Netherlands Institute for Radio Astronomy

Probing the Ionosphere with Broadband Low-Frequency Observations of Ionospheric Scintillation

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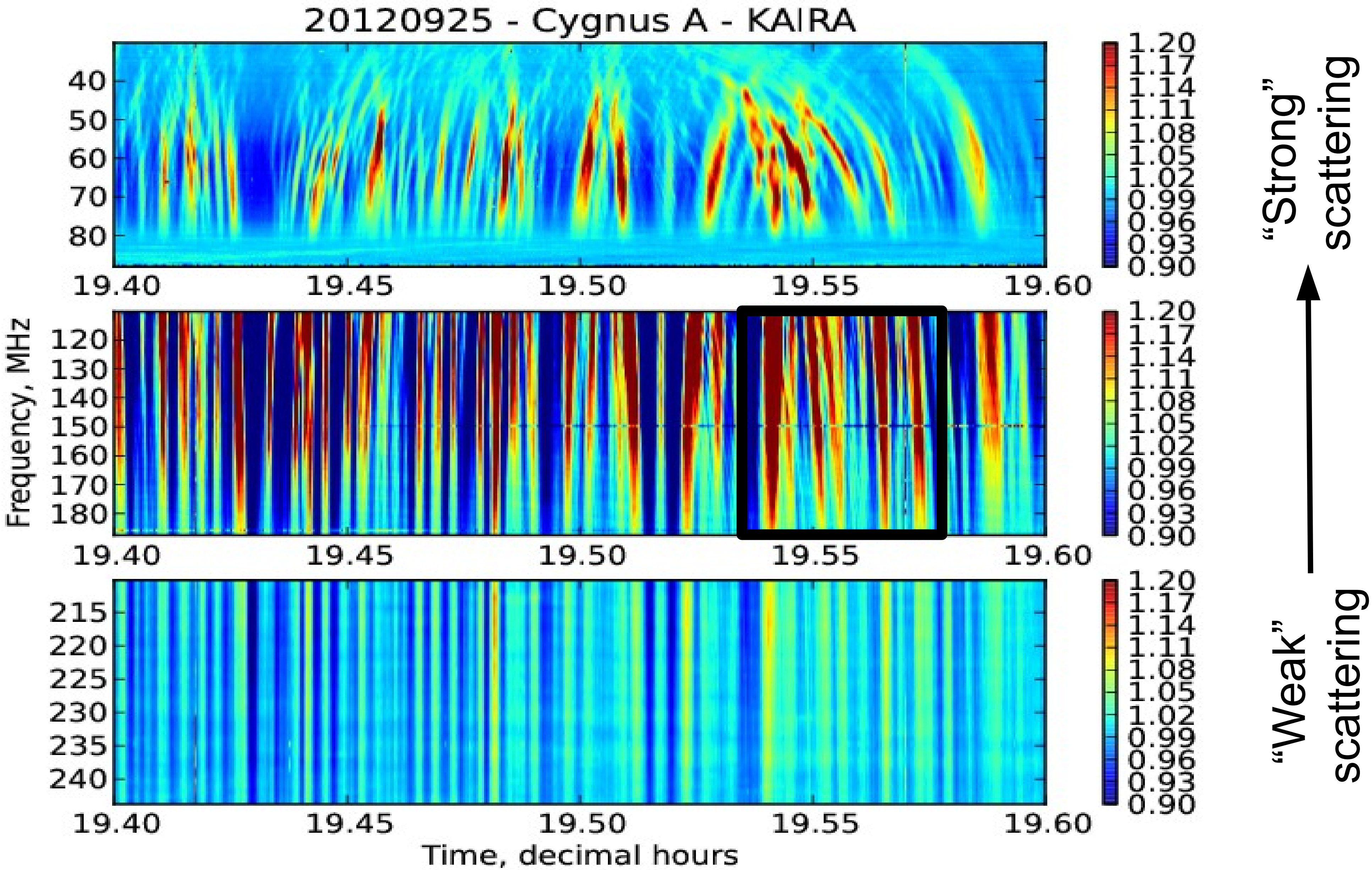
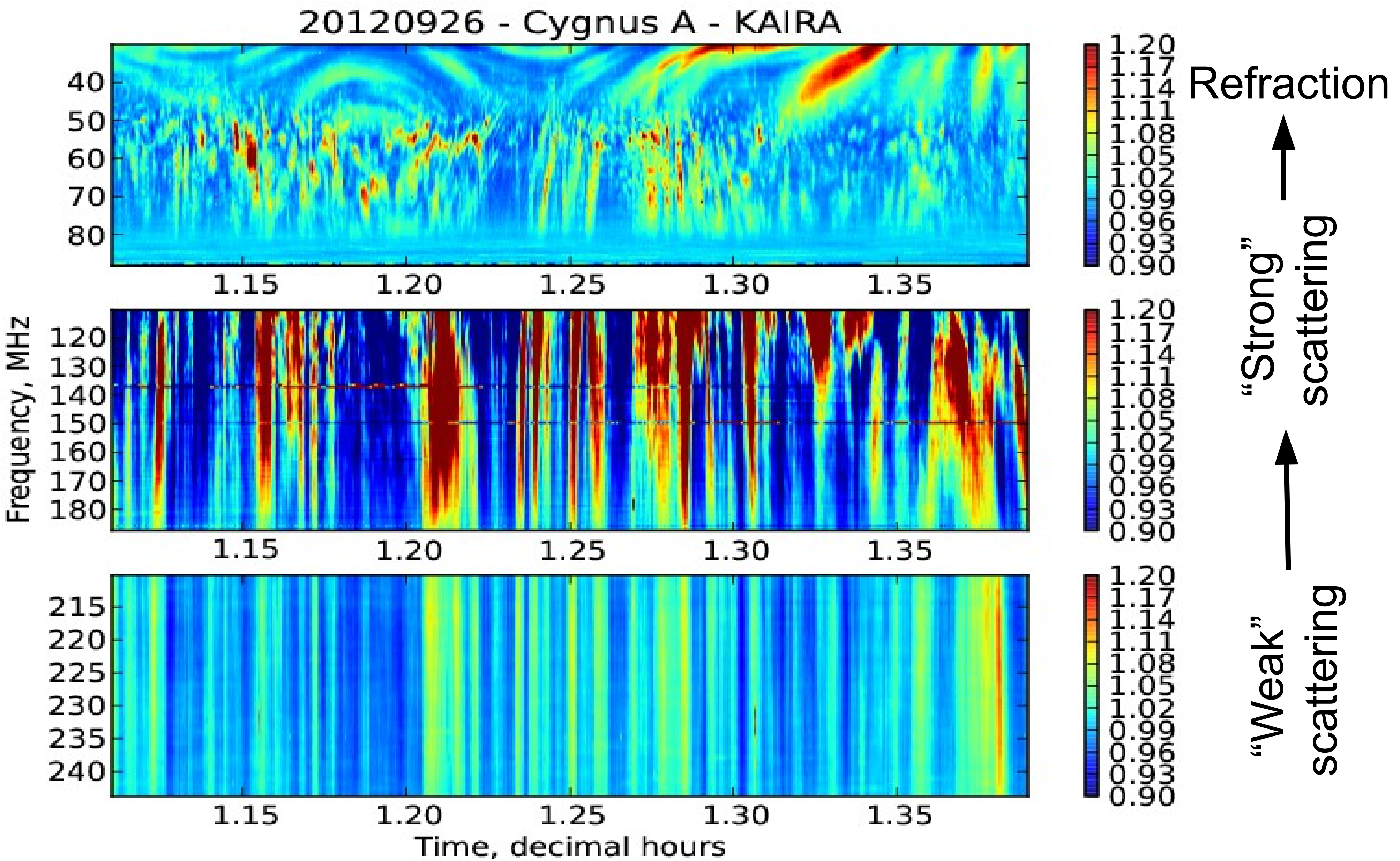
Ionospheric scintillation seen almost continually above LOFAR stations across the full bandwidth in observations of strong radio sources such as Cassiopeia A.

