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Netherlands Institute for Radio Astronomy

Demonstration of Space Weather Monitoring with LOFAR

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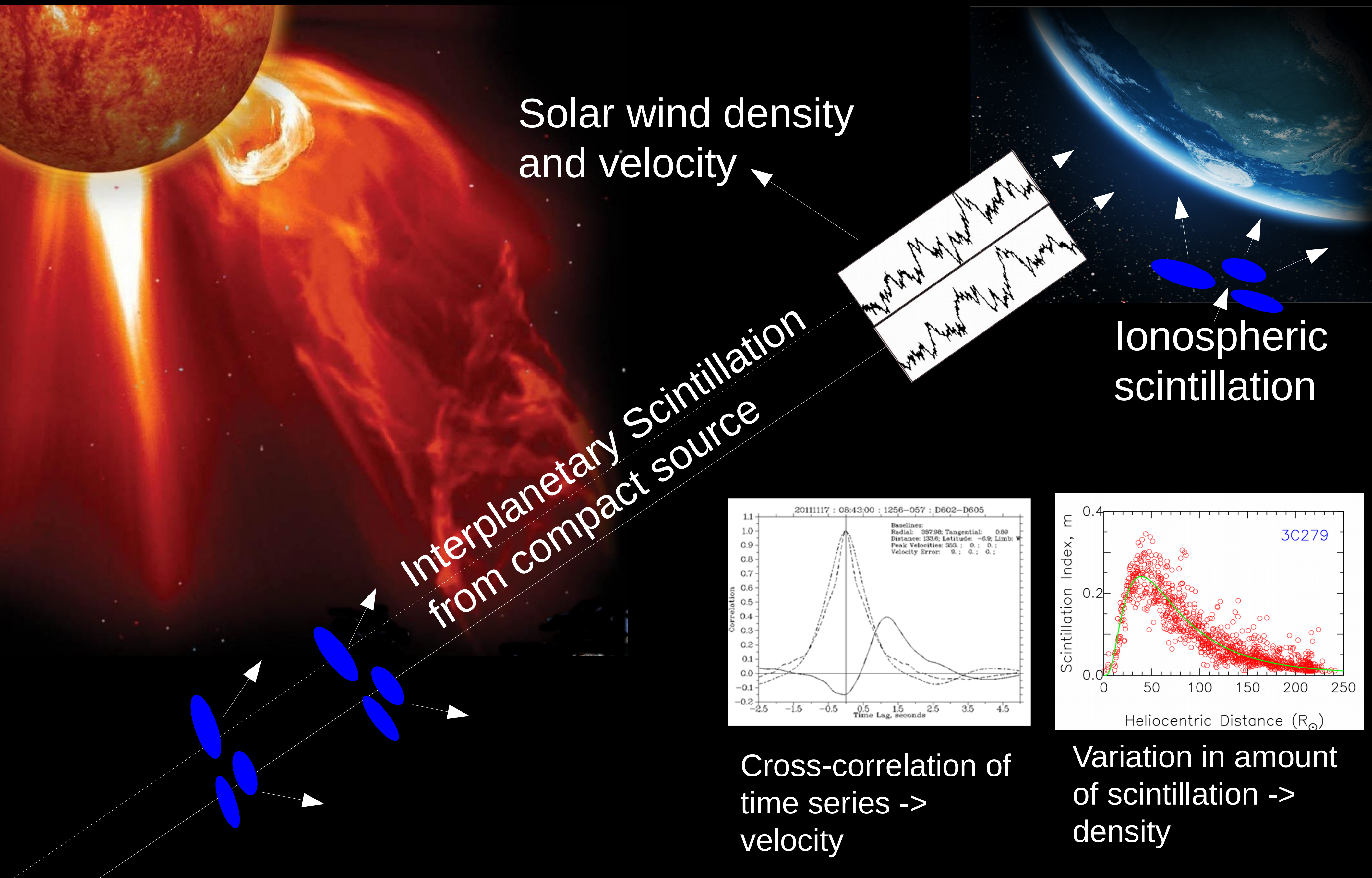
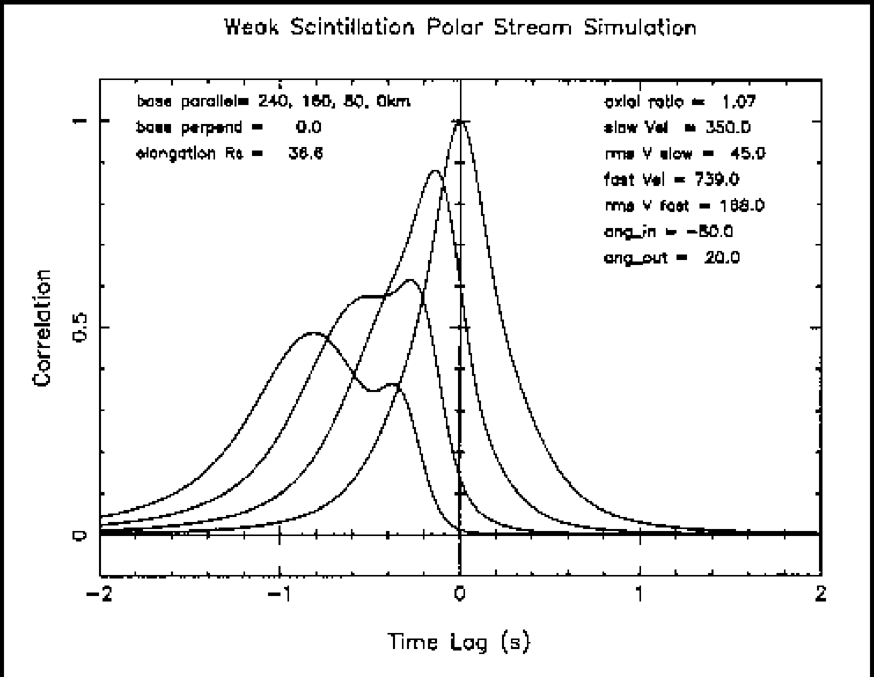
Interplanetary Scintillation

