Observing the Solar Wind with Interplanetary Scintillation

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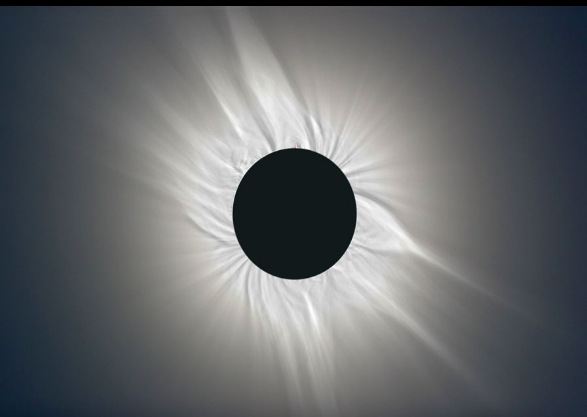
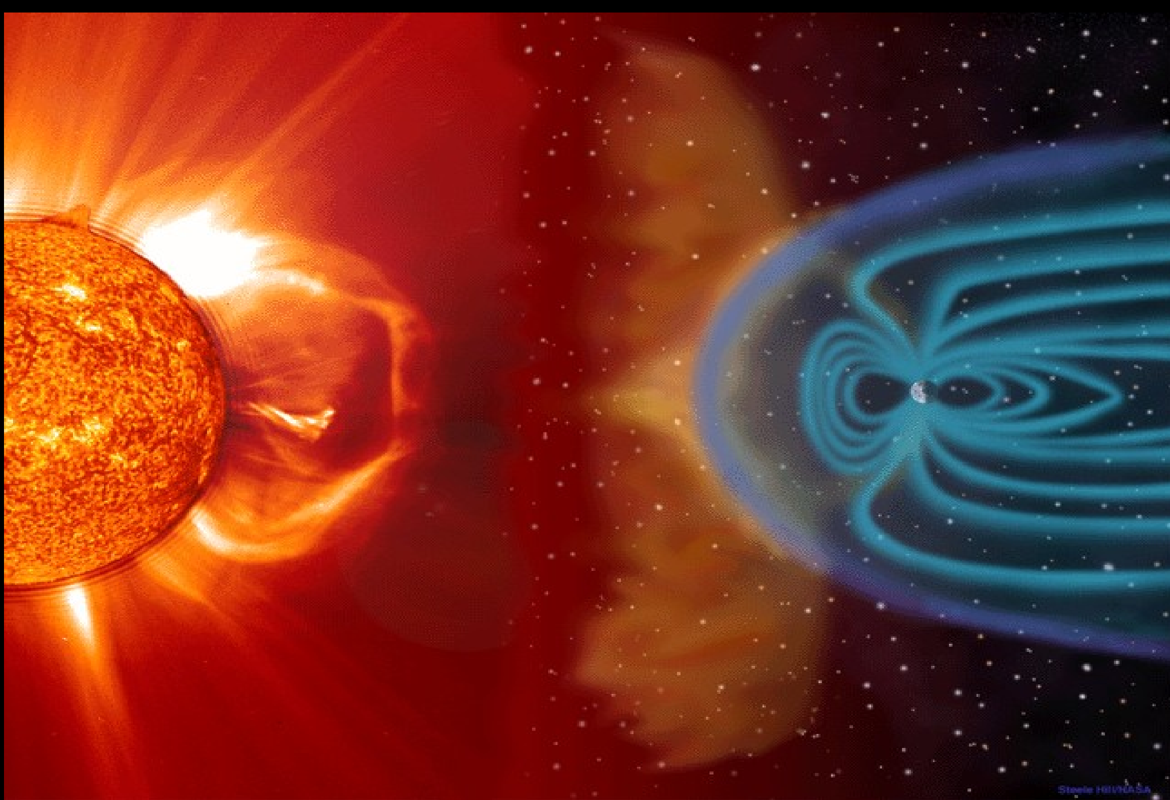
ASTRON

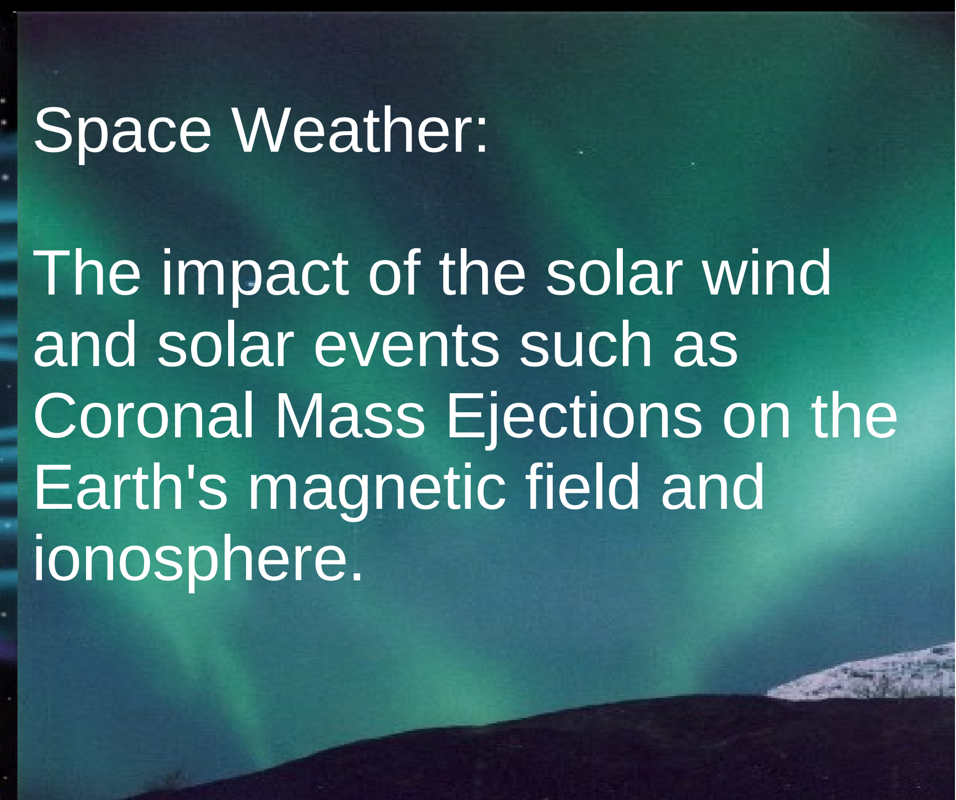
The Sun's Atmosphere



The Solar Corona (March 2006 eclipse).

The Solar Wind: Expansion at supersonic speeds of the Corona through the solar system. Often two streams: “Fast” at ~750km/s and “slow” at ~350km/s.