Ionospheric Scintillation – KAIRA

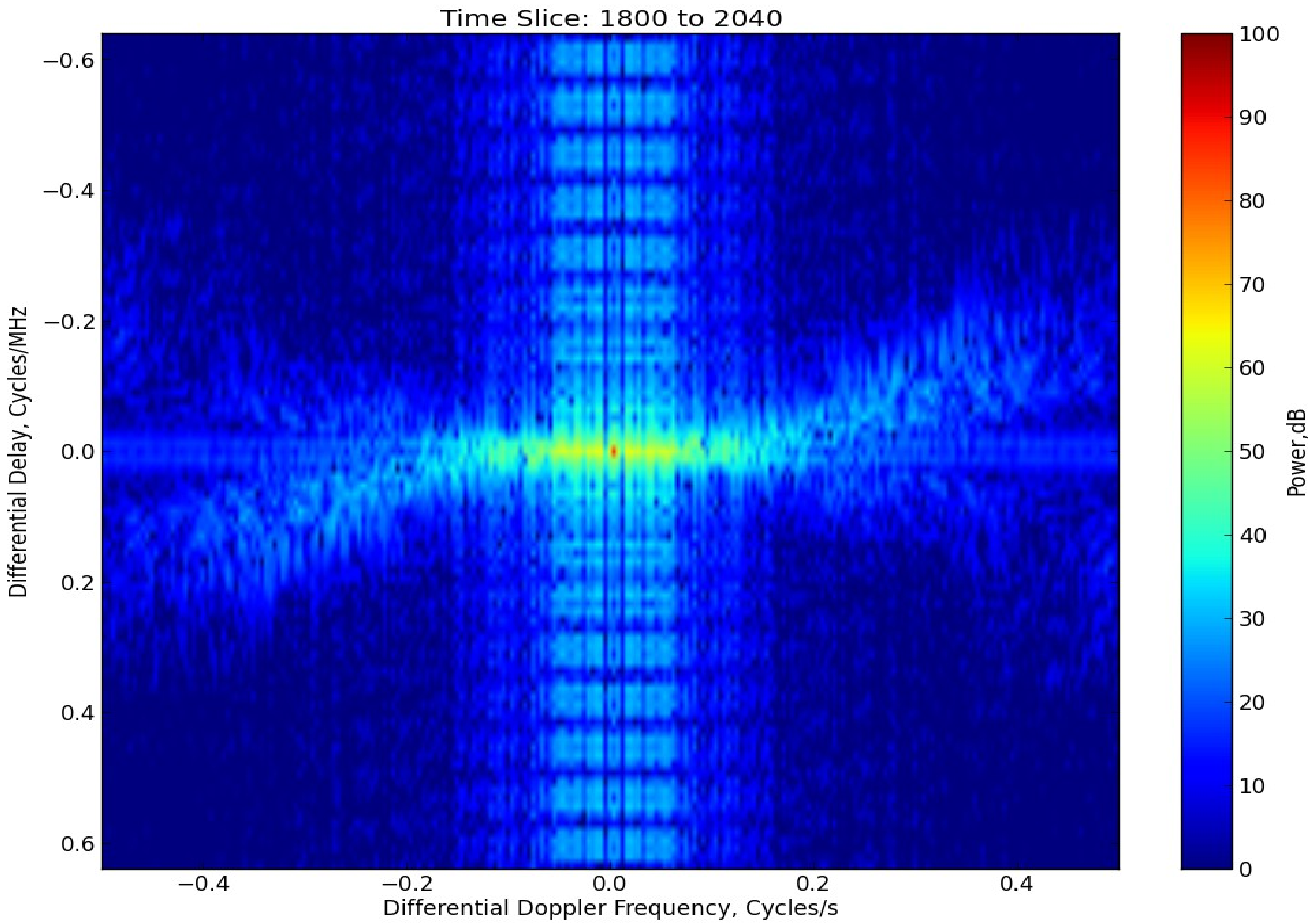


Ionospheric Scintillation – KAIRA



2D Power Spectrum – the "Secondary Spectrum"

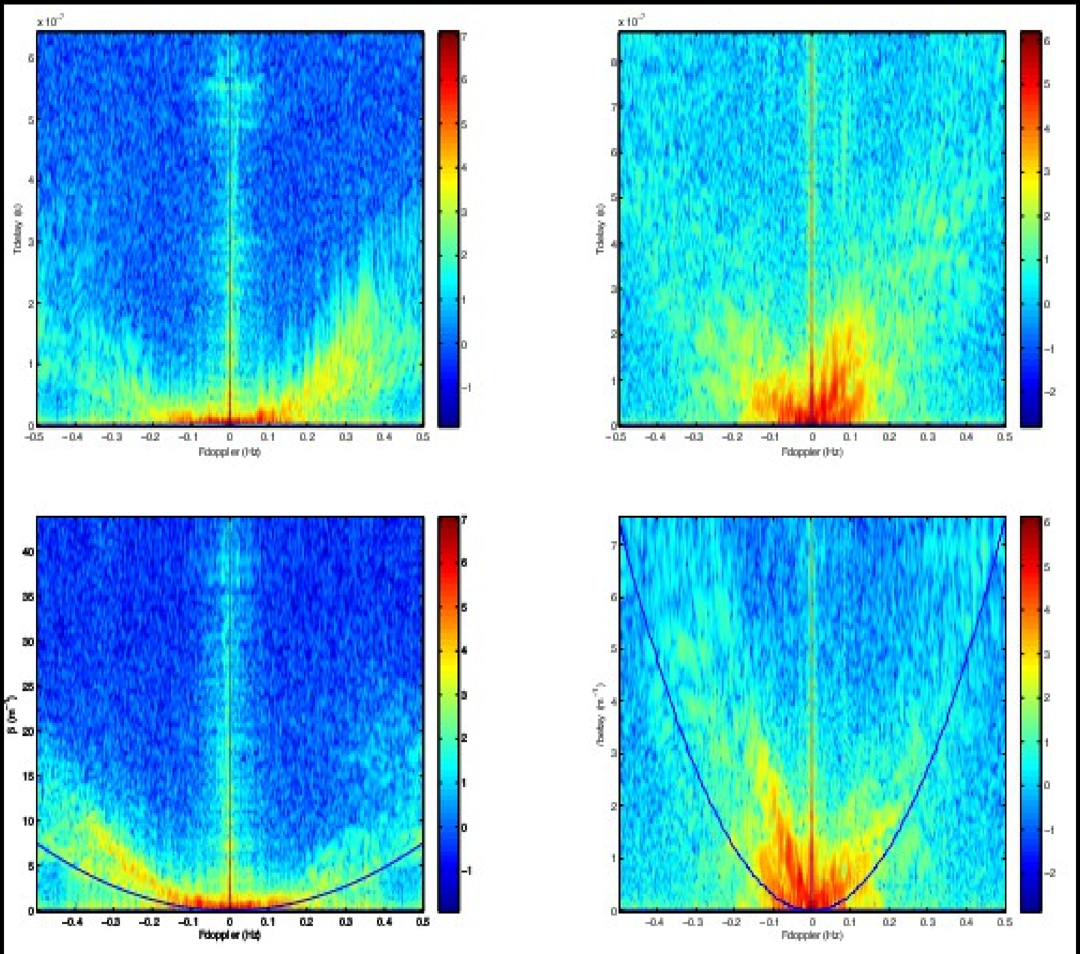
- Following methods of Stinebring et al in analysing Pulsar data to investigate Interstellar Scintillation:
  - Take 2D FFT of the dynamic spectrum and calculate the square of absolute values of the result.
- "Scintillation Arcs" seen in secondary spectra of interstellar scintillation:
  - Used as an invaluable aid to probing the interstellar medium, providing information on, for example, distance to a scattering 'screen' and velocity of the screen across the line of sight.
- Not detected yet in interplanetary scintillation
- Now found in ionospheric scintillation:


Time Slice: 1800 to 2040
−0.6
−0.4
−0.2
0.0
0.2
0.4
0.6
Differential Delay, Cycles/MHz
−0.4
−0.2
0.0
0.2
0.4
Differential Doppler Frequency, Cycles/s
100
90
80
70
60
50
40
30
20
10
0
Power,dB

Interpretation of the Secondary Spectra

- Interpretation requires quite some thinking... We imagine scattering as coming from a 'scattering screen' in the line of sight:
- Differential delay:
  - This represents the delay between different scattered waves.
  - Related to distance to the scattering screen.
- Differential Doppler frequency:
  - Can be thought of as the beat frequency due to different Doppler shifts of scattered waves.
  - Related to velocity of the scattering screen across the line of sight.
- Secondary spectrum can be considered as a delay Doppler spectrum, similar to the spectra obtained by radar.