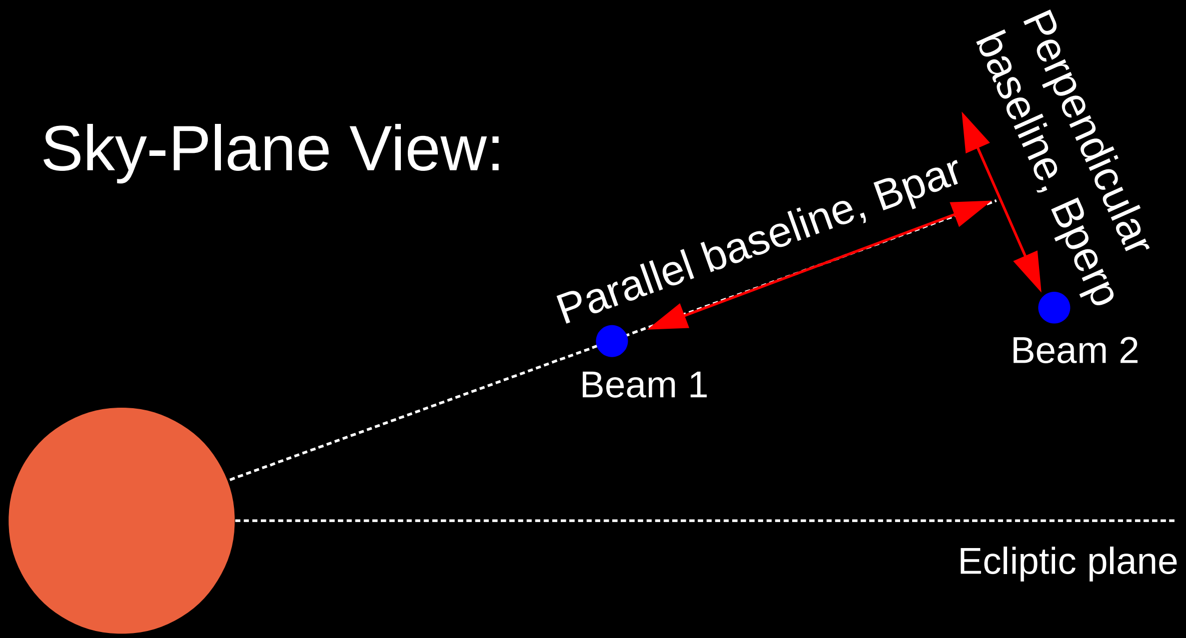


Resolving Structure in the Line of Sight: the Advantage of Long Baselines



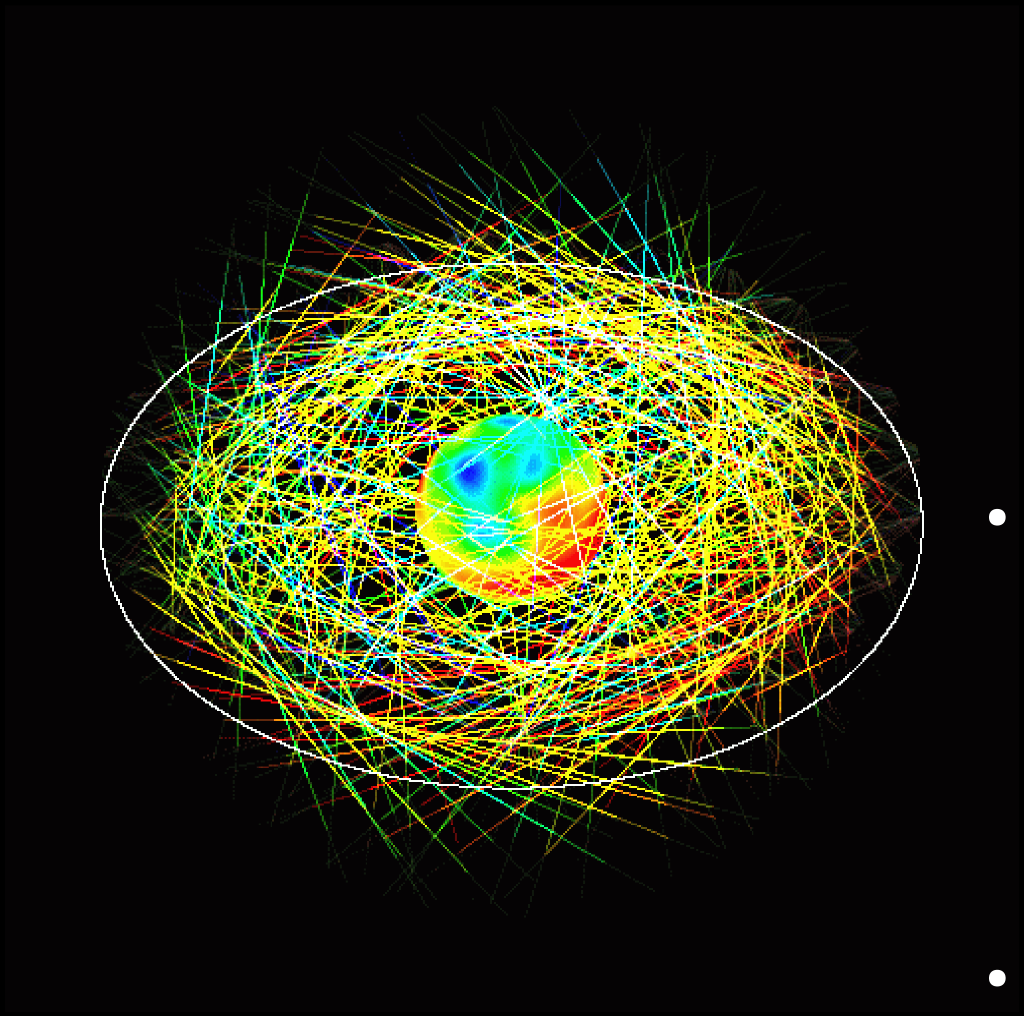
Different solar wind streams become “resolved” in the cross-correlation function as longer baselines are used.