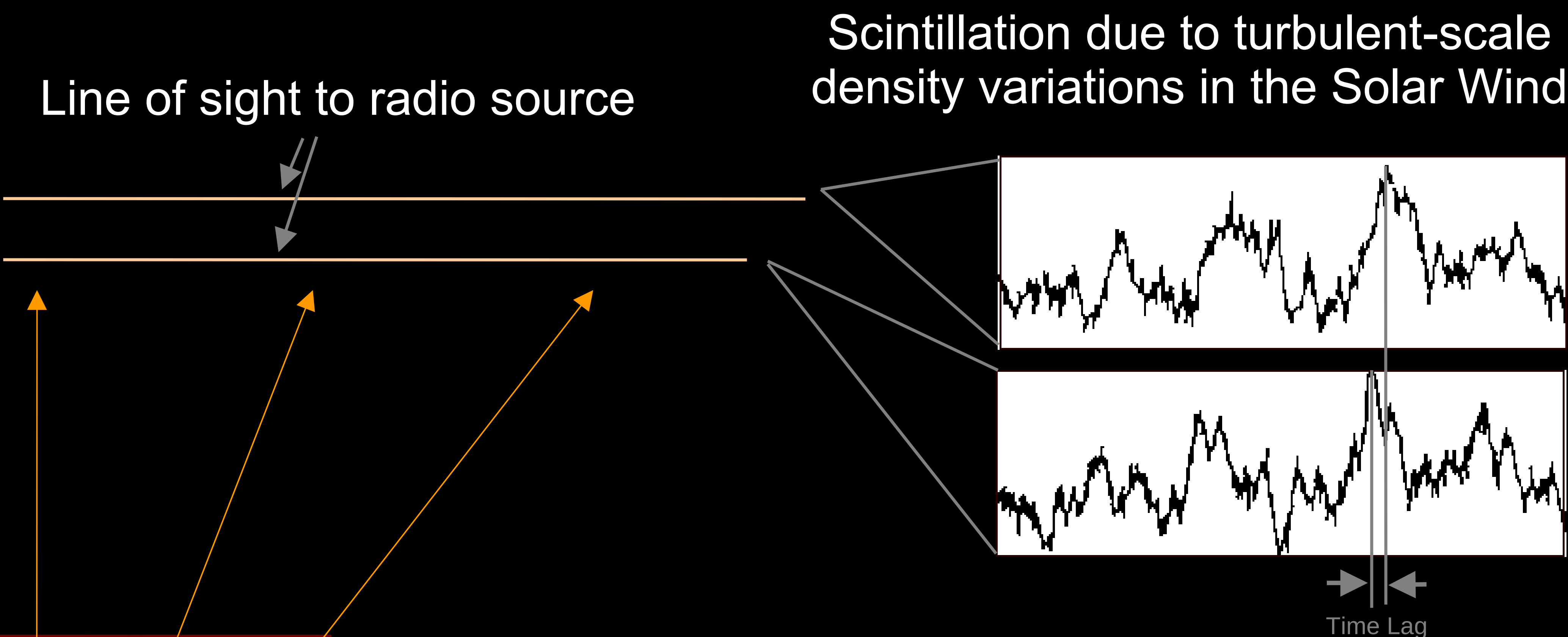


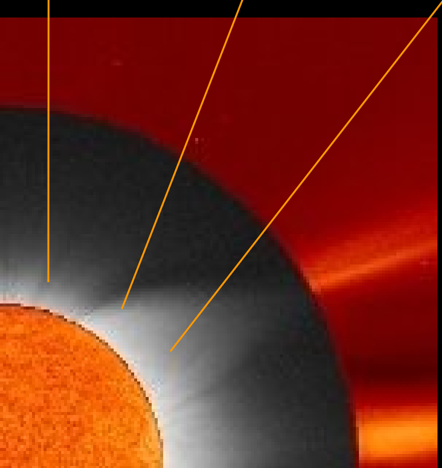


Space Weather:

The impact of the solar wind and solar events such as Coronal Mass Ejections on the Earth's magnetic field and ionosphere.

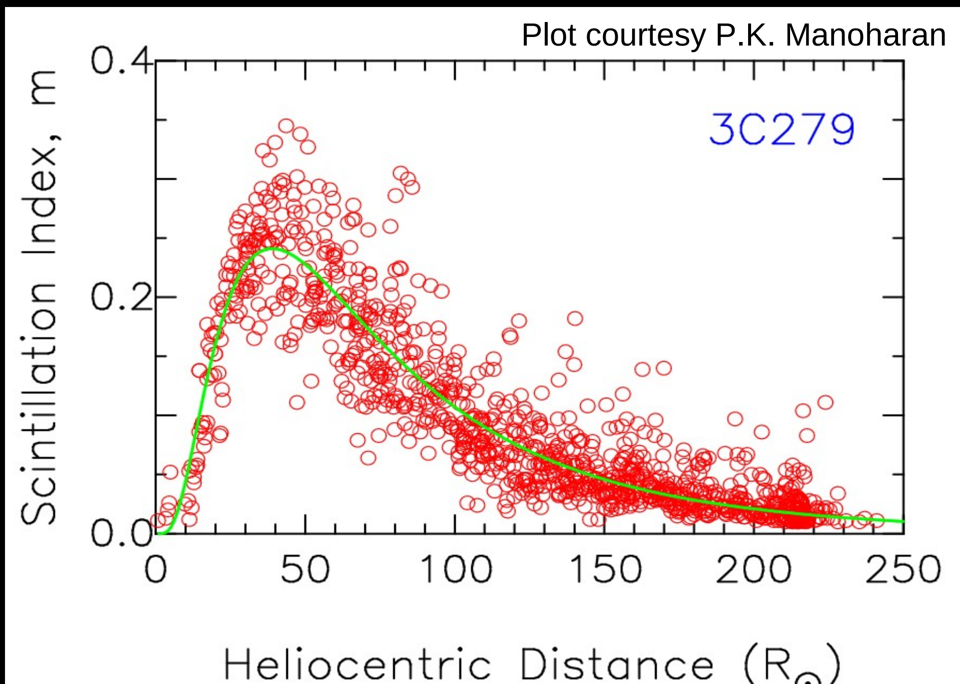
Radio Measurements

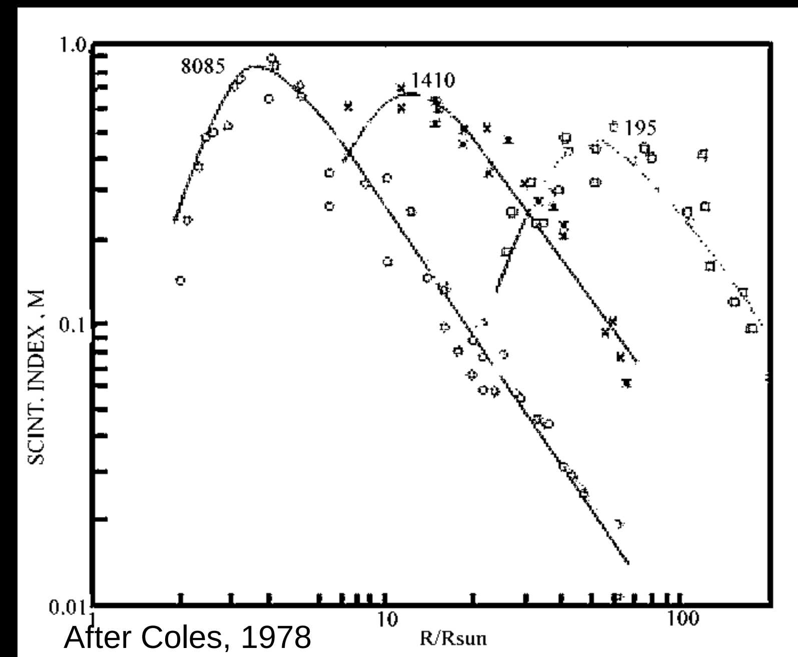




- Simultaneous measurements by two antennas show similar patterns of scintillation.
- Time-lag for maximum cross-correlation gives estimate of solar wind outflow speed.