Modelling Secondary Spectra



- Curvature of scintillation arcs is dependent on wavelength rather than frequency, so arcs become clearer if resampled in wavelength.
- Top plots are calculations from original dynamic spectra.
- Lower plots are calculated from dynamic spectra following resampling in wavelength.

Modelling Secondary Spectra

- Scintillation arcs can be defined by a simple model β, rela the conjugate of wavelength, to Doppler frequency, the conjugate of time in this case:

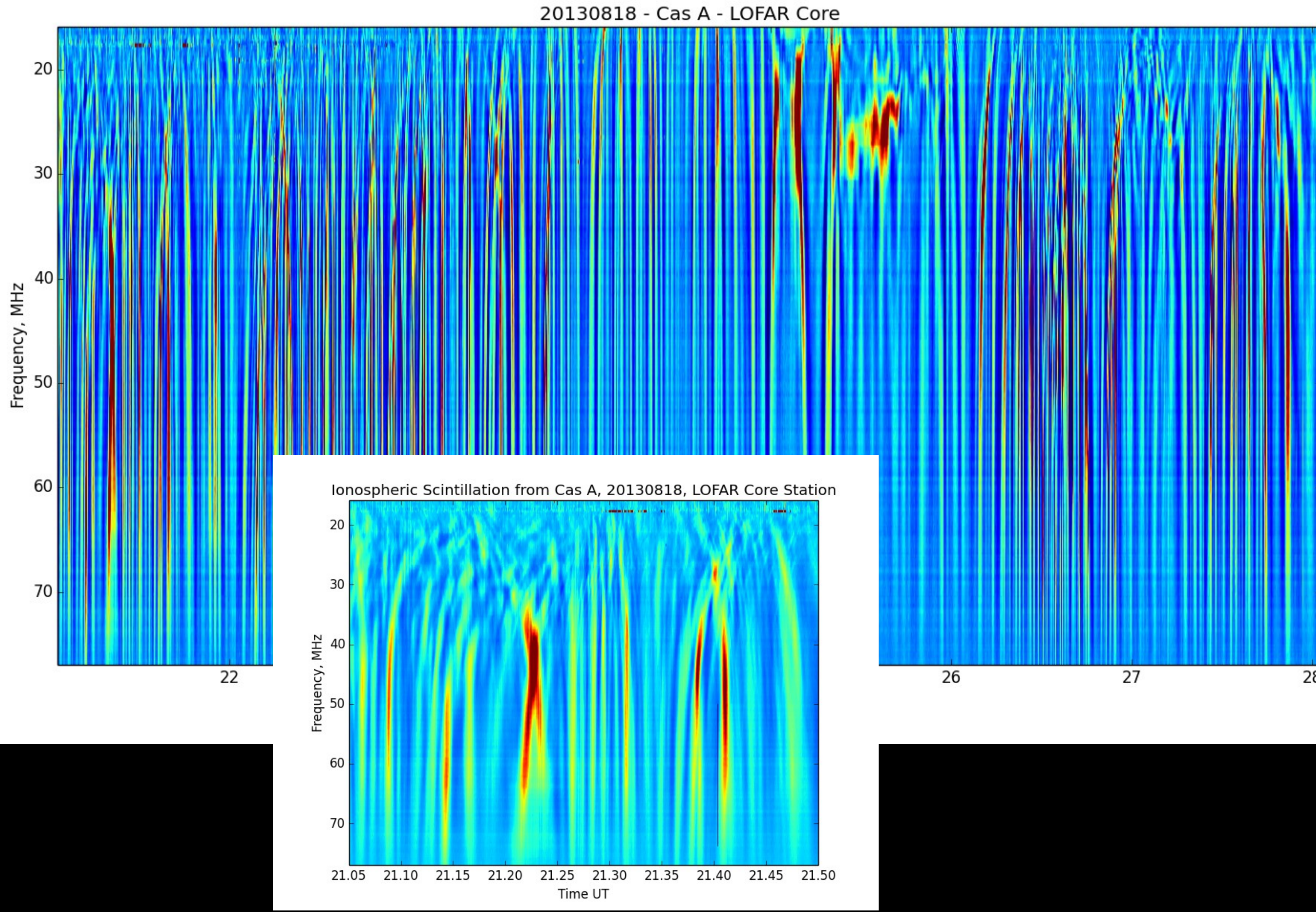
$$\beta = Cf^{2}_{Doppler} + Bf_{Doppler}$$

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.

