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Netherlands Institute for Radio Astronomy

Observing Ionospheric Scintillation with LOFAR

Richard Fallows
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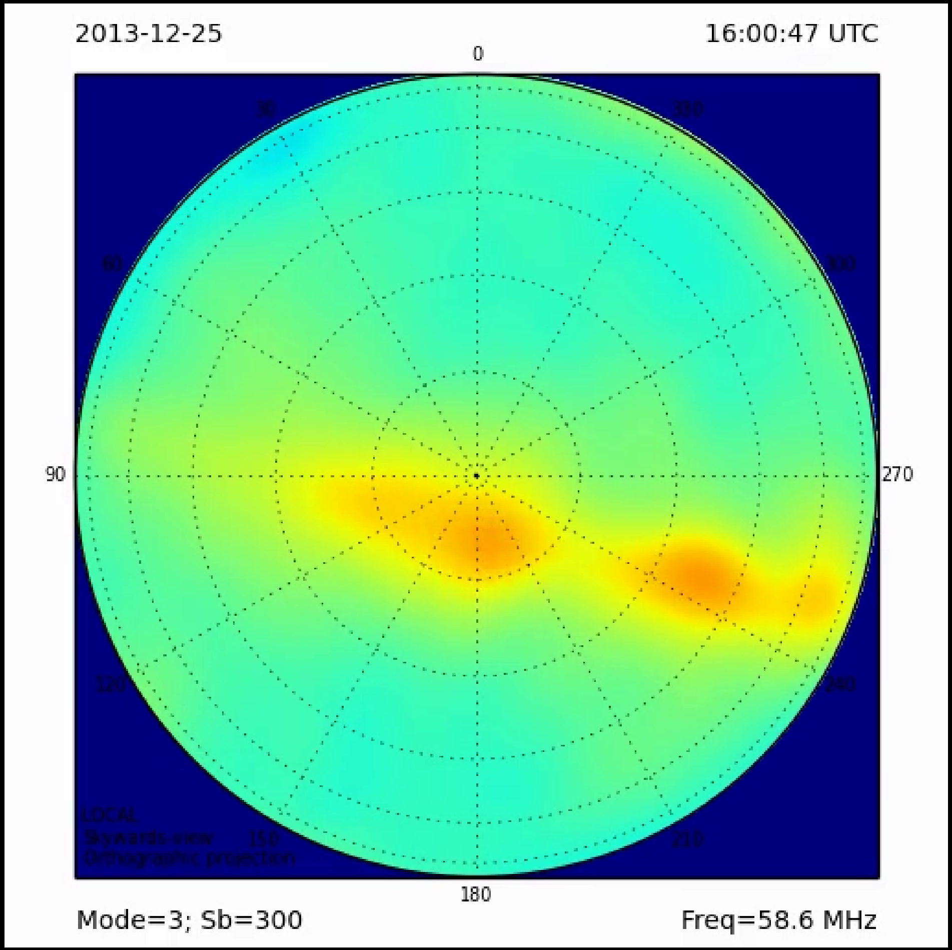
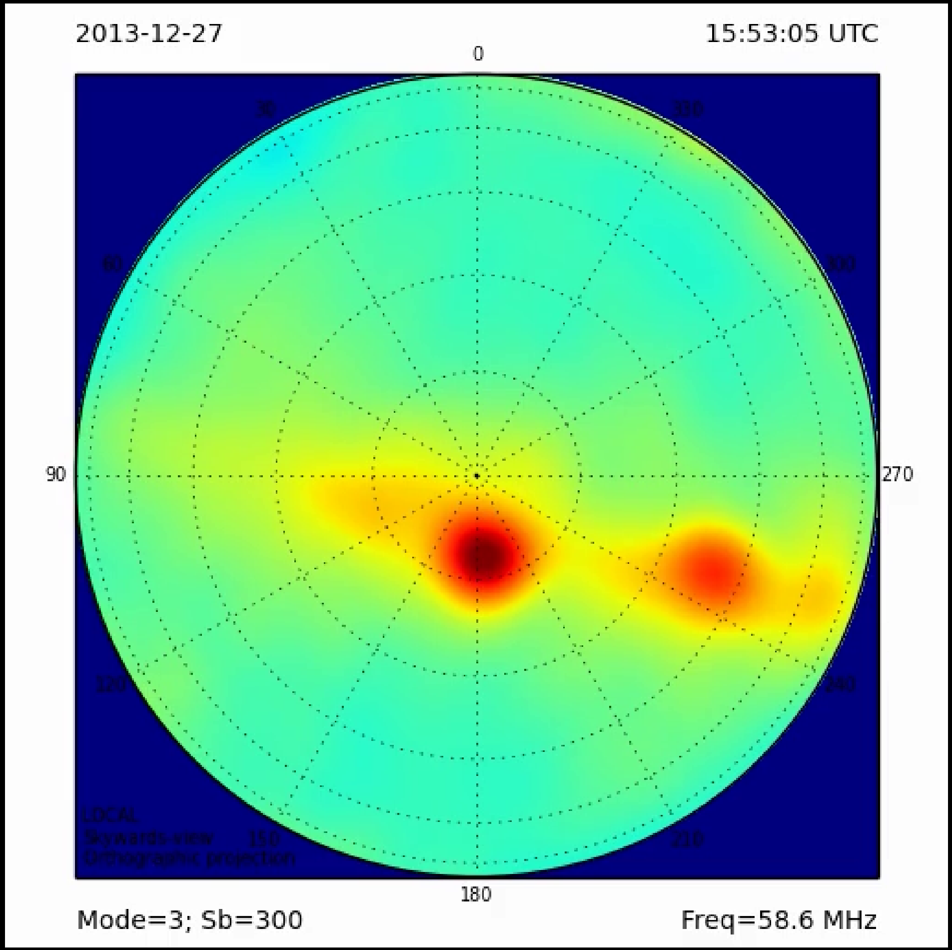
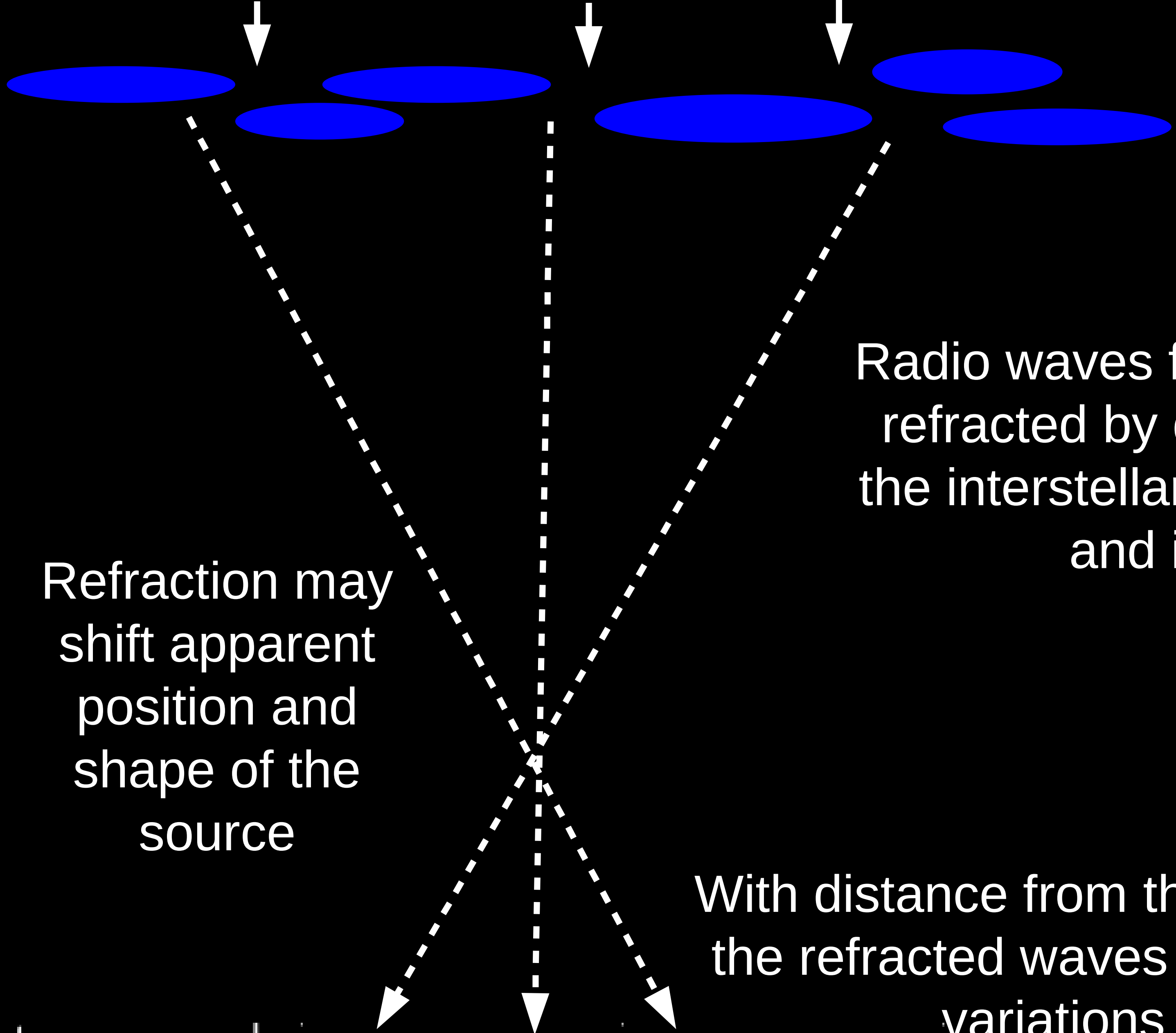
KAIRA – Christmas Day 2013