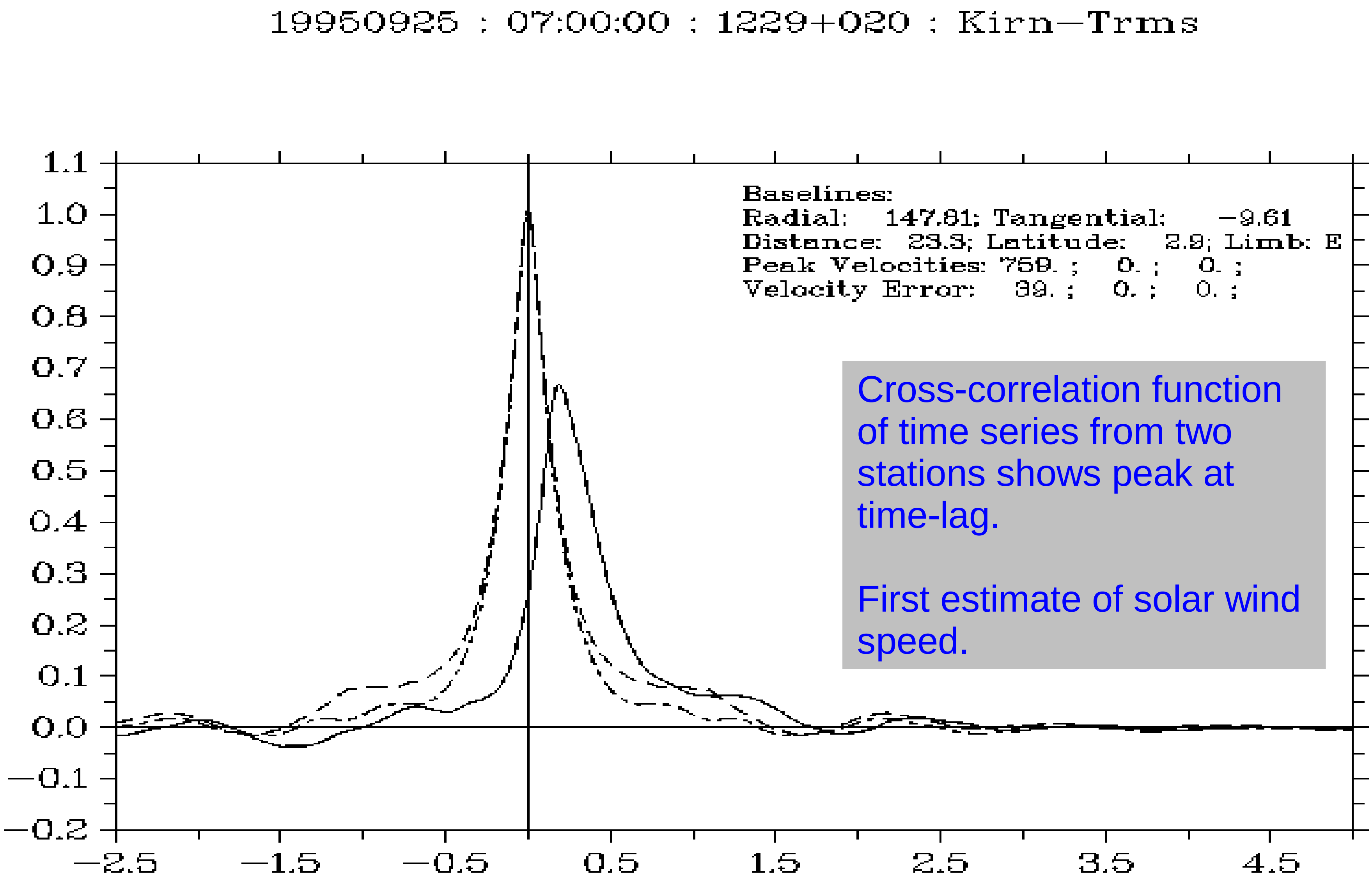
Scintillation Index - "g-level"





- Scintillation index is basic measure of the amount of scintillation:
  - g-level is index normalised for distance: Can be related to solar wind density.
- Peak at certain distance:
  - "Strong" scattering closer to the Sun; "Weak" scattering further away.
  - Distance of peak depends on observing frequency'.

Cross-Correlation

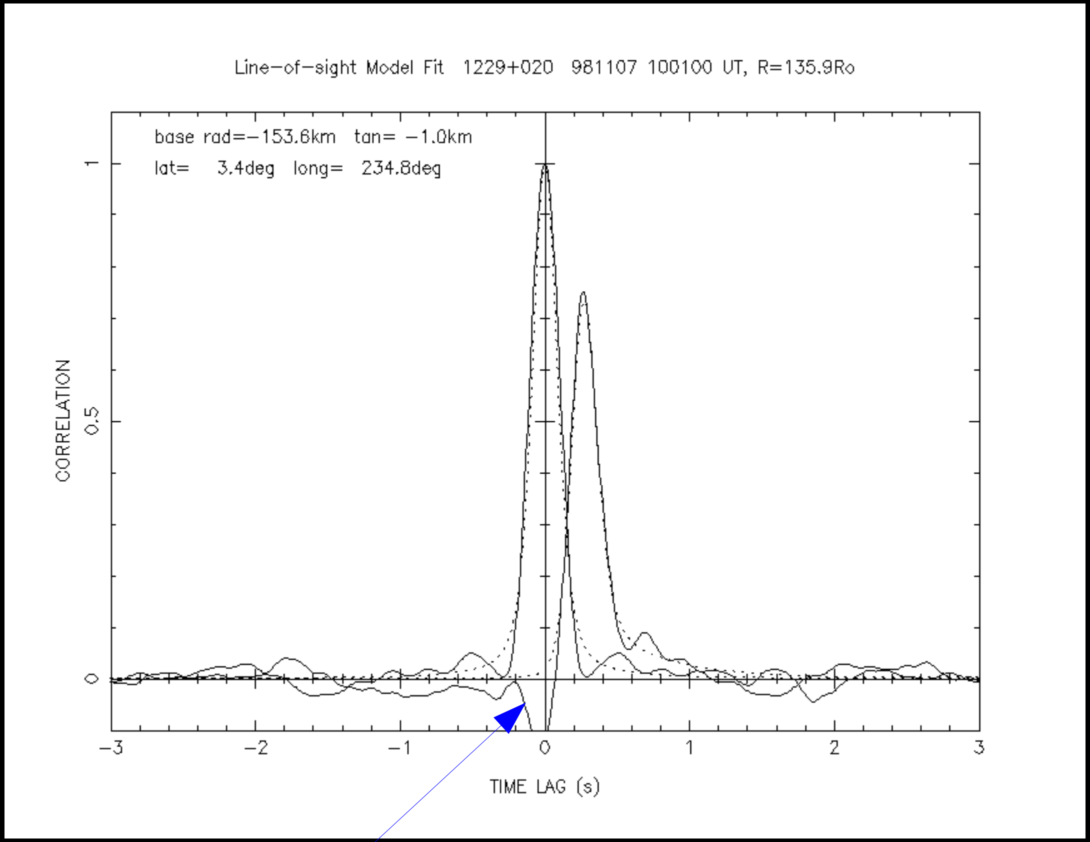


Cross-correlation function of time series from two stations shows peak at time-lag.

First estimate of solar wind speed.