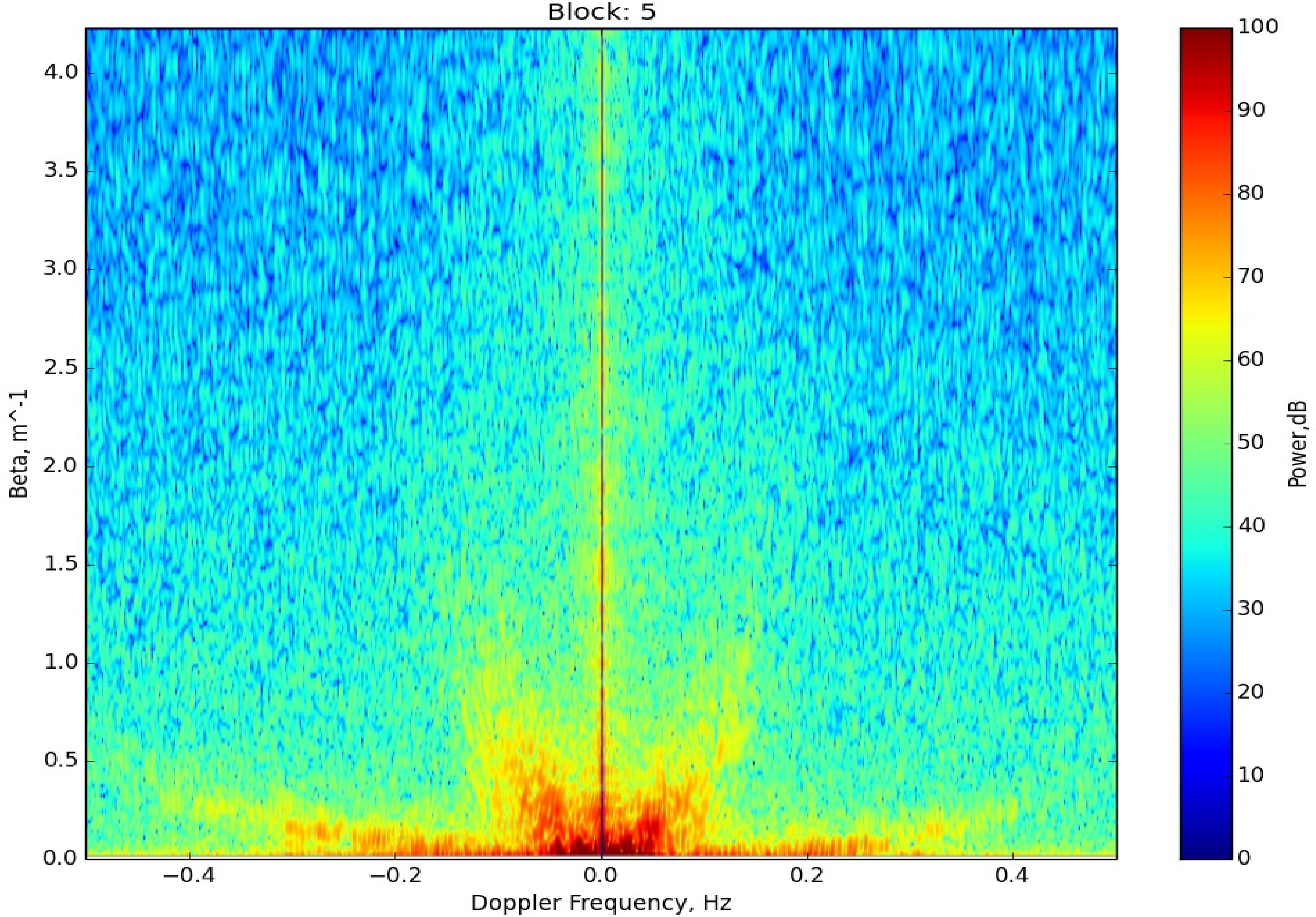
LOFAR Core Data – Cassiopeia A on 18th August 2013



LOFAR Core Data – Cassiopeia A on 18th August 2013

- Calculate secondary spectra from successive five-minute chunks of data.
- Restrict to only lower frequencies, up to about 40 MHz:
  - This is where the structure giving rise to scintillation arcs is.
  - Structure from higher frequencies does not add power to scintillation arcs detected, only obscures them with other parallel structure.
- In many chunks, two arcs seen in secondary spectra.
- Movie demonstrates change in structure through the observation.