All-sky imaging, one image per second, 58.6MHz

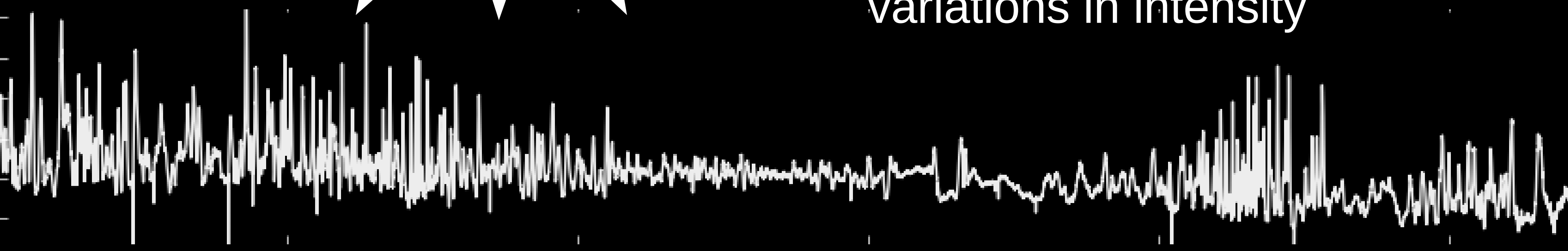
Kilpisjärvi Atmospheric Imaging Receiver Array – northern Finland



Radio waves from compact source refracted by density variations in the interstellar medium, solar wind and ionosphere

Refraction may shift apparent position and shape of the source

With distance from the scattering medium, the refracted waves interfere, resulting in variations in intensity



LOFAR

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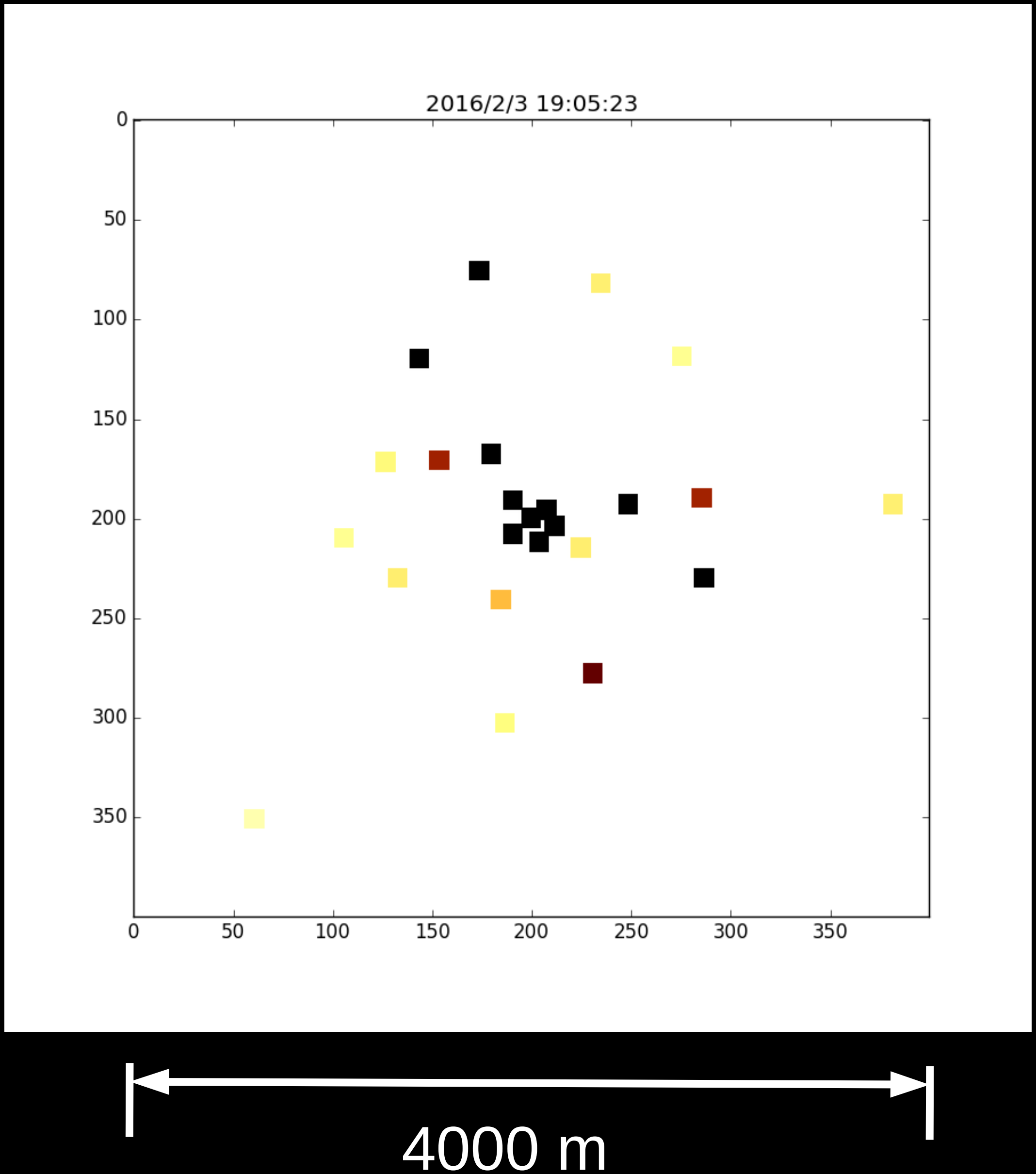
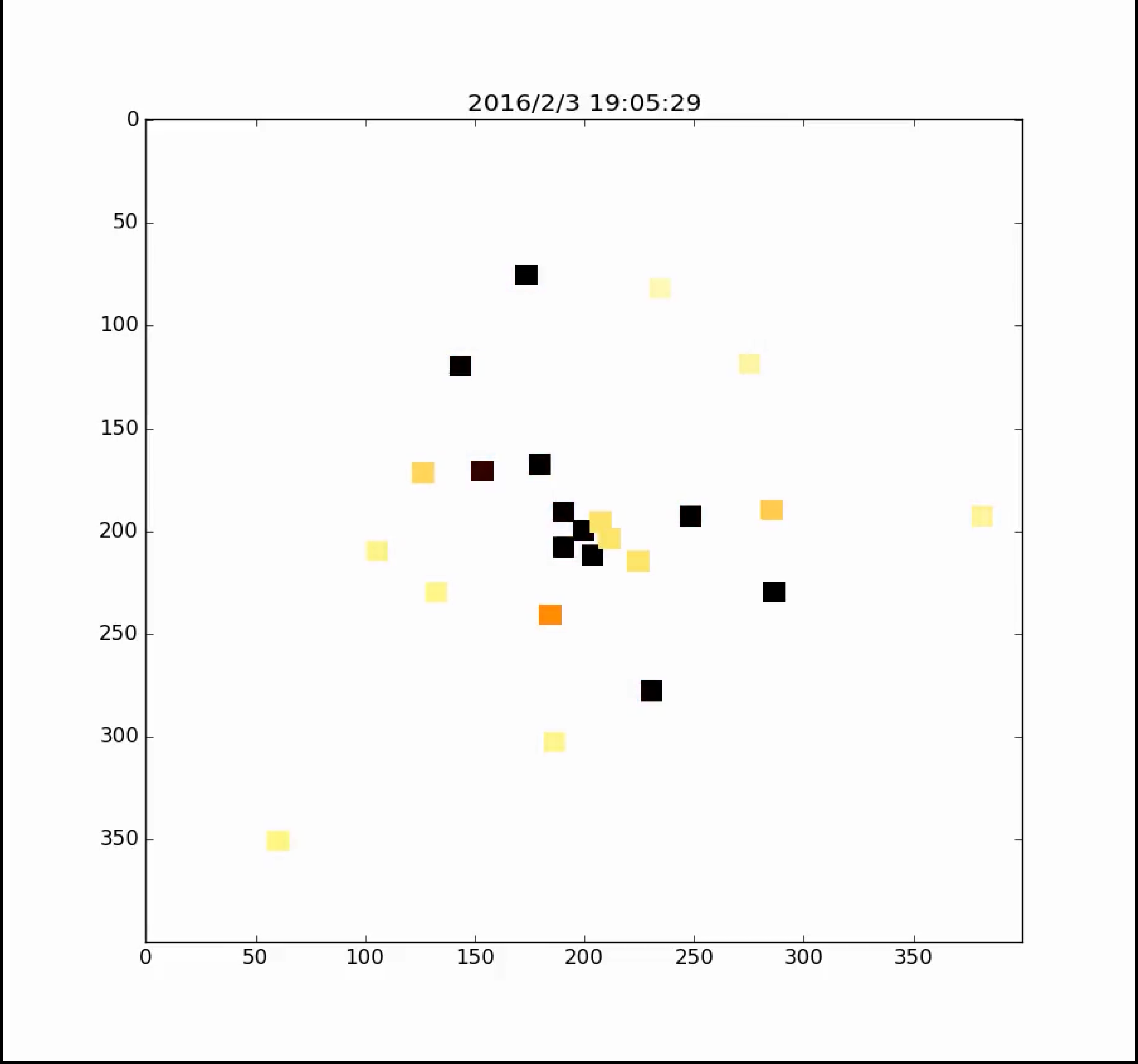
Scintillation Mapping

