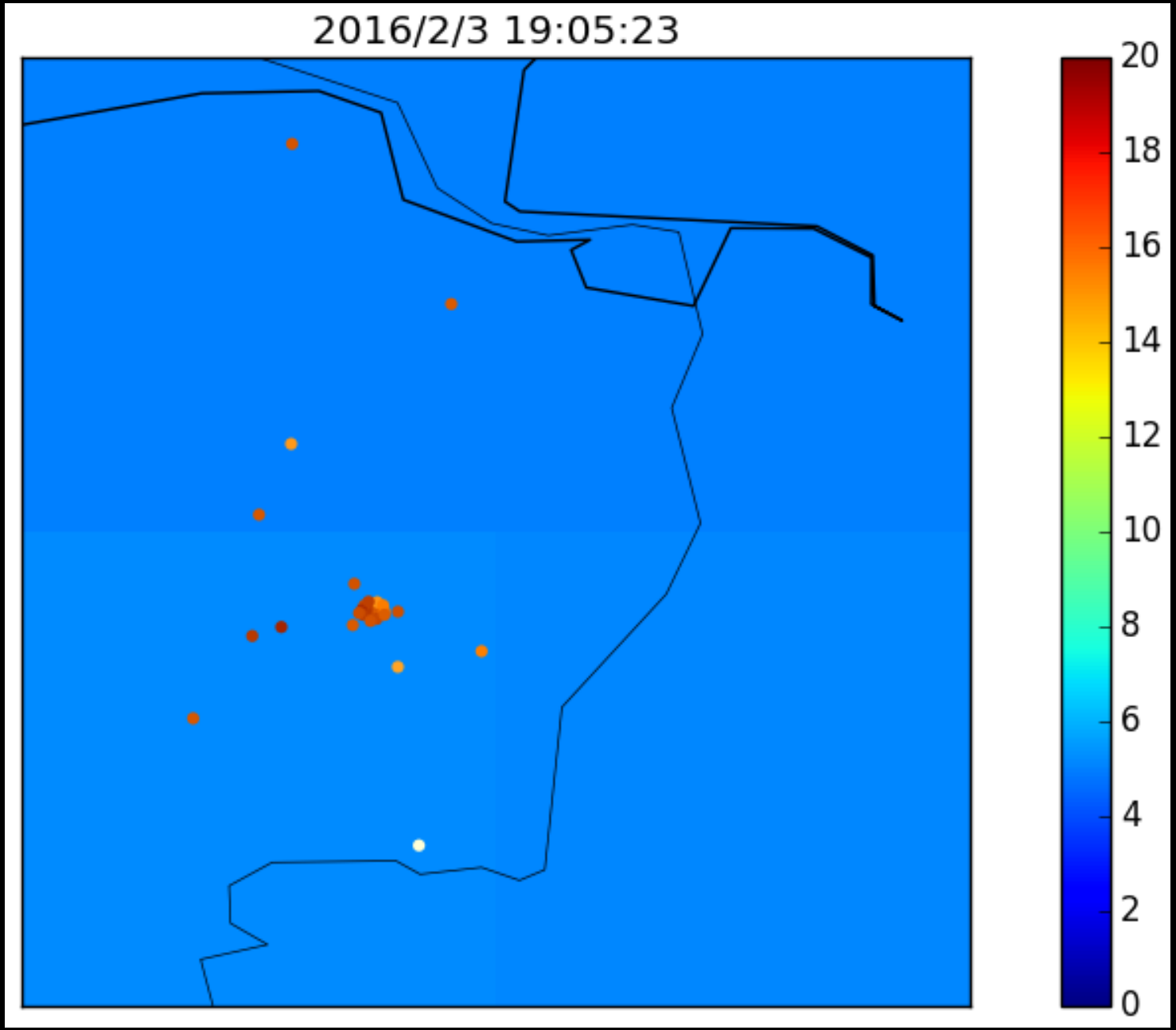
Ionospheric Scintillation on Cas A: An average night above LOFAR