Sky-Plane View:



Level of cross-correlation rises and falls as baseline rotates through the solar wind flow direction.

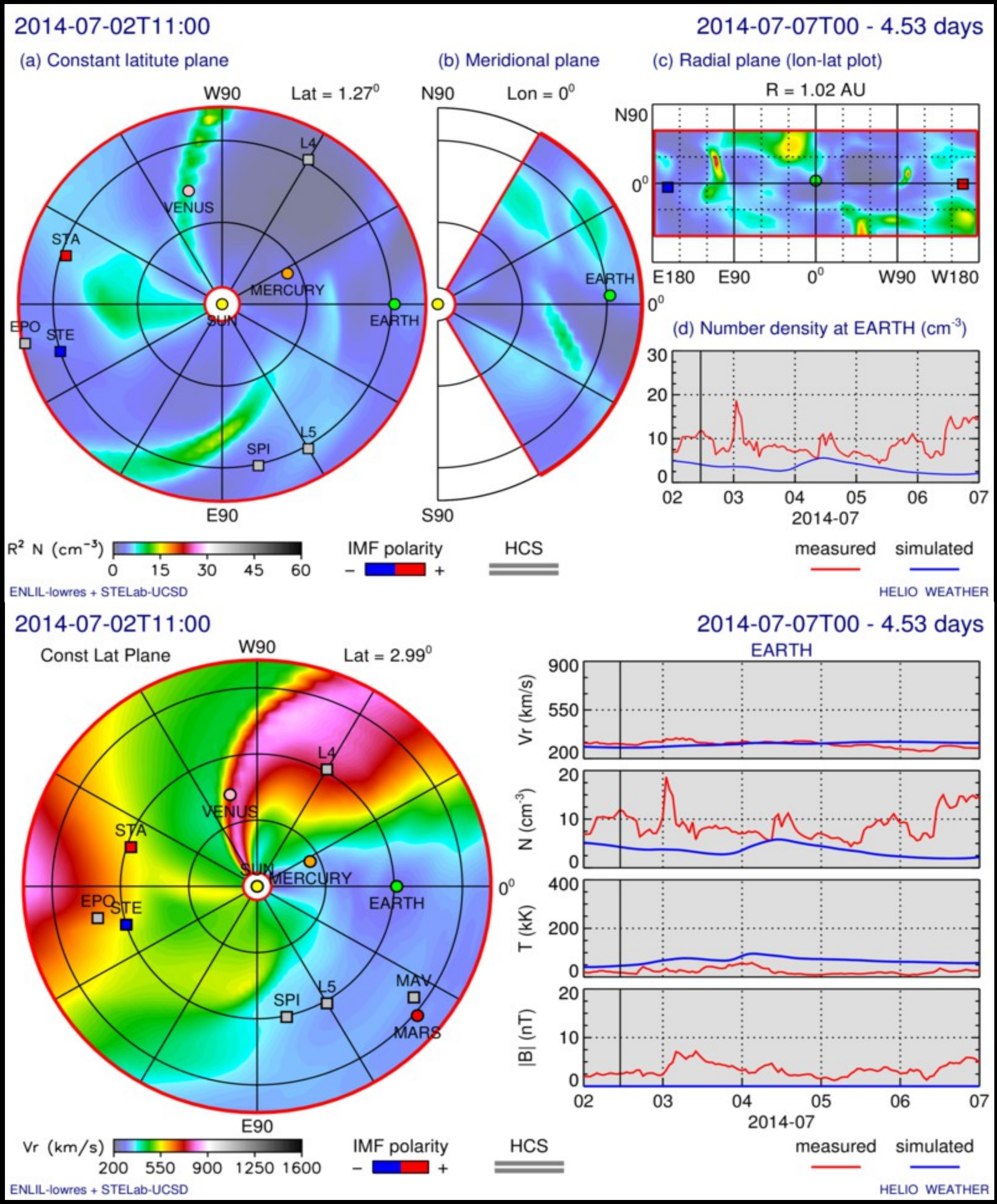
“Imaging” the Solar Wind with Tomography



- 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.
- Mitigates line of sight integration problem.

Feeding into Space Weather Models

- Tomographic reconstructions currently produced daily from ISEE (Japan) IPS instrument.
- Project now underway to try and incorporate these into space weather forecasting models.
- Results suggest this improves background solar-wind environment at Earth compared to standard modelling and shows strong promise for CMEs.



However, full monitoring needs to include stations worldwide 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.