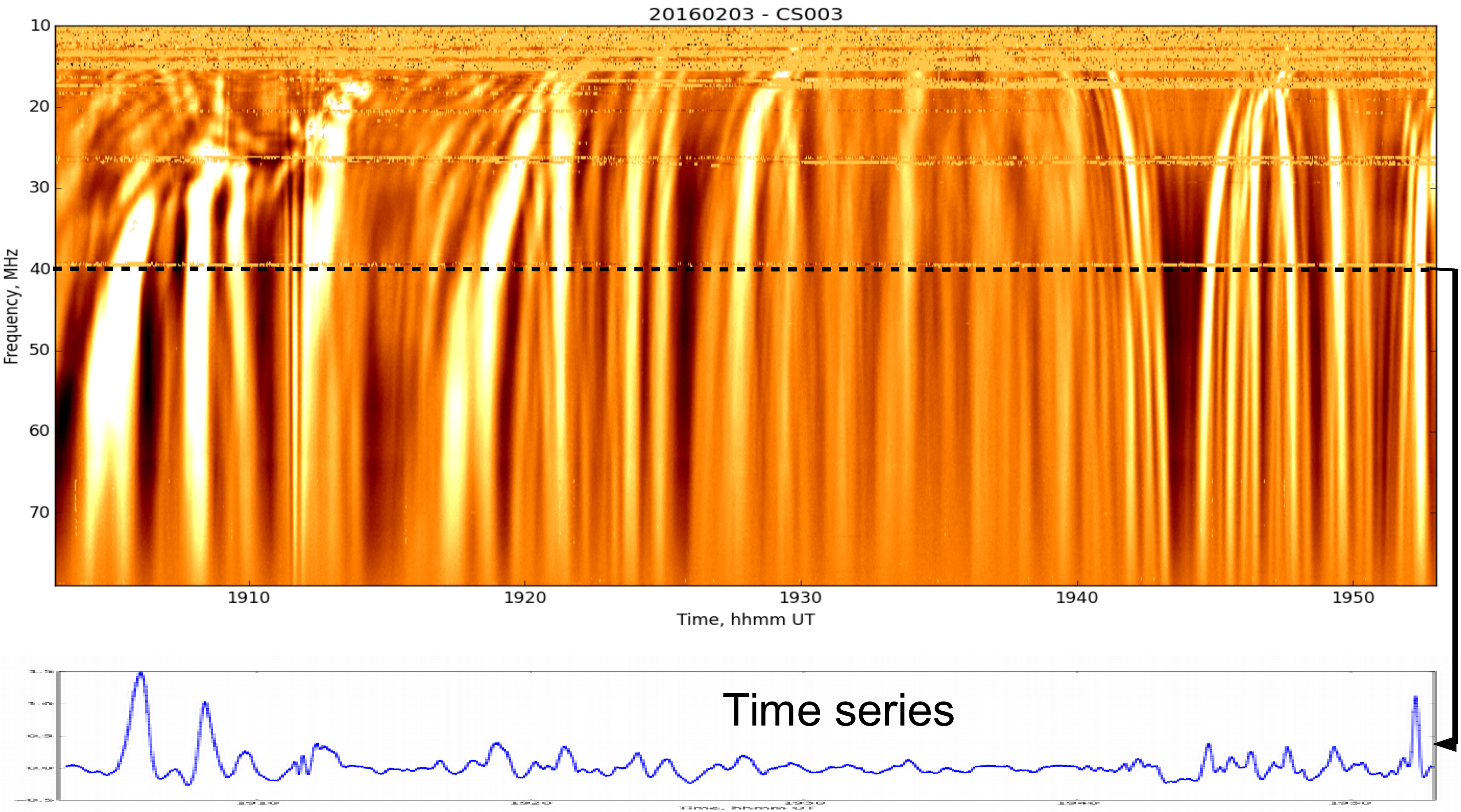
With many stations, we can record the scintillation at each station and plot the intensities as pixel values on a map of the stations.