LOFAR Core Data – Cassiopeia A on 18th August 2013



LOFAR Core Data – Cassiopeia A on 18th August 2013

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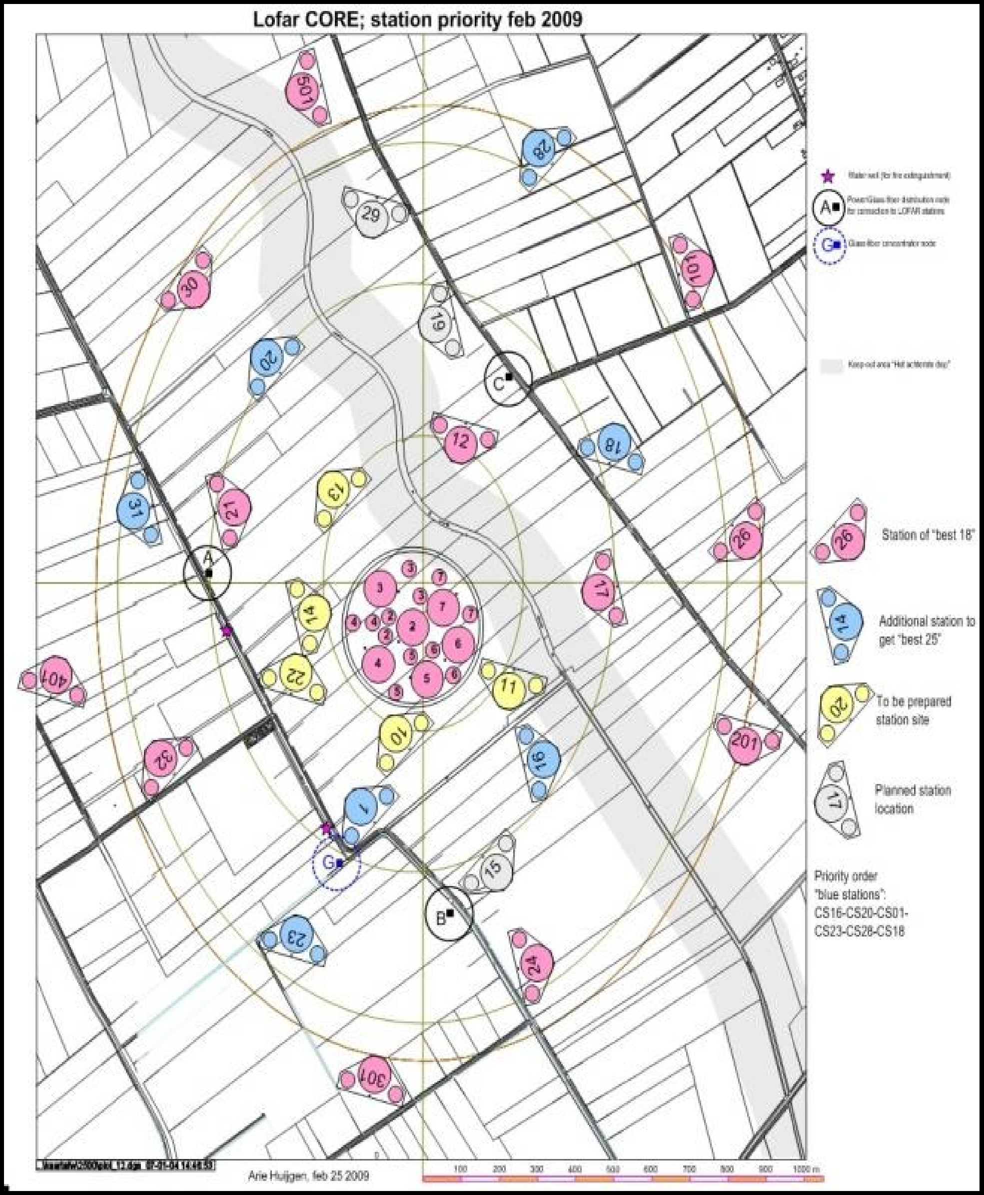
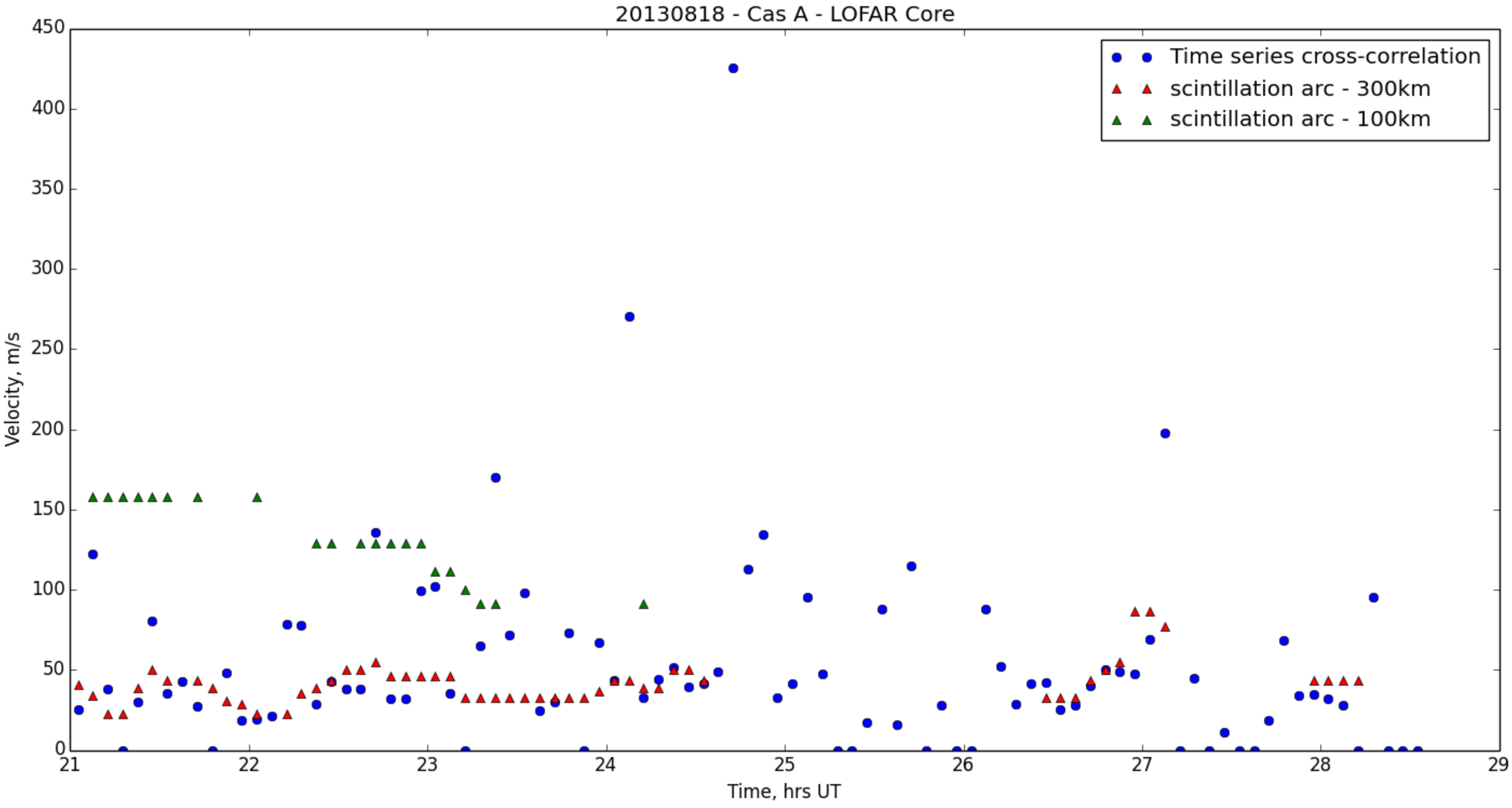