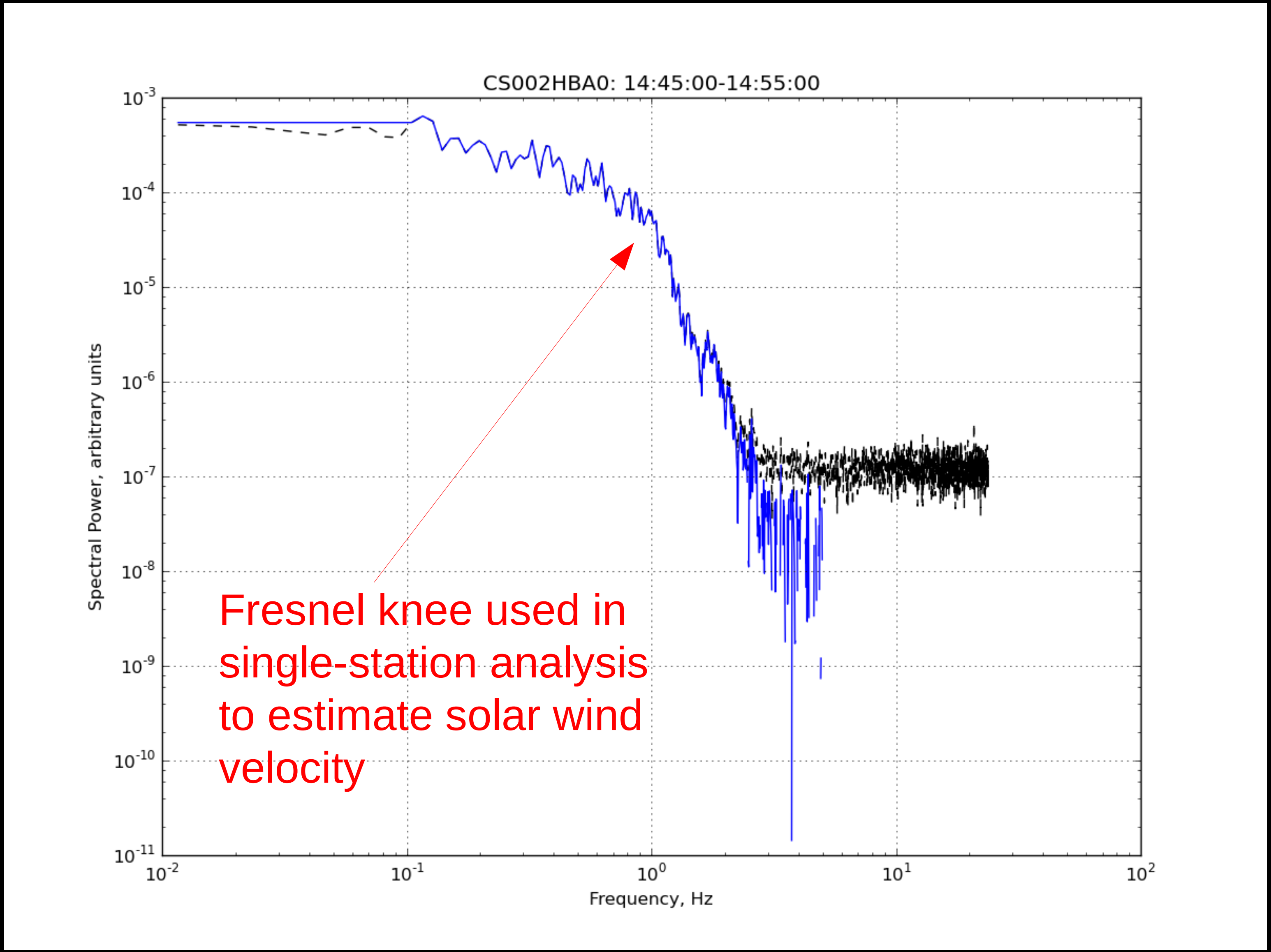
Most are also transit instruments, limiting the number of possible observations per day.

A trial campaign took place in October 2016 involving LOFAR 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.

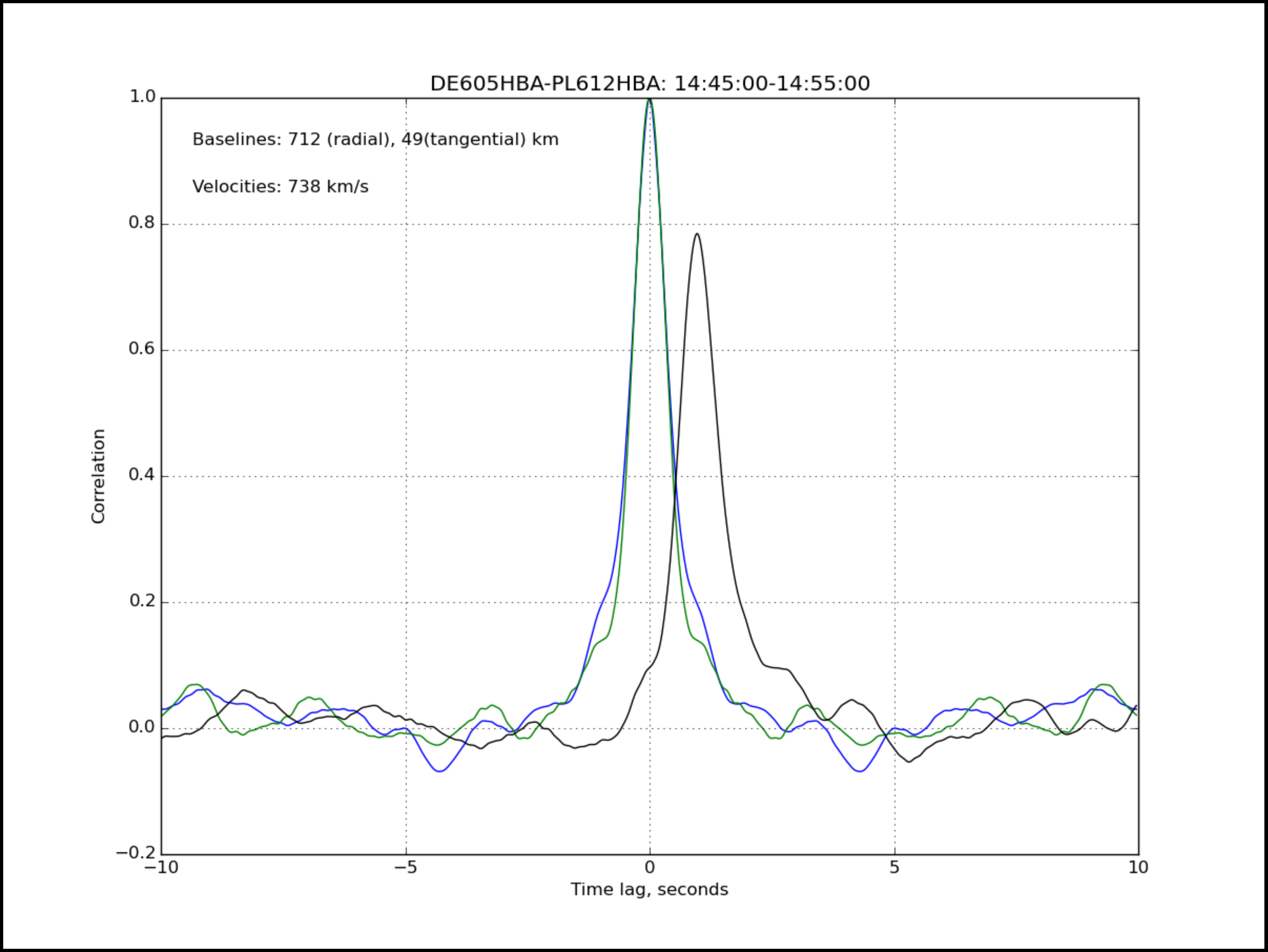
With the wide bandwidth and geographical coverage of LOFAR, we can compare the different methods of analysis currently in use and try analyses which are not possible with any other instrument: e.g., cross-correlating different frequencies could lead to more direct measurement of the solar wind density and investigation of “velocity dispersion”, where different density scales could be moving at different speeds.