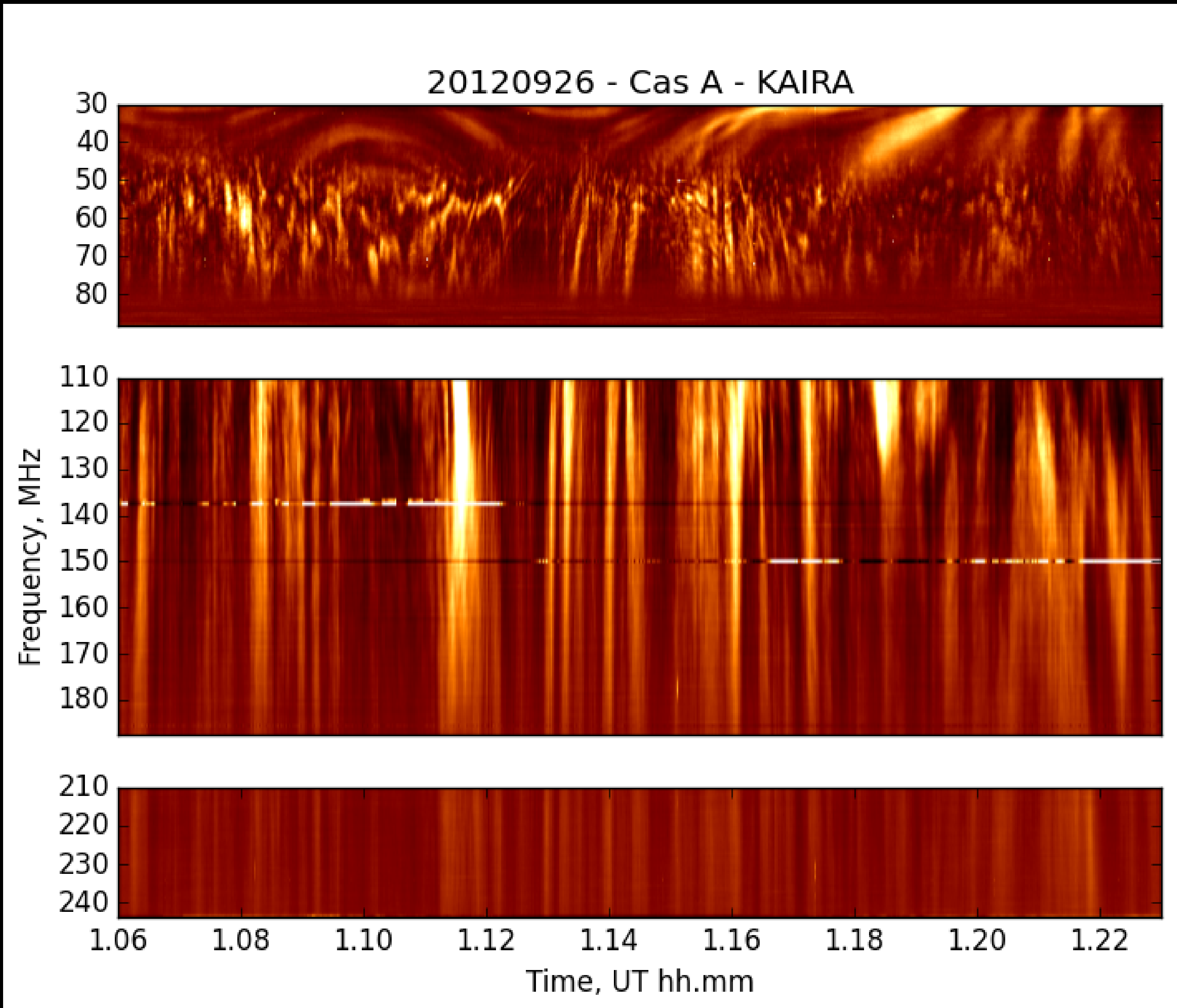
Cas A – 20160203 – 19:03 to 19:53 UT – 1s cadence



Dynamic Spectrum



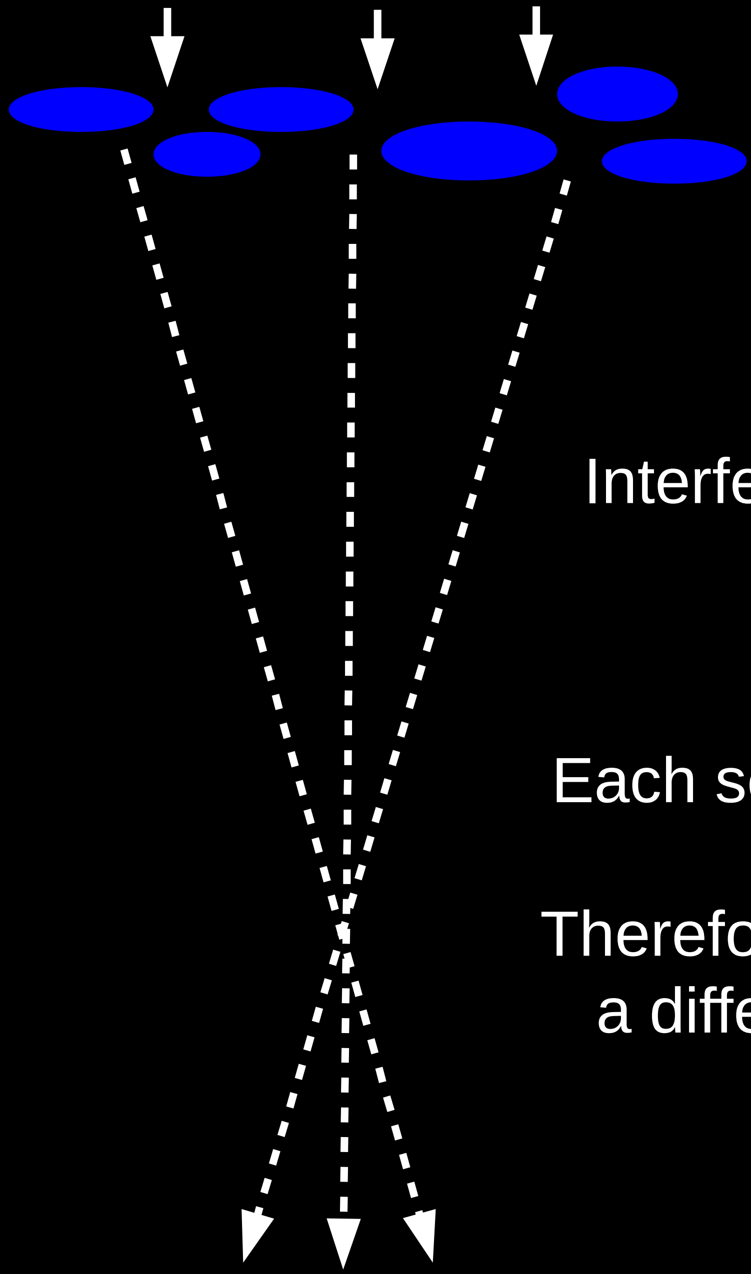
Wider Bandwidth



Refraction

"Strong" scattering

"Weak" scattering



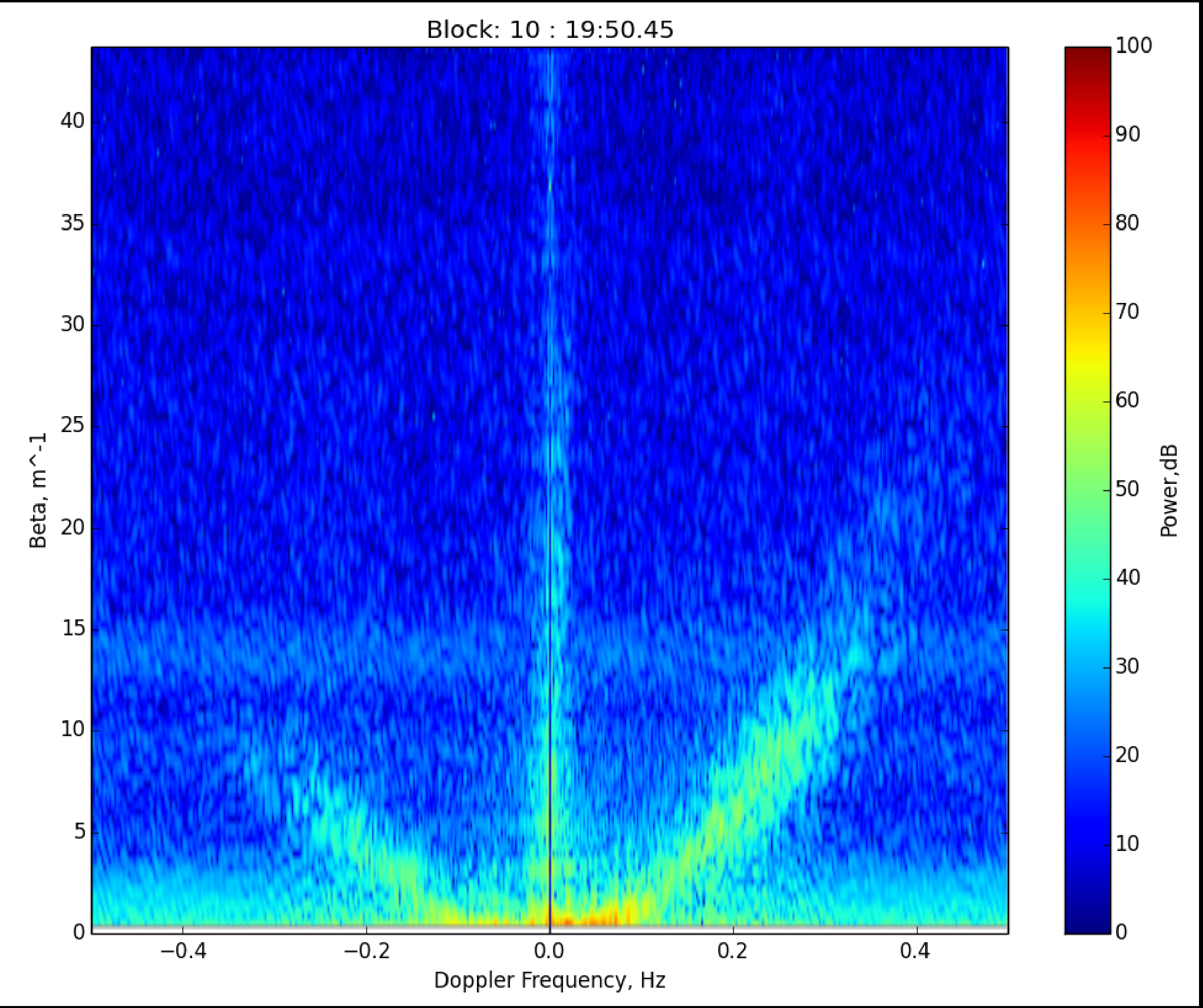
Interference can occur between any pair of plane waves