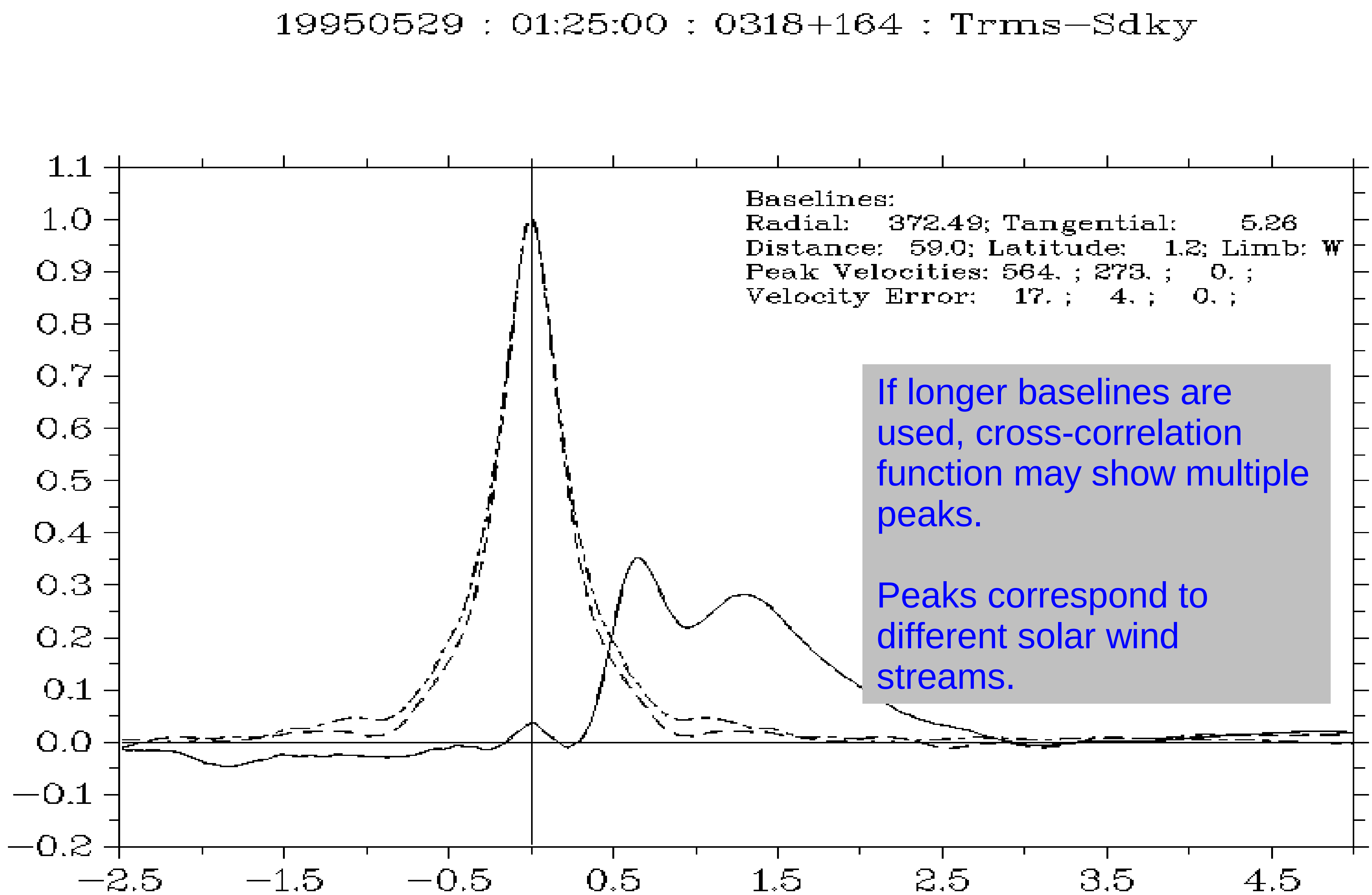
Coronal Mass Ejections (CMEs)

- Presence of CME can be indicated by different features:
  - Substantial changes in form of cross-correlation function
  - Sudden increase in scintillation level
  - Negative lobe on cross-correlation function.



Large “negative lobe” indicates magnetic field rotation

Longer Baselines



If longer baselines are used, cross-correlation function may show multiple peaks.

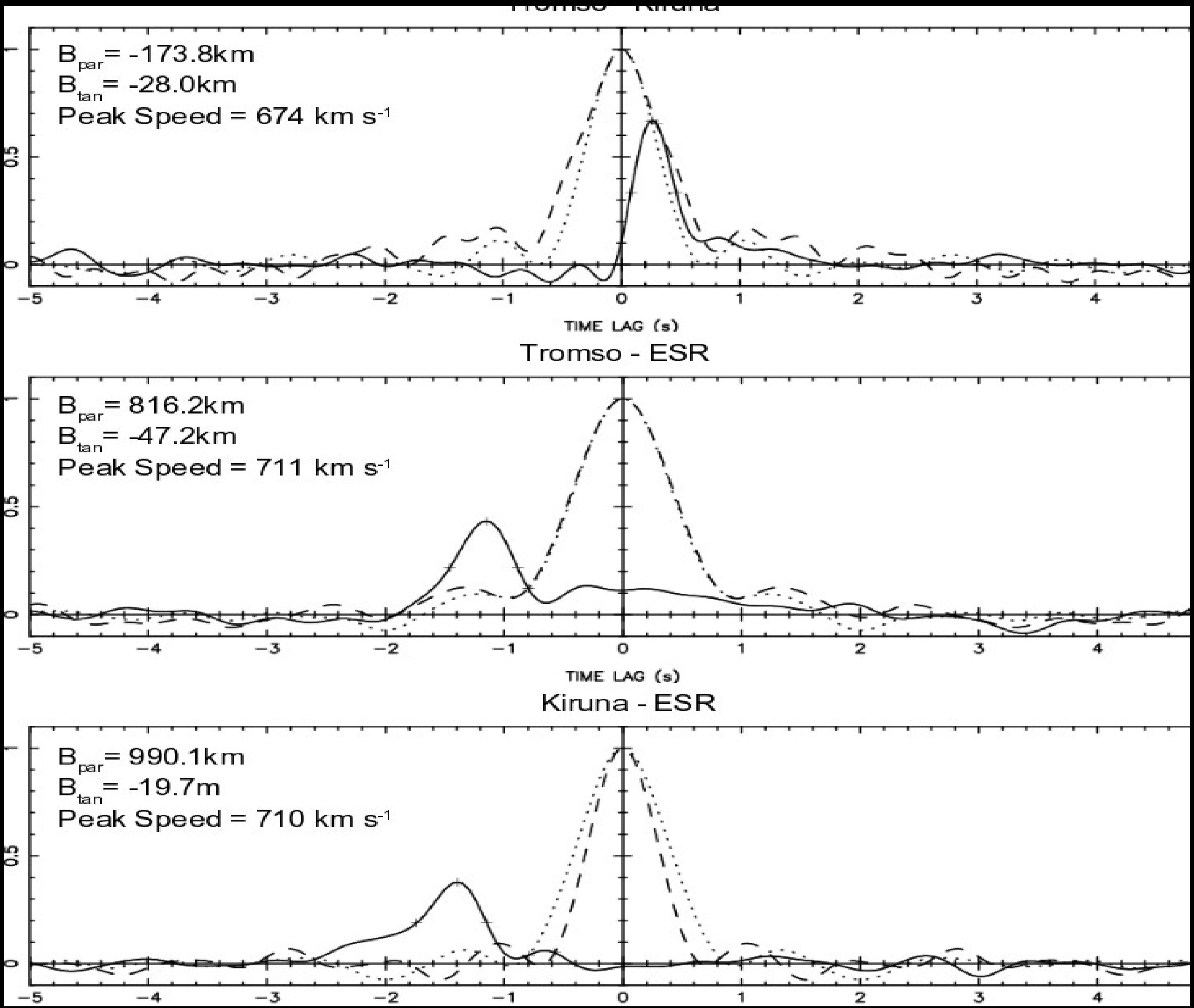
Peaks correspond to different solar wind streams.