- Can estimate velocity separately by cross-correlating time series' from single subbands of individual core station data:
- Cross-correlation gives time lag of 'flow' of scintillation structure from one line of sight to the next.
- Baseline between stations combined with time lag to estimate velocity.
- 'Quick and dirty' analysis performed: use best correlation between CS002 and other non-superterp stations.
- Also estimate velocities assuming heights of 300km (main arc) and 100km (secondary arc) from scintillation arc curvatures.

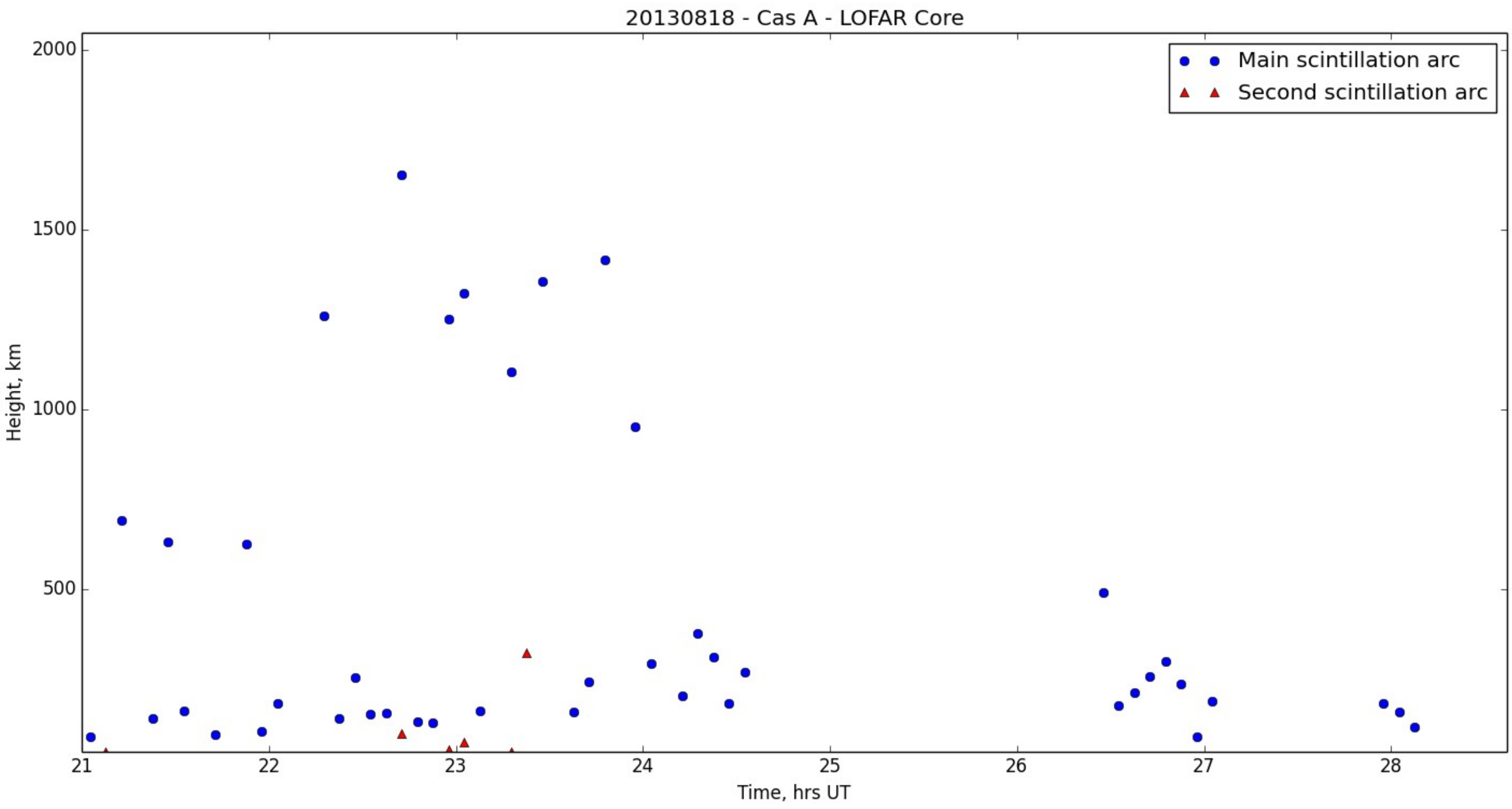
LOFAR Core Data – Cassiopeia A on 18th August 2013