Each scattered wave has followed a different path

Therefore, between each pair of scattered waves is a differential Doppler frequency and time delay

Delay-Doppler spectrum (“secondary spectrum – FFT of dynamic spectrum) can show “scintillation arc”

25 September 2012 - KAIRA – Cyg A



Modelling Scintillation Arcs

Scintillation arcs can be defined by a simple model relating β, the conjugate of wavelength, to Doppler frequency, the conjugate of time:

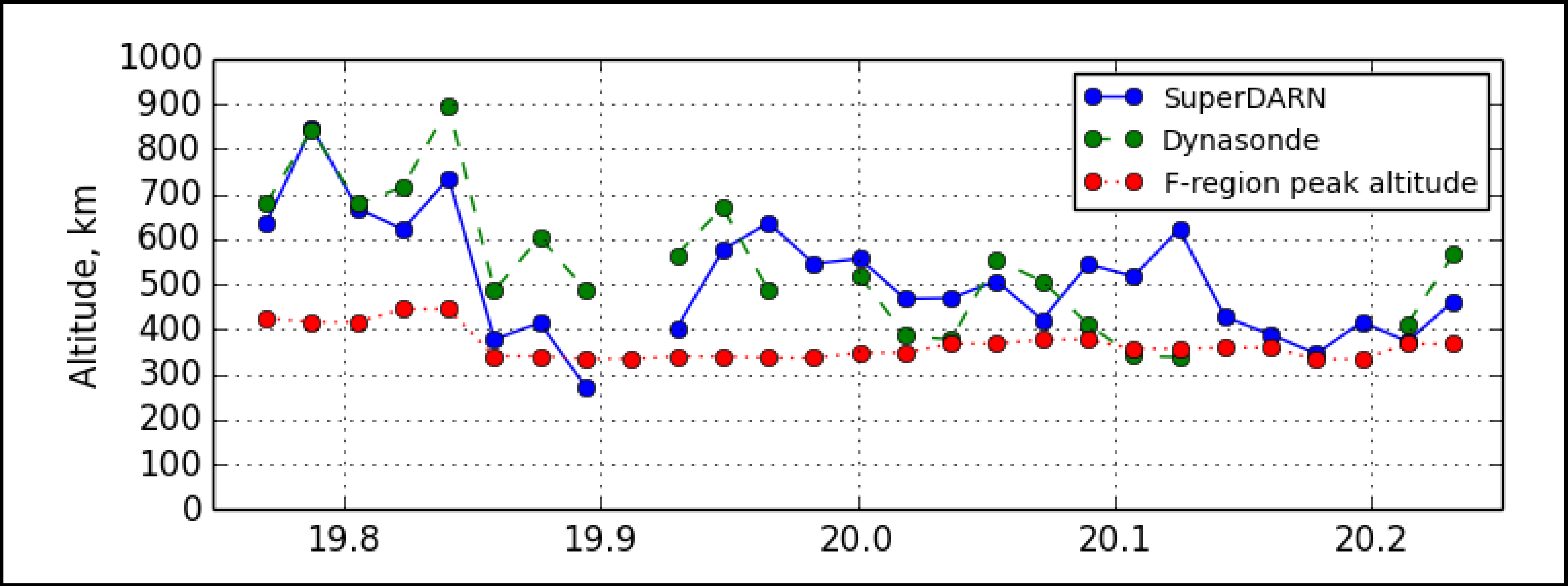
$$\beta = C f^{2}_{Doppler} + B f_{Doppler}$$

where curvature, C, can be defined as: $$C = \frac{L}{2V^2}$$

for a distance, L, to a scattering 'screen' traversing the line of sight with velocity, V

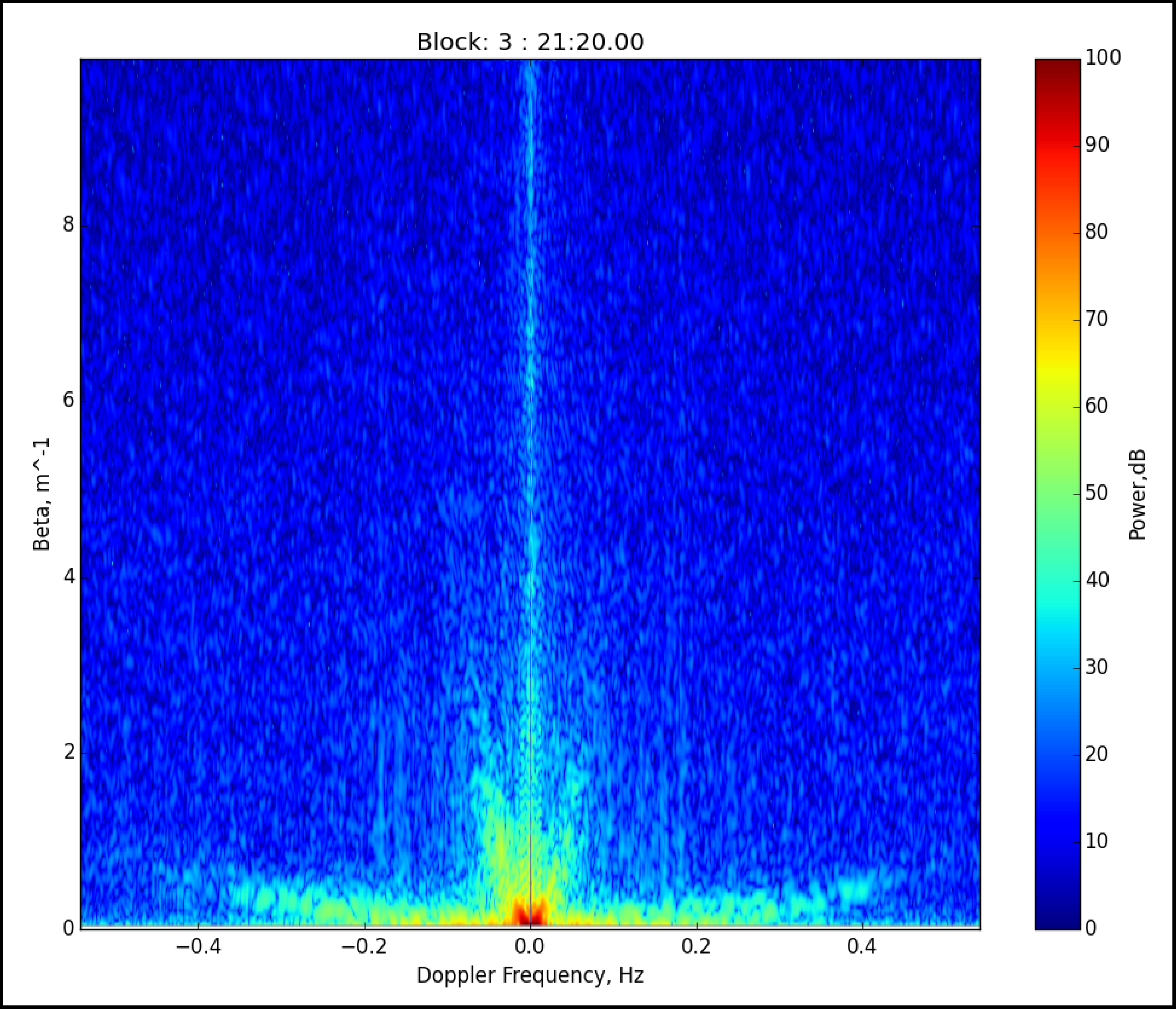
B is a parameter to describe any phase gradient which would shift an image of the radio source.