Power Spectrum



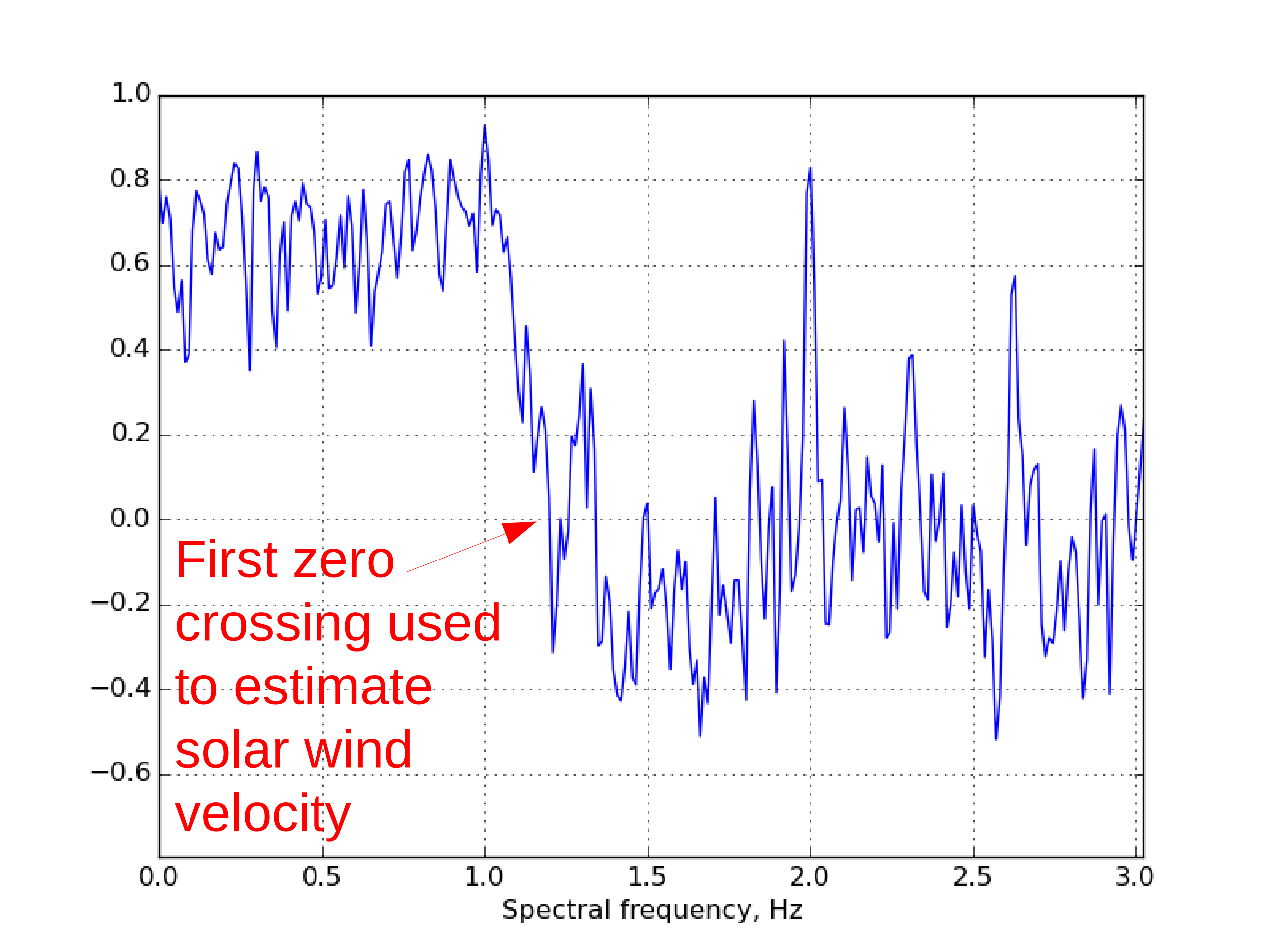
3C298 – LOFAR core - 2016-10-05

Spatial Cross-Correlation



3C298 – Julich (DE) to Baldy (PL) - 2016-10-05

Normalised Cross-Spectrum



Cross-correlation of time series’ from two widely-spaced observing frequencies offers a more-robust method of calculating velocity from a single station.