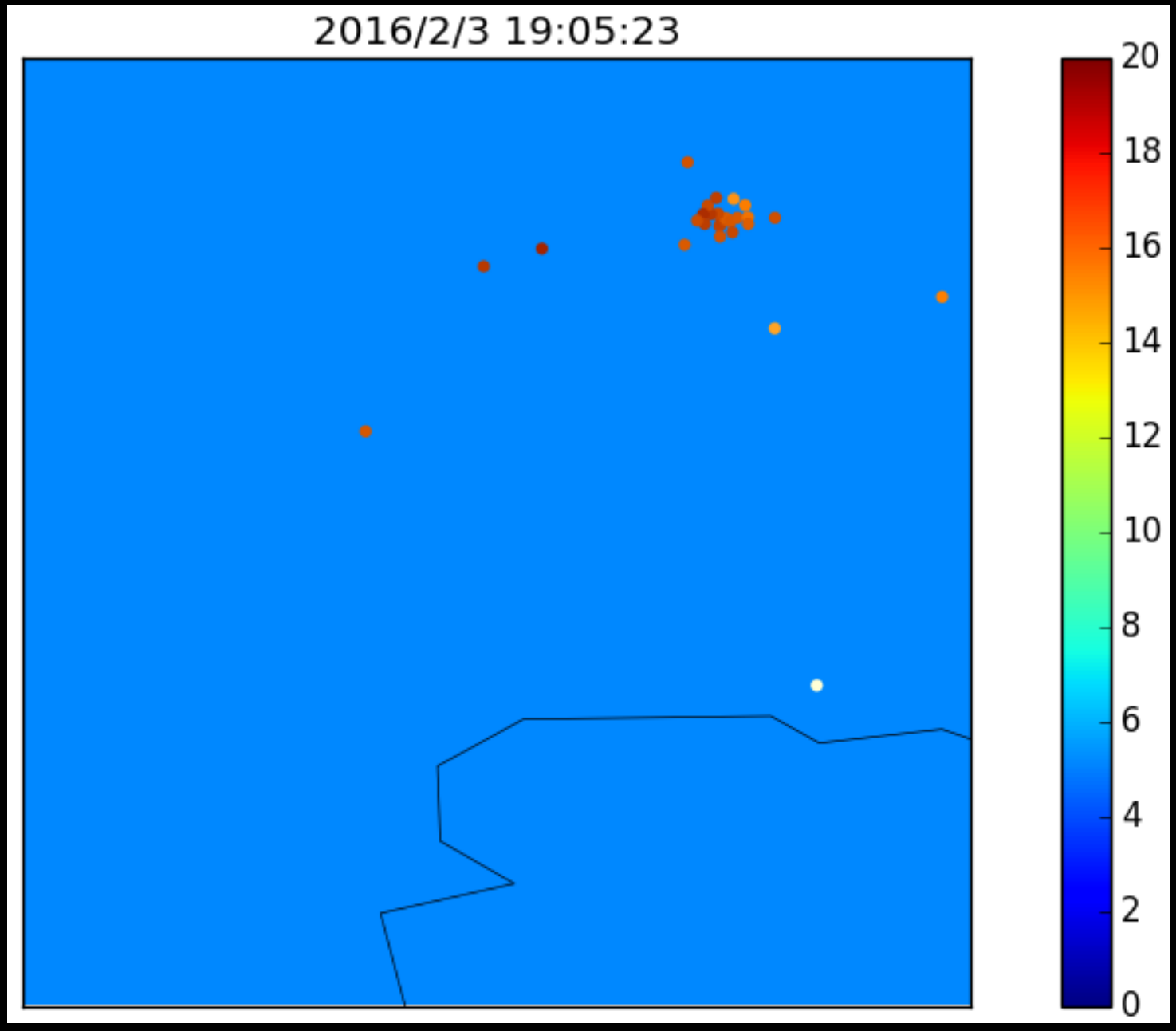
Looking down through the ionosphere



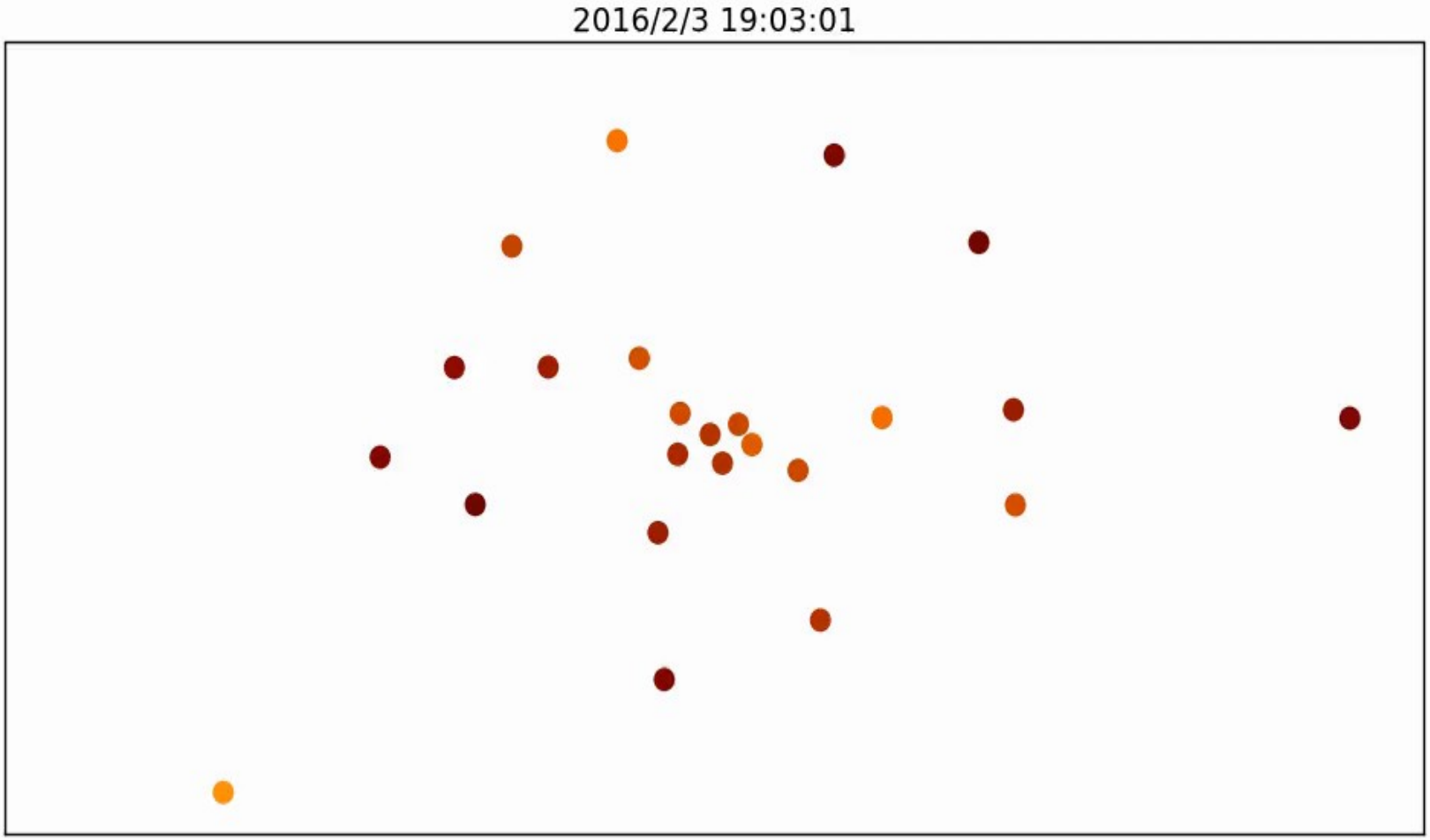
Zooming in: 4 TEC pixels



Zooming in: 1 TEC pixel



Zooming in: LOFAR core



This is only a brief snapshot of the space weather science being undertaken with LOFAR, and only a tantalising glimpse into the advances that can be made with the new generation of radio telescopes.