Possible Scintillation Altitudes

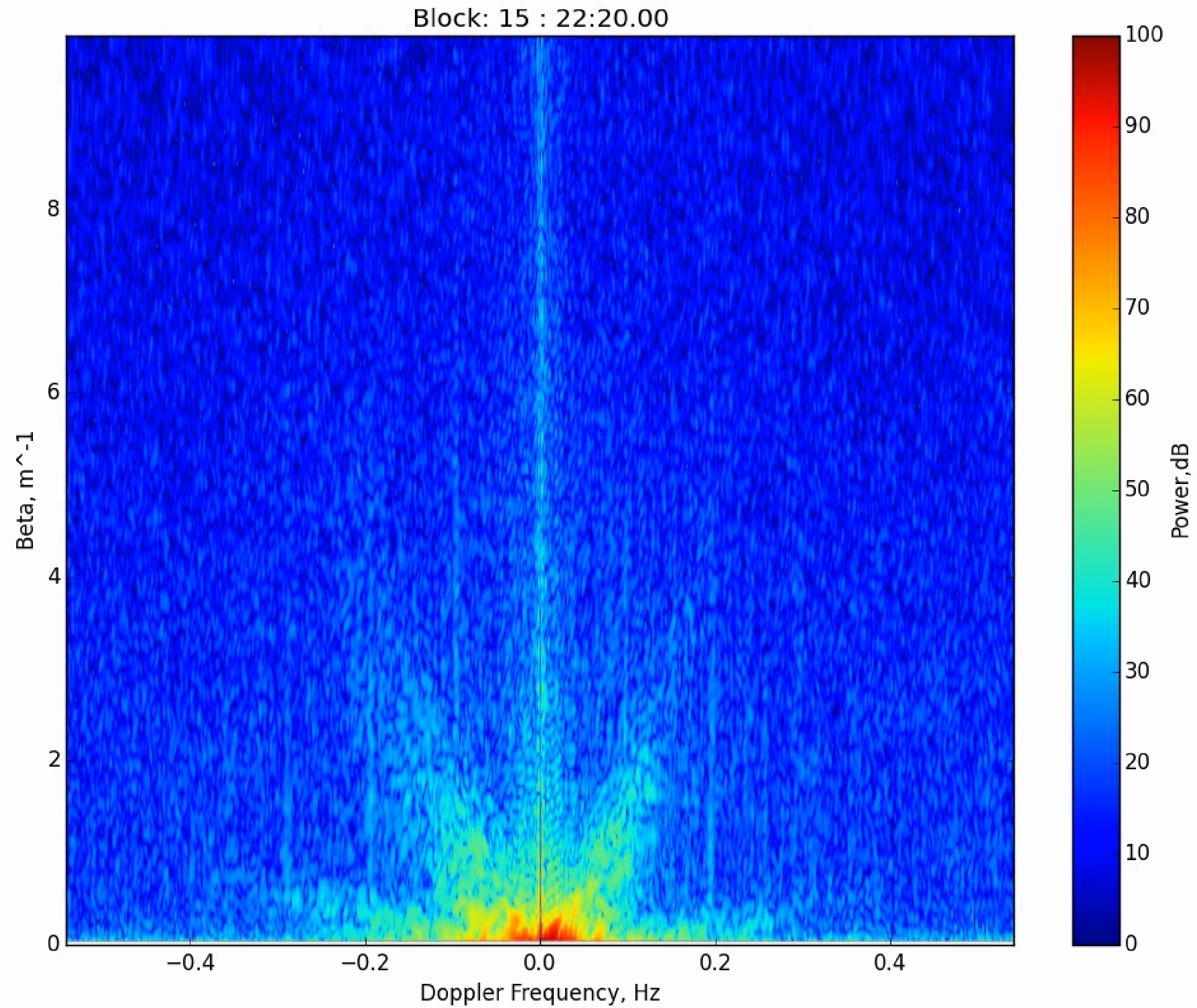


Ionospheric velocities measured by nearby radar systems used to estimate altitudes dominating the received scintillation.