Dual-Frequency Correlation

928/1420MHz

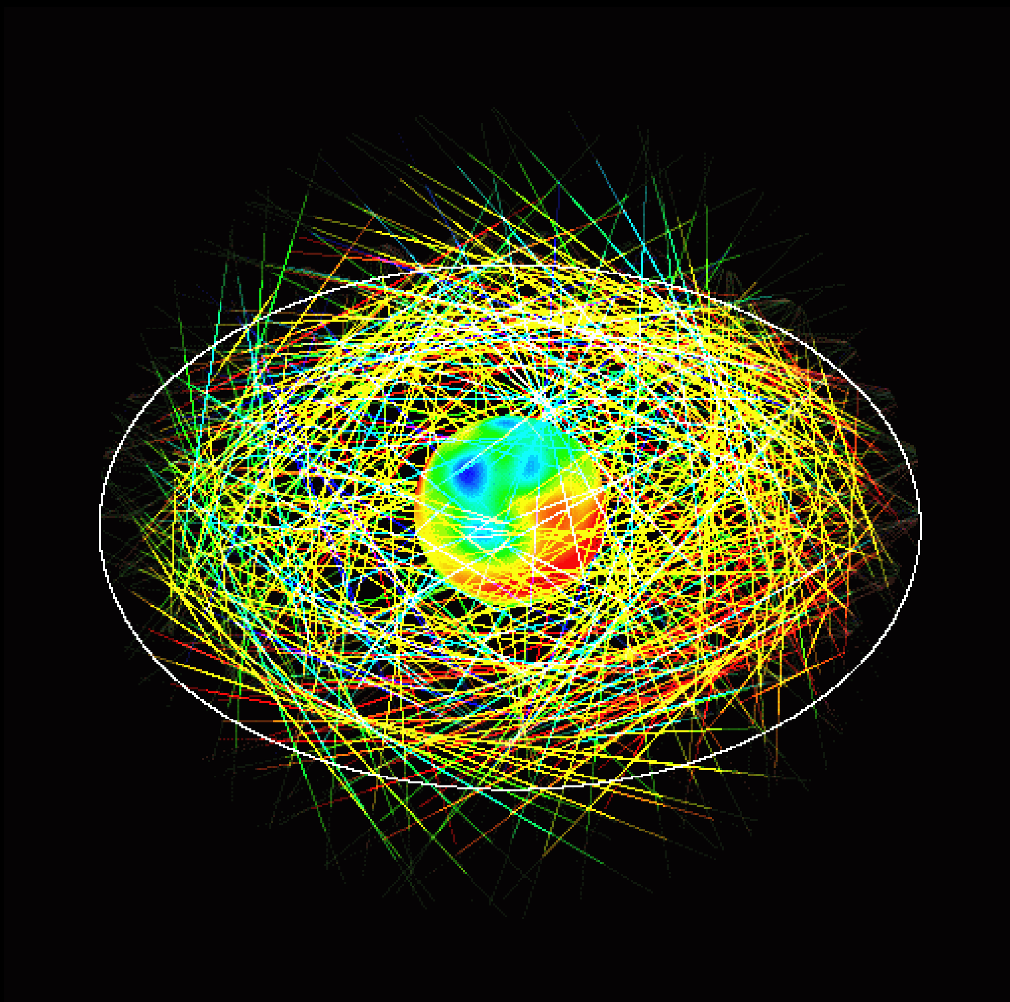
928/500MHz

1420/500MHz



0319+415, distance = 85Rs

Tomography

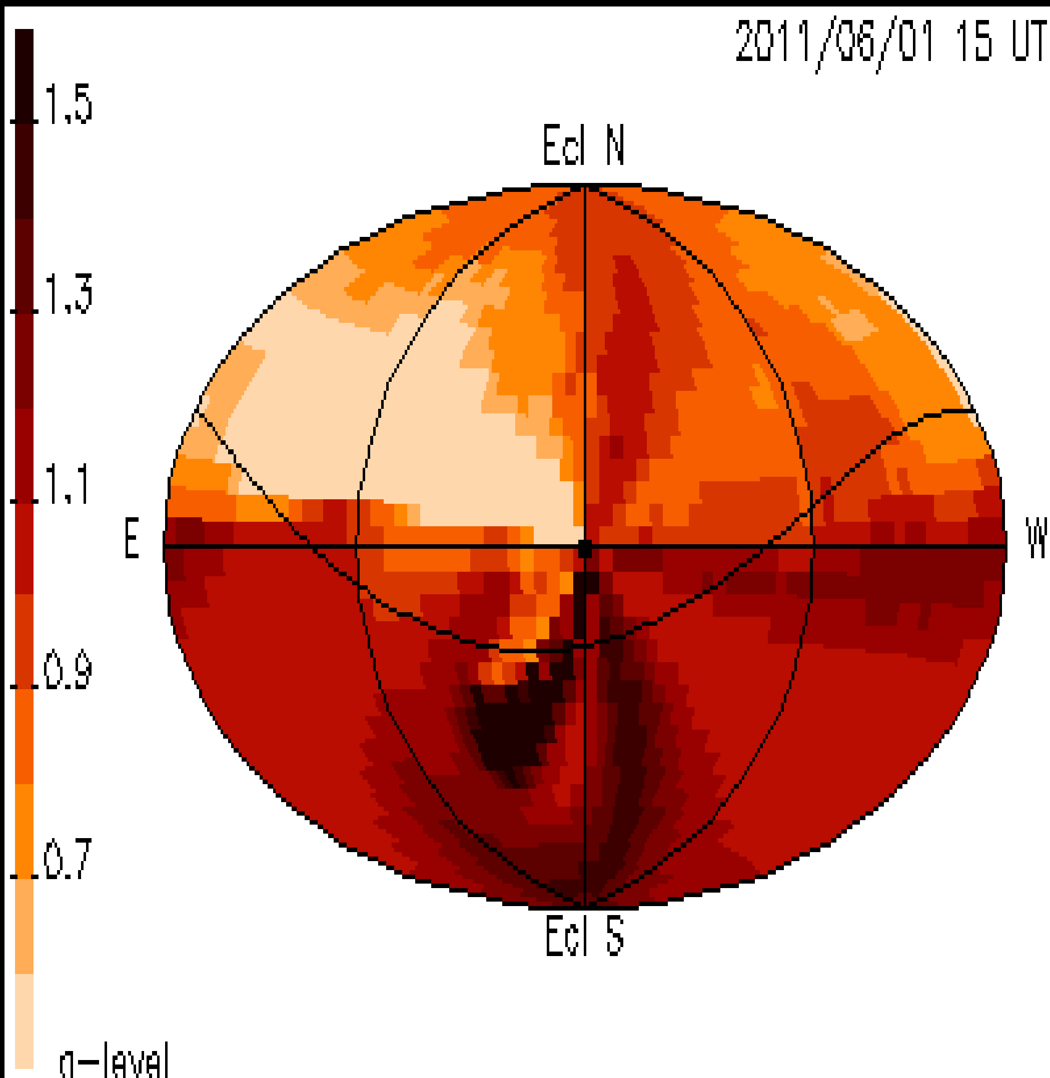


- Many observations taken as Sun rotates results, in the Sun's frame of reference, in many overlapping lines of sight between antennas and radio sources.

- These used to create a “tomographic” image of the inner heliosphere in both g-level and solar wind speed.