Frequency Cross-Correlation

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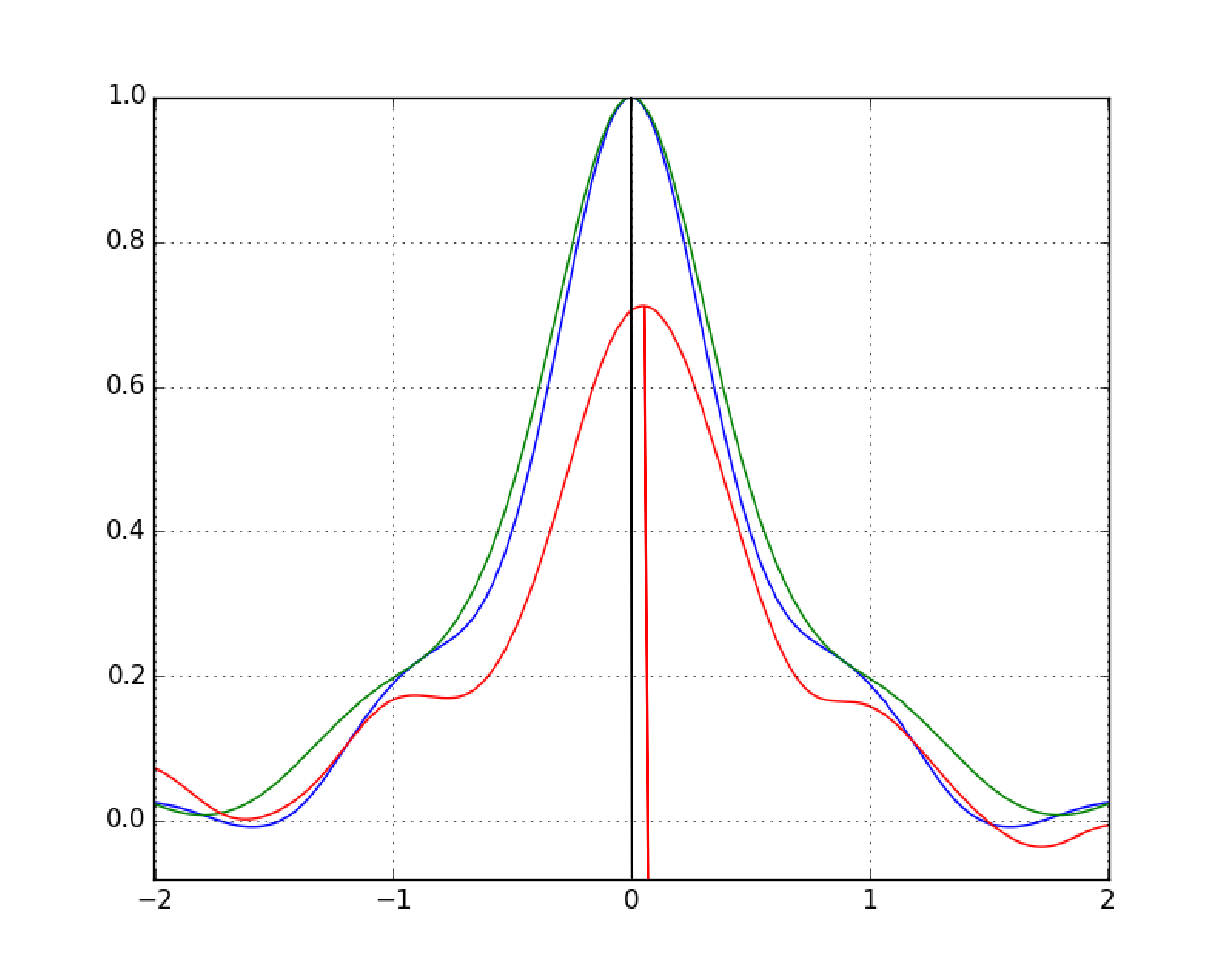
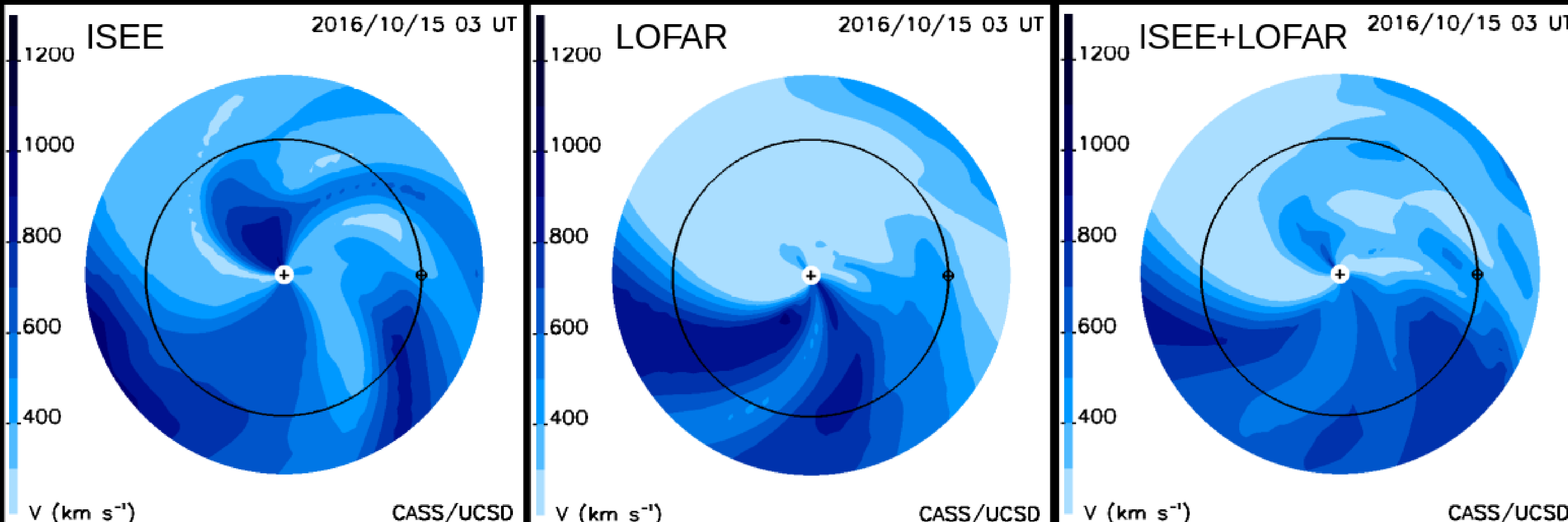


Time delay in single-station frequency cross-correlation function related to refraction through large-scale density structures.