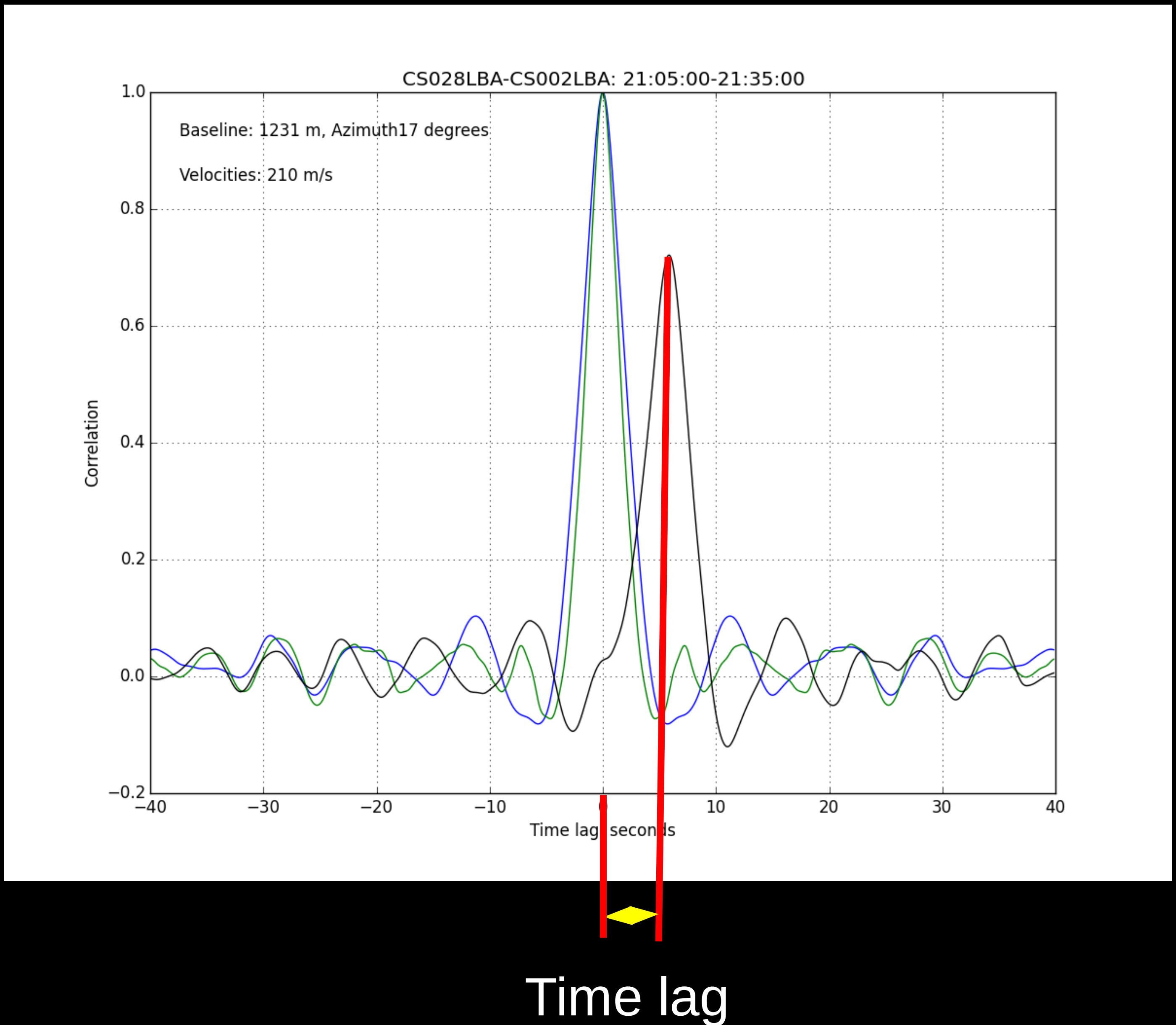
18 August 2013 – LOFAR – Cas A



18 August 2013 – LOFAR – Cas A



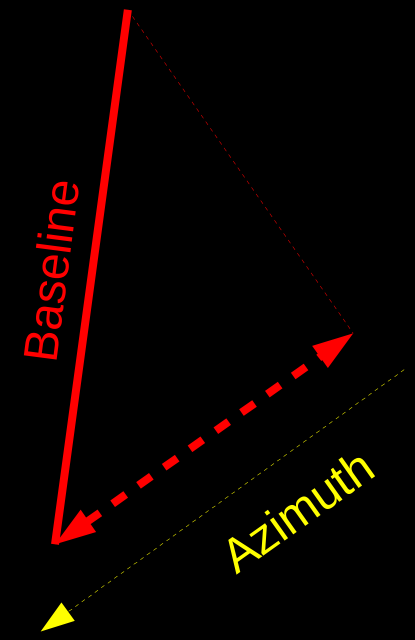
Estimating Velocities

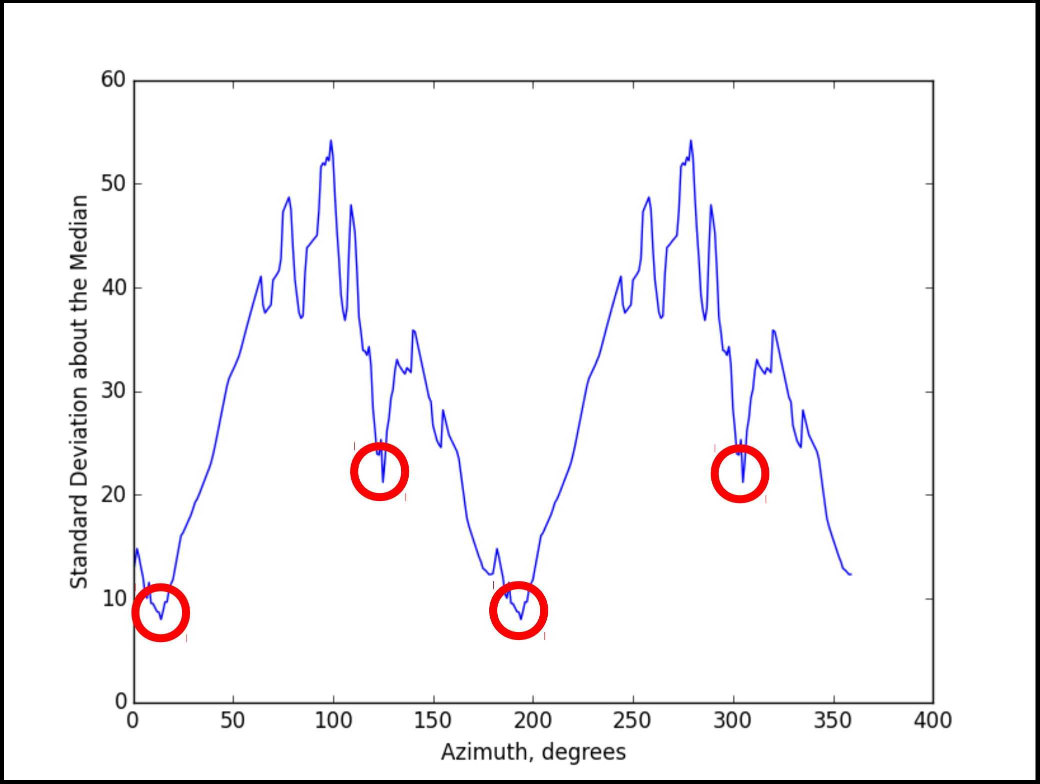


Cross-correlate time series' for every baseline in the core and find the time lags of the cross-correlation function peaks.

Estimating Velocities

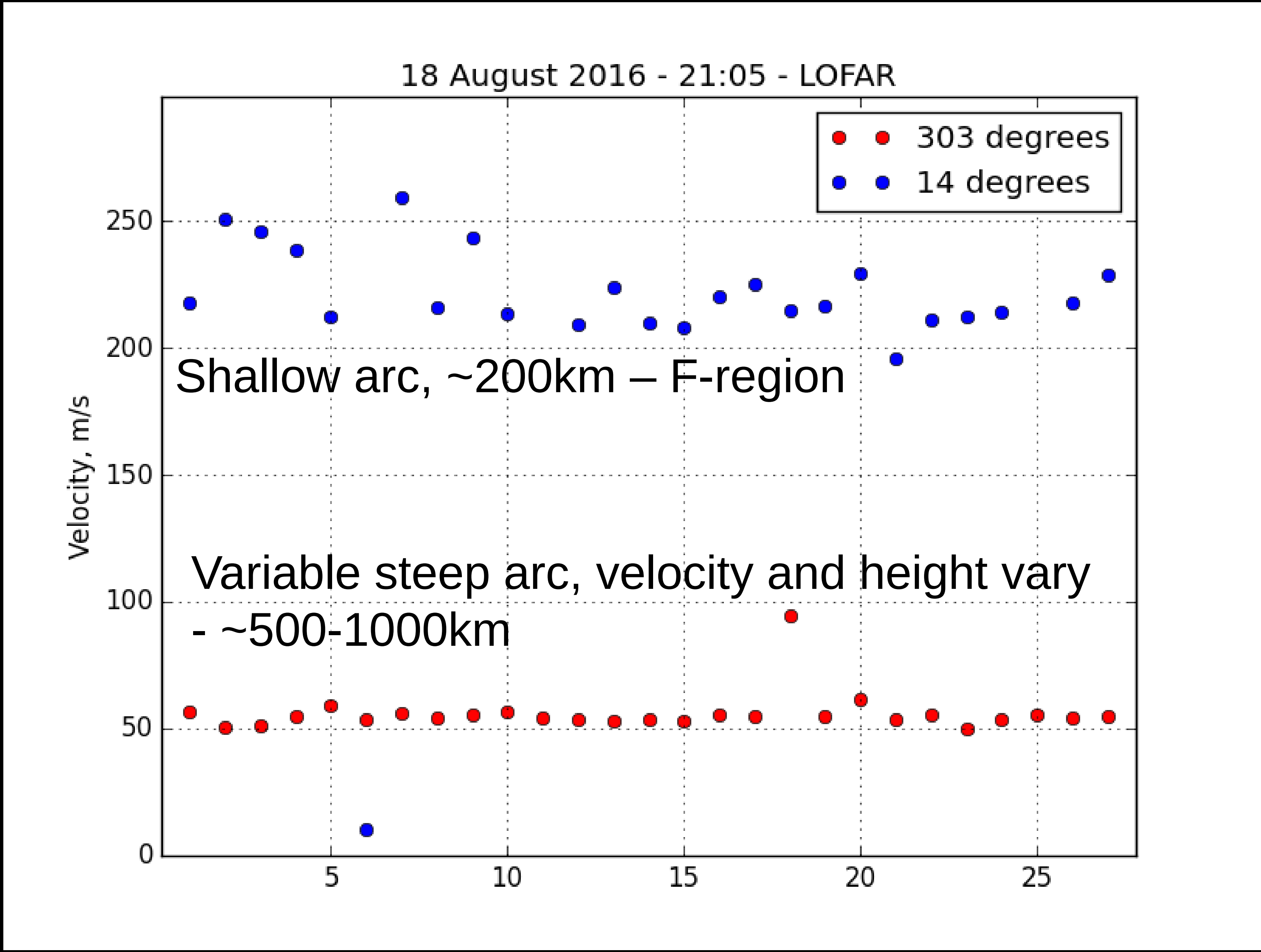
For every azimuth, calculate velocities using component of the baseline aligned with the azimuth.