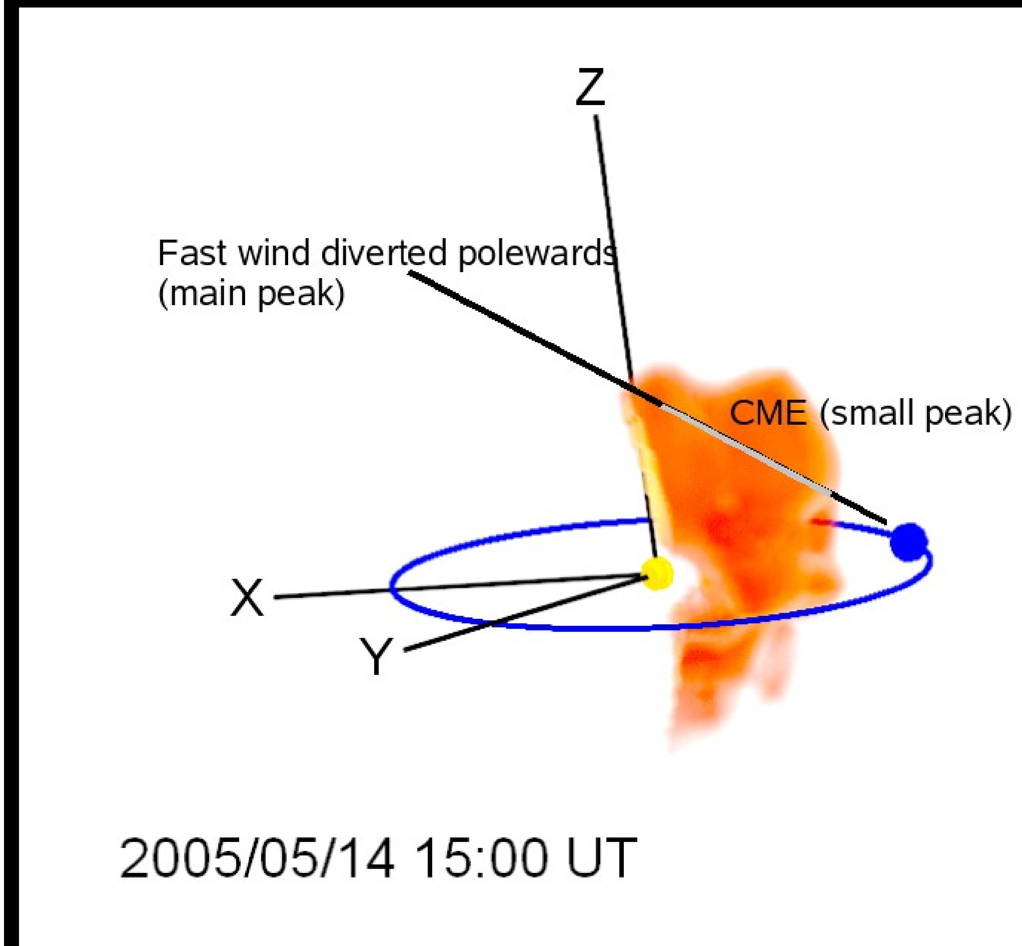
After Manoharan, 2008

Tomography



Co-rotating analysis

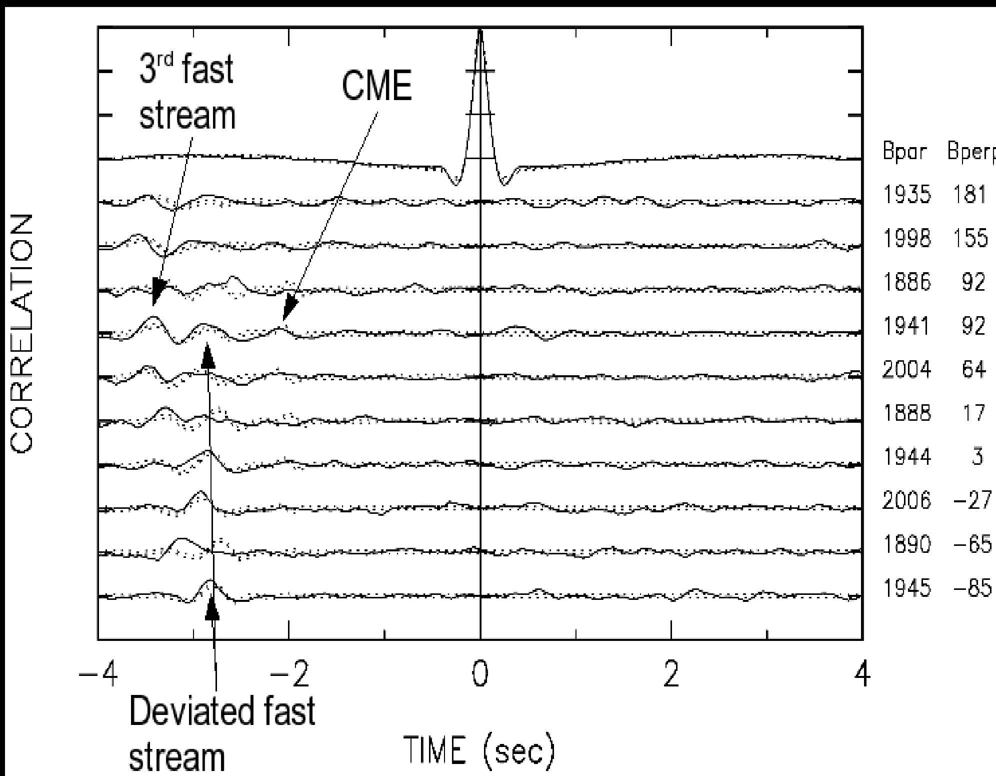
Combination of methods



EISCAT IPS line of sight through tomographic image of CME. CME gave Earth glancing blow; registered in ACE spacecraft data.

Images courtesy M. Bisi (Aberystwyth) and B. Jackson (UCSD)

Cross-Correlation Analysis



- Longer antenna baselines allow different solar wind streams in line of sight to be measured accurately.
- Variation of height of cross-correlation functions with baseline can be used to determine flow direction.
- Data are analysed by fitting a weak-scattering model to the power spectra.

EISCAT IPS observation of CME on 14th May 2005; auto-correlation is top, remaining are cross-correlations. Cross-correlation functions also show two adjacent fast streams. Baselines projected onto sky plane: Bpar in radial direction, Bperp in meridional direction.

Why EISCAT?

- Observing frequency was, historically, convenient for looking closer to the Sun.
  - Now, with space weather becoming more important, the changes in observing frequency mean we can look further from the Sun and closer to the Earth.
- Longer baselines mean better resolution of solar wind streams.
- Being a passive experiment means that time awarded equates to much more in real time.
- Time is only “used” when data are recorded:
  - Can have many short observations through a day, and observe over a few weeks.

What's Needed?