Time delay varies with distance from the Sun reflecting the corresponding density decrease.

Tomographic Reconstruction of Solar Wind Velocity: October 2016

Japan LOFAR Combined

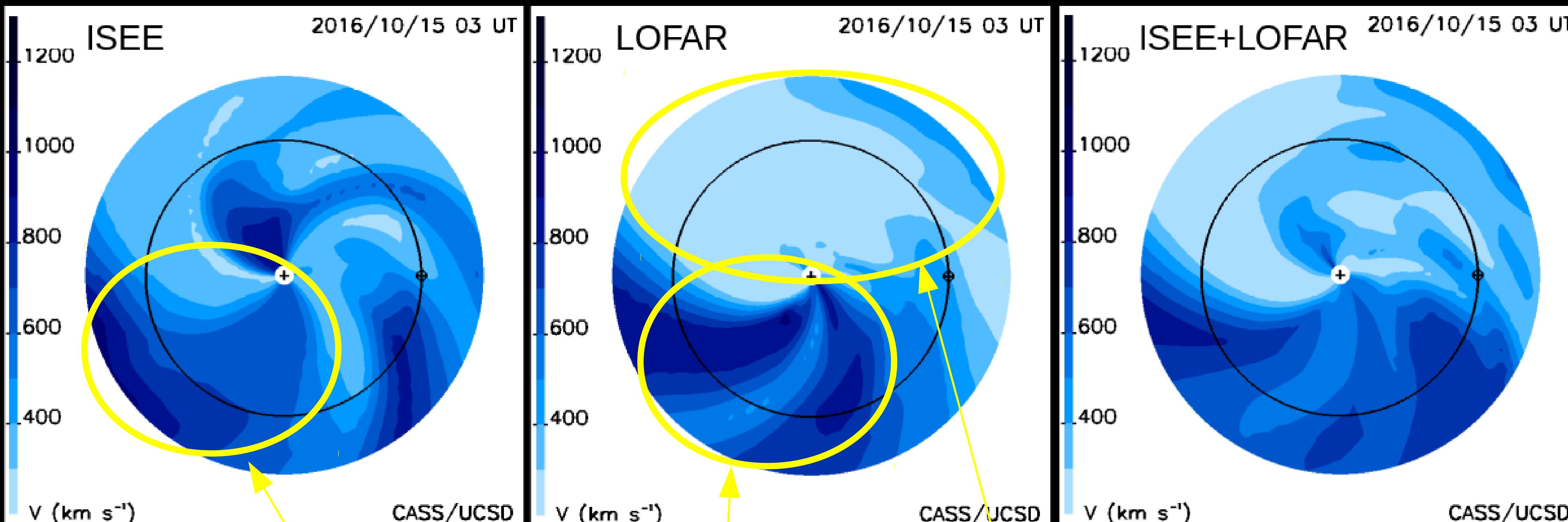


Reconstructions look good, but some key differences between ISEE and LOFAR, most likely due to spatial and temporal coverage of observations of IPS. All results **preliminary**.