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

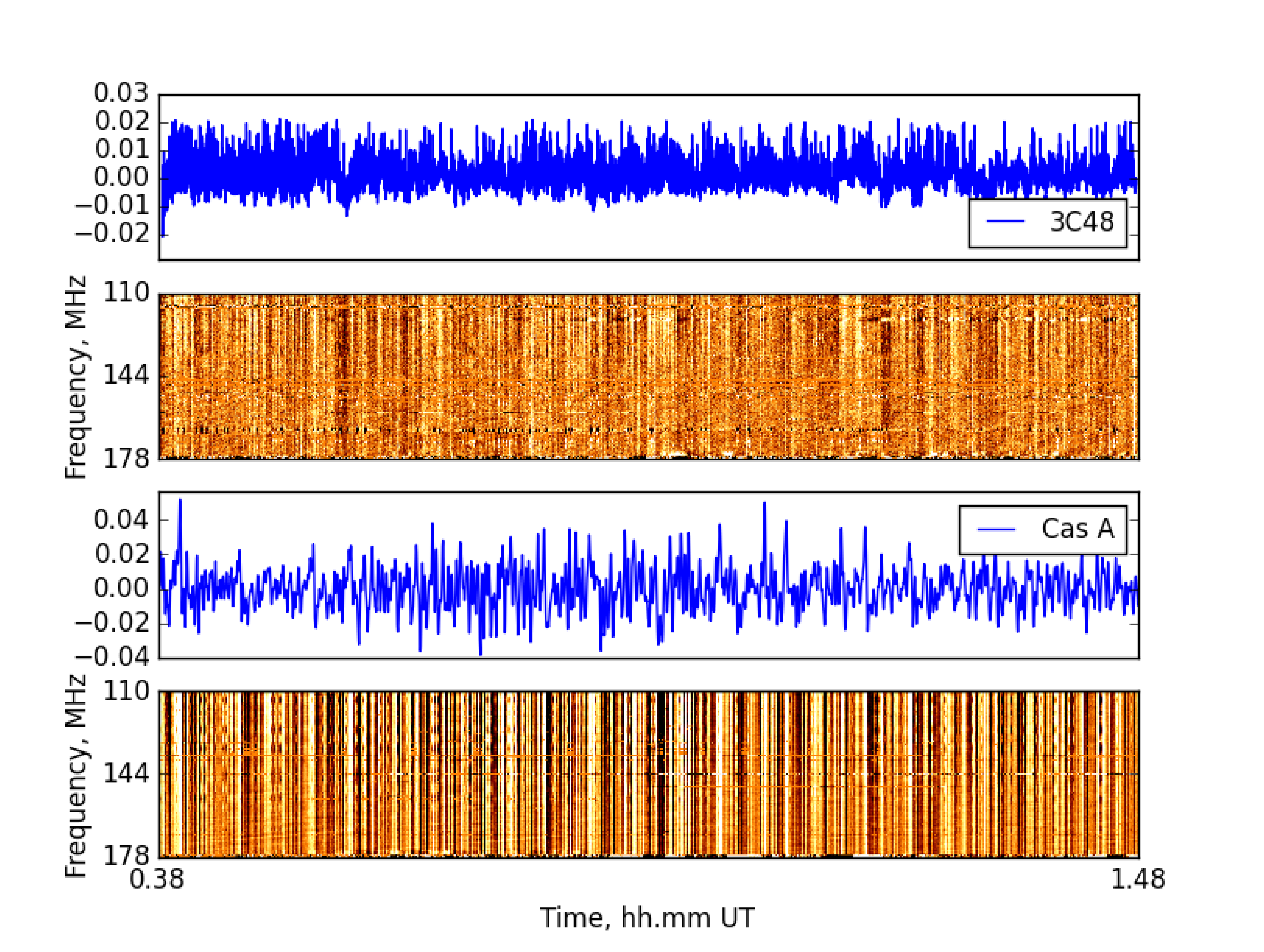
Estimating Velocities



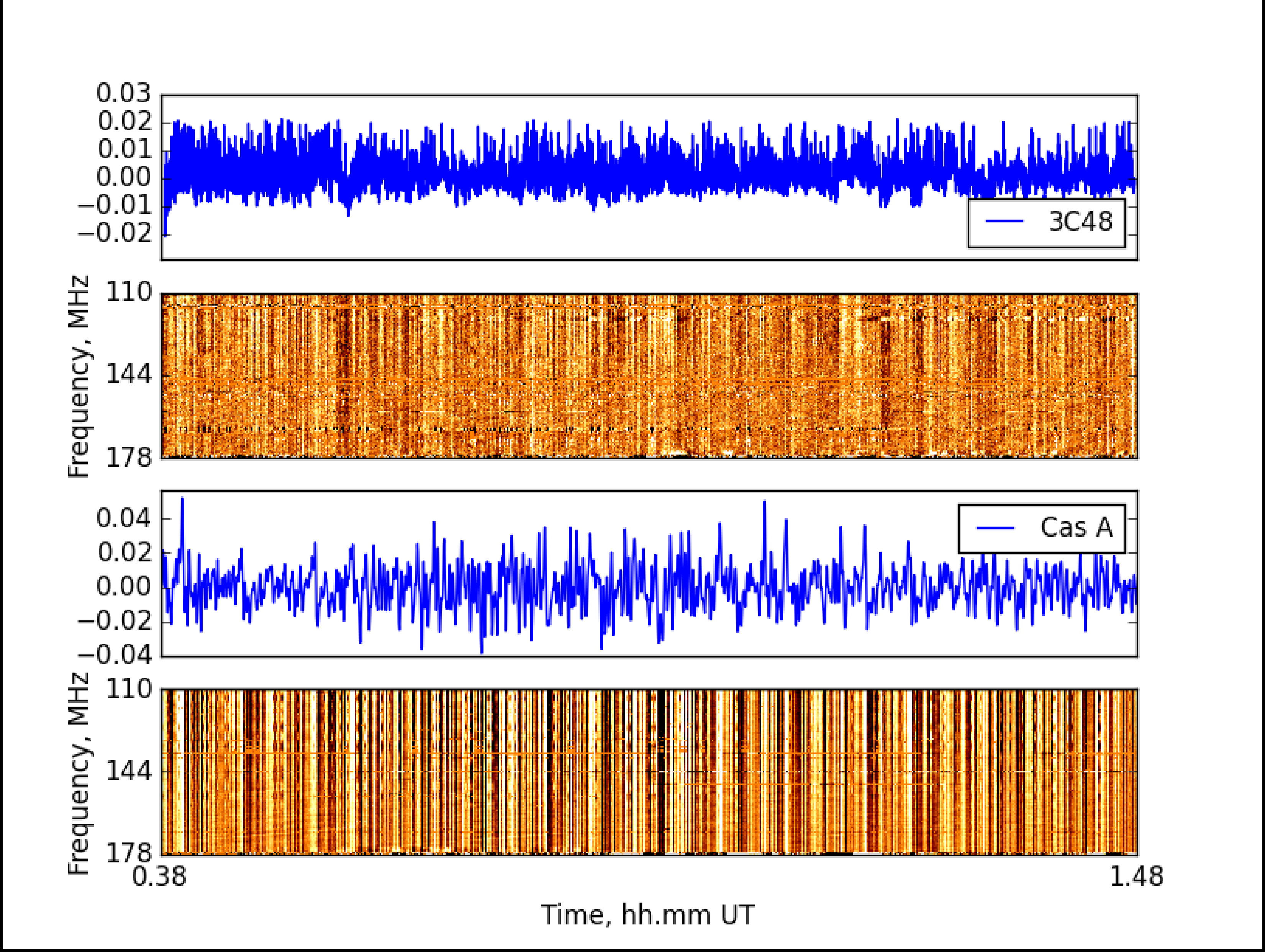
Ionospheric scintillation is highly variable and assuming a single, thin scattering screen may not make sense...

Just one more thing:

Interplanetary Scintillation on 3C48



At Night. 157 degrees from the Sun



Have fun...