- Need ability to track radio sources
- Need a reasonable bandwidth
- Need high time resolution (~ 100Hz)

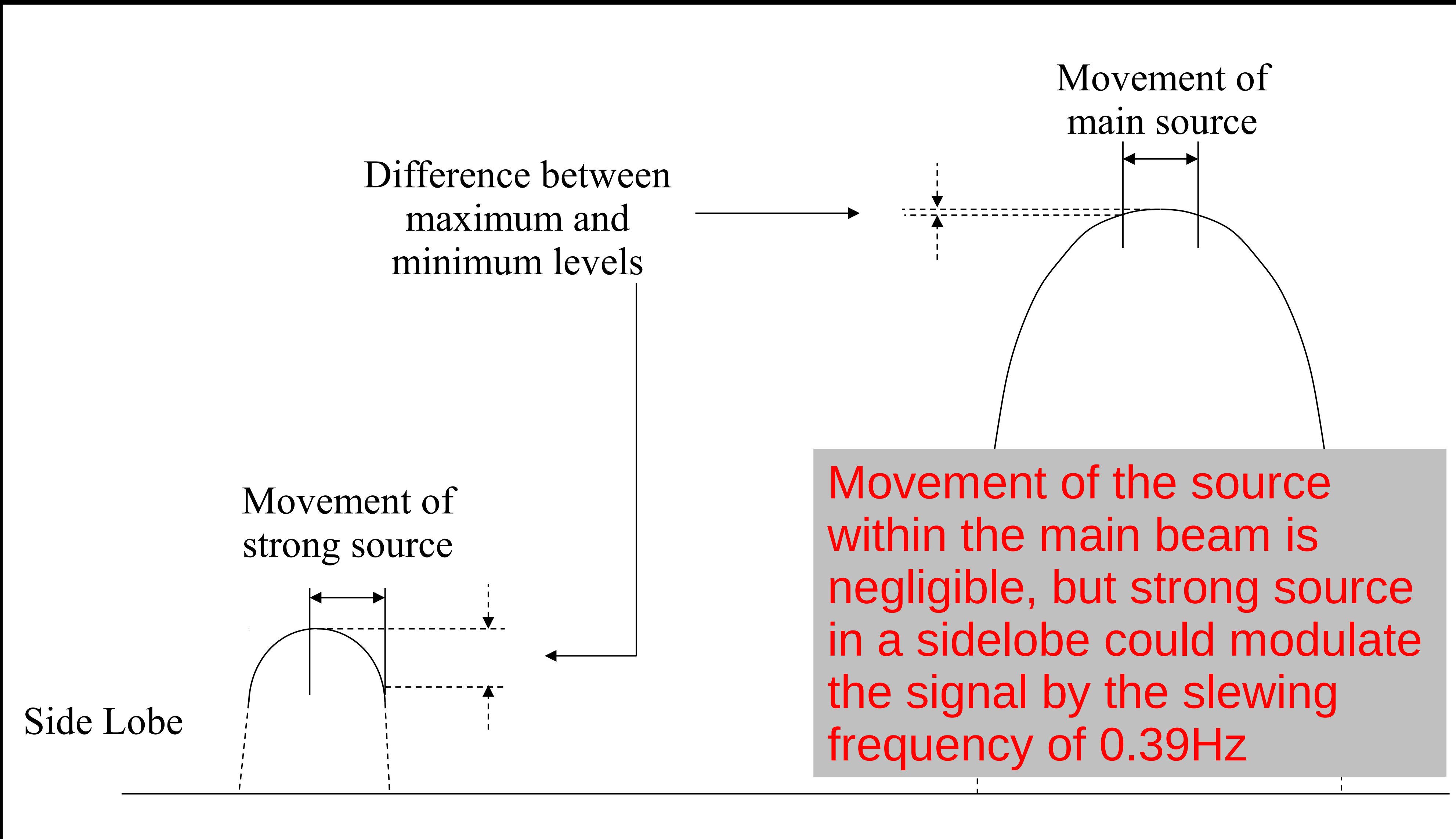
- May also need remote sites to be converted to 1420MHz

Radio Source Tracking

- The mainland EISCAT antennas were never designed to track radio sources, only to slew at a constant speed between fixed positions.
- Tracking is achieved by slewing the antenna to a new position just ahead of the radio source every few seconds.
- The radio source then drifts through the beam before the position is updated again.
- Rate of antenna position update set to 2.56s for convenient filtering of any effect of doing this.

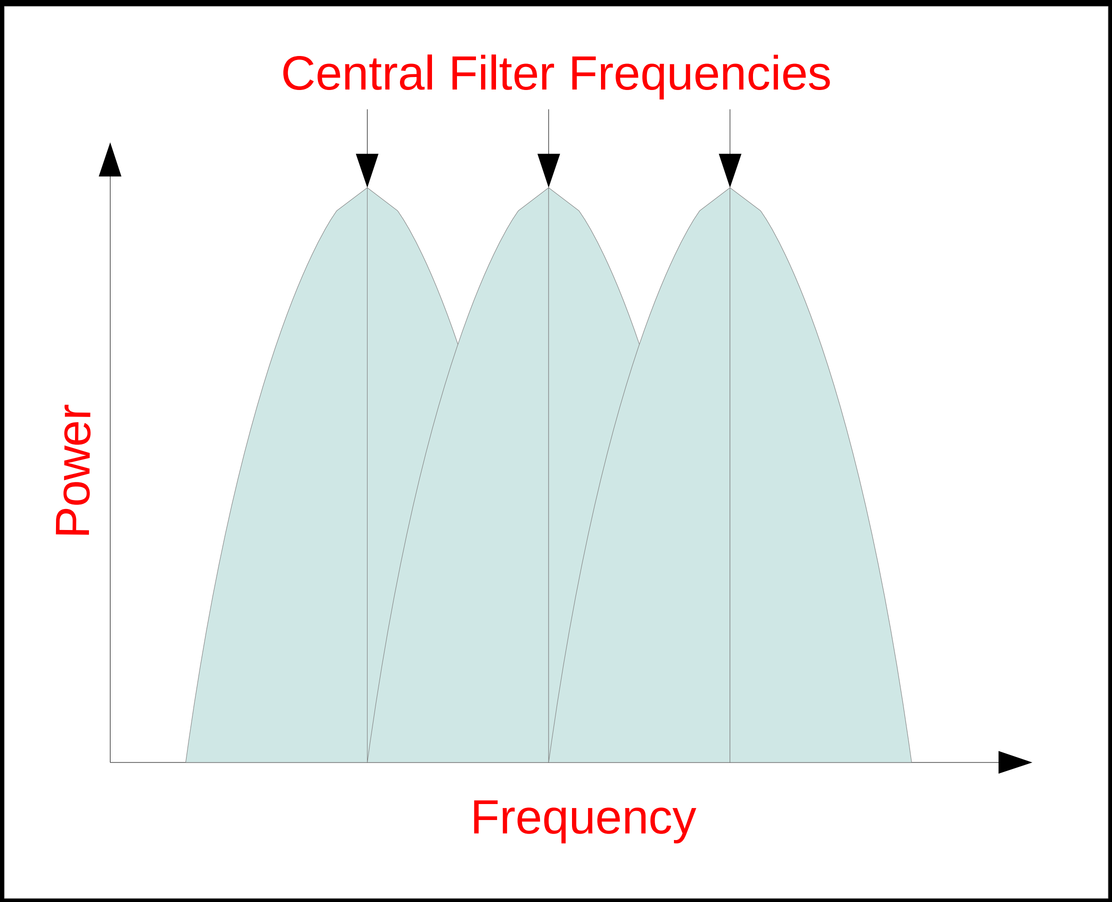
- The ESR does have a tracking mode, so this does not apply to that antenna.

Radio Source Tracking



Movement of the source within the main beam is negligible, but strong source in a sidelobe could modulate the signal by the slewing frequency of 0.39Hz

Filter Settings



- Signal passes through a rack of six channel boards.
- Filters on these boards are used to sample different parts of the signal.
- For IPS, these filters are set to 1.8MHz wide with central frequencies such as to cover a bandwidth of 5.4MHz.

We can/could only use three channel boards:
Data rate too high for more!

Interference Issues

- Rise of mobile phones has encroached on the traditional observing band of EISCAT.
- Space around 930MHz now very limited, especially at Sodankylä.