LOFAR Core Data – Cassiopeia A on 18th August 2013

- Some velocities seem rather high: probably due to incorrect choice of baseline for alignment with actual velocity direction.
- Heights for scintillation arc modelling chosen to correspond to approximate heights of peak F-region density and peak density of any sporadic-E layer which may account for second arc.
- Velocities for 300km height seem most consistent with velocities obtained from cross-correlation.
- Now use cross-correlation velocities to estimate heights of dominant scattering screen for each arc.

LOFAR Core Data – Cassiopeia A on 18th August 2013



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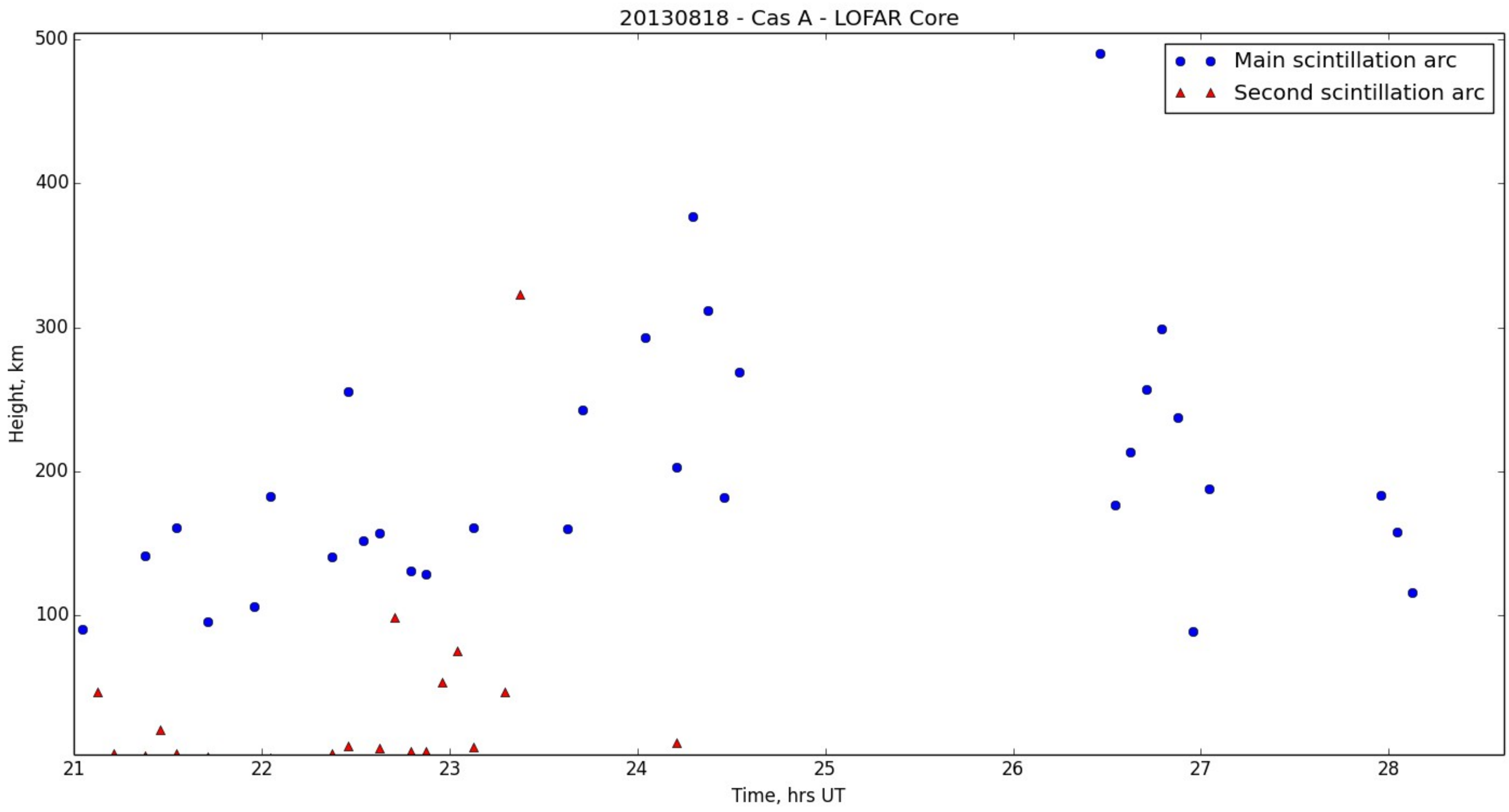

Summary

- First attempt to model scintillation arcs using velocities obtained via another method.
- Enables attempt to calculate height of scattering 'screen'.
- Heights and velocities consistent with scattering in the F-region of the ionosphere.
- Secondary scintillation arc also observed: sporadic-E layer?
- Issues:
  - Some velocities rather high, possibly due to incorrect choice of stations to use in cross correlation.
  - Relation of scattering height to velocity squared makes any calculation of height very sensitive to error in velocity.