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

Tomographic Reconstruction of Solar Wind Velocity: October 2016

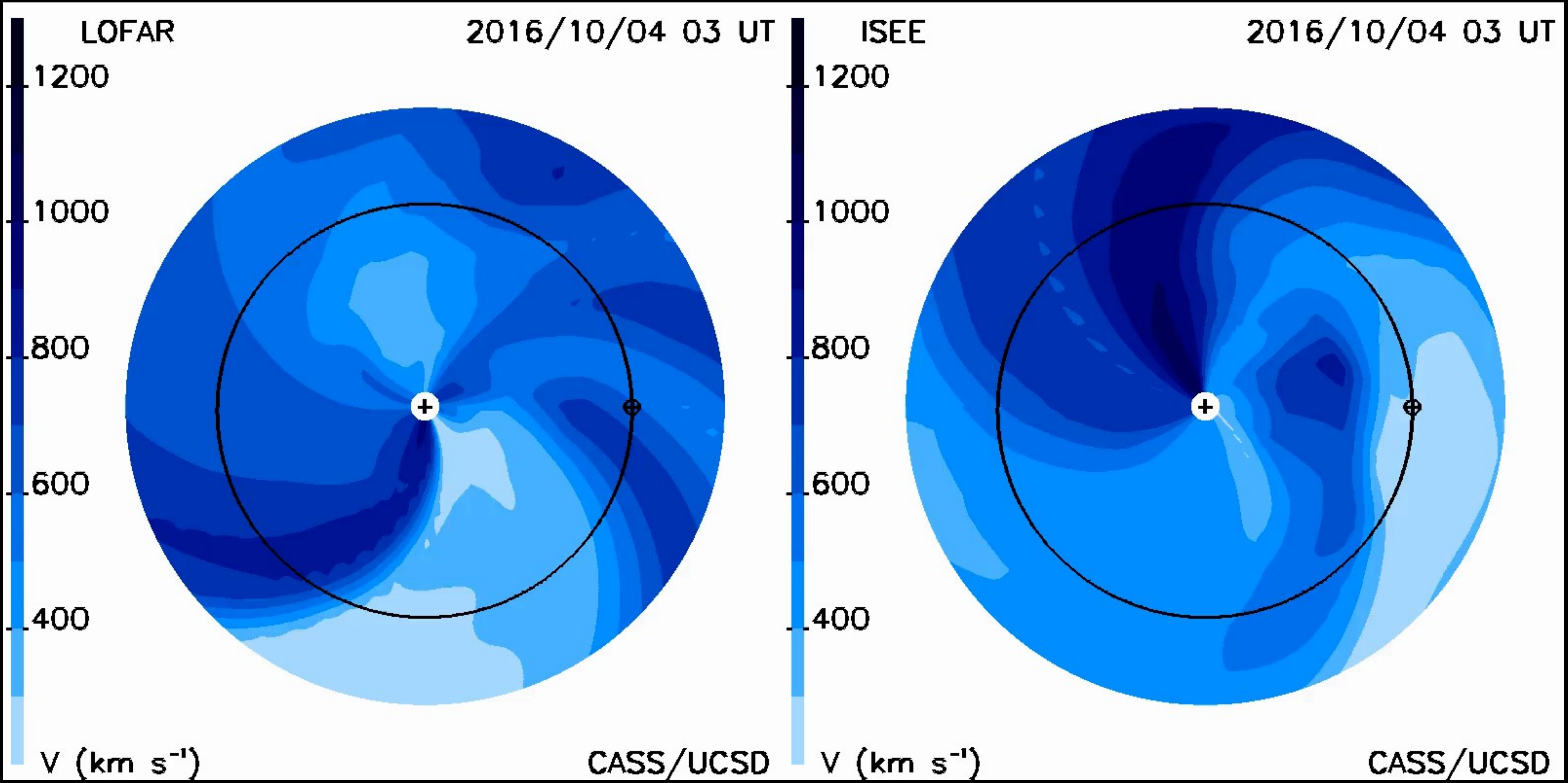
Japan | LOFAR | Combined



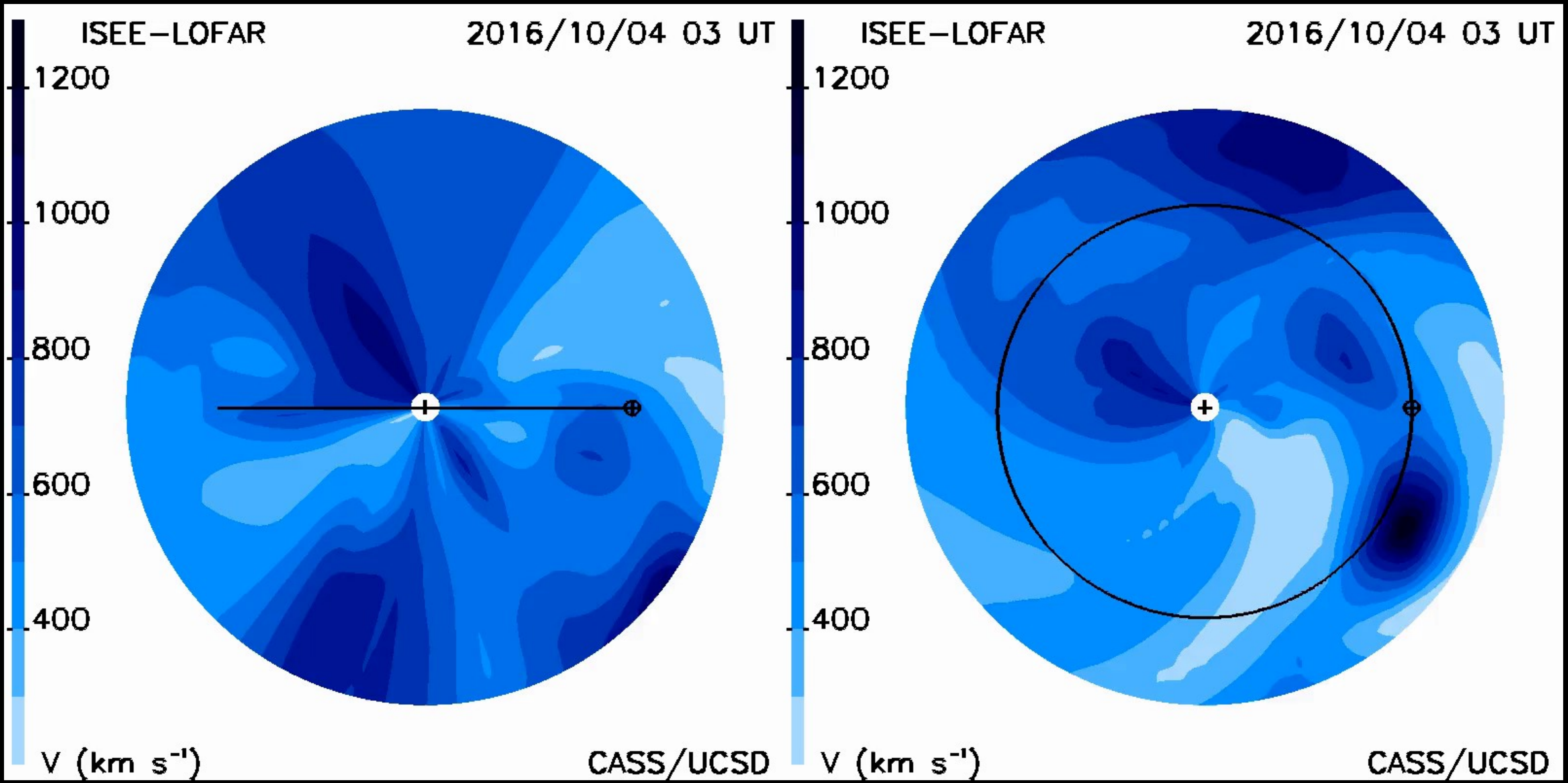
ISEE sees single, broad fast stream, where LOFAR resolves two.

No source coverage with LOFAR due to system issues.

Solar Wind Velocity in the Ecliptic Plane



Combined View



Meridional plane

Ecliptic plane

That's All Folks!