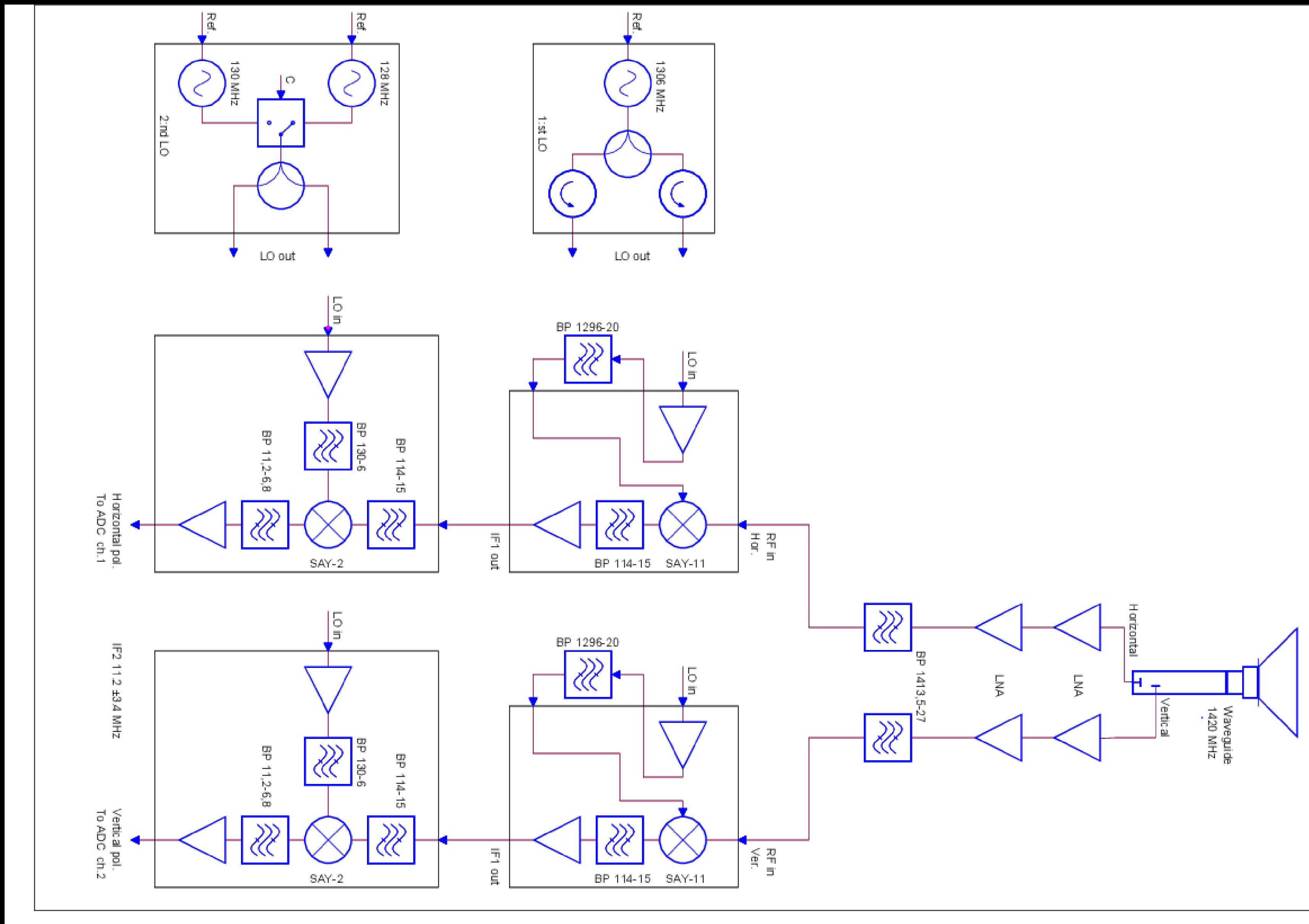
Median Sampling

- Data usually sampled initially at a very high rate and then averaged down to a sampling rate of 100Hz later.
  - Historically, the averaging was done in a separate 'IPS card'
  - Now done by the channel board filters.
  - Averaging performed using a standard mean.
- Averaging using the *median* is less susceptible to interference spikes (if there are not too many...).
  - Can do this at EISCAT, but only by recording data at the full rate and averaging in software later!
  - Sometimes results in data drops because of the rate...

1420MHz System

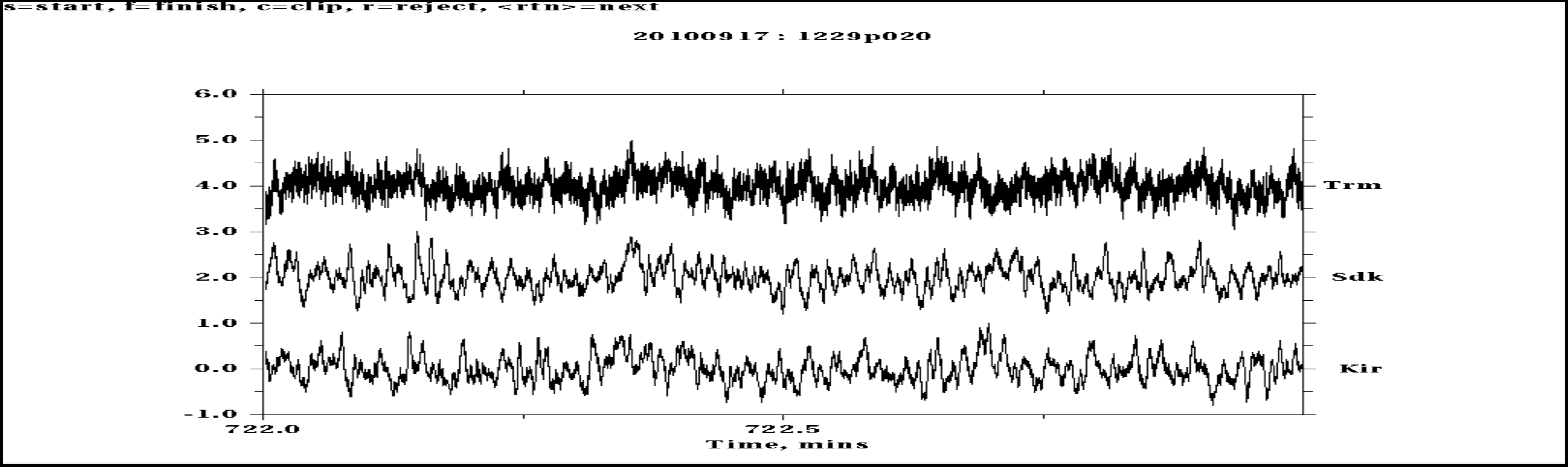
- 1420MHz system established for the remote sites in 2003.
  - Protected astronomy band (cannot transmit here!).
  - Requires replacement of several waveguide and other parts.
  - Takes ~1.5 hours per antenna.
  - Not possible to do this at Tromsø.

1420MHz System



1420MHz System

- Now have ability to use full front-end bandwidth at 1420MHz:
  - New total-power receivers installed at remote sites.
  - These sample the signal over the full bandwidth for each polarisation.
  - The sampled signals are then passed straight through the channel boards without further filtering.



Summary

- EISCAT used for observing IPS since early 1990s.
- Proved a reliable system over the years which offers a number of advantages over others.
- New move to VHF frequencies will open up more detail on the heliosphere closer to Earth.
- EISCAT 3D should provide extra opportunities!