# Measuring the equatorial spread F irregularity k-space spectrum with the Jicamarca radar: Preliminary results

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# Outline

- A recipe for measuring ESF irregularity k-spectrum from ground-based coherent scatter radars
- Technical and processing challenges
  - Frequency vs. range aliasing (overspread target)
  - Varying the scattering volume (radar imaging)
- Preliminary results using radar imaging and range aliasing.
- Concluding remarks.

# Recipe for getting "k-spectrum" from radar obs. (1)

- Following *Hysell and Chau* [2004]
  - we predict the shape of ESF coherent scatter spectra associated with plasma turbulence [R(t) is a time integrated diffusivity].
  - shape is hybrid Gaussian – Lorentzian
  - spectral width depends on the turbulent energy within the scattering volume

$$ACF \propto \exp[-k_s^2 R(t)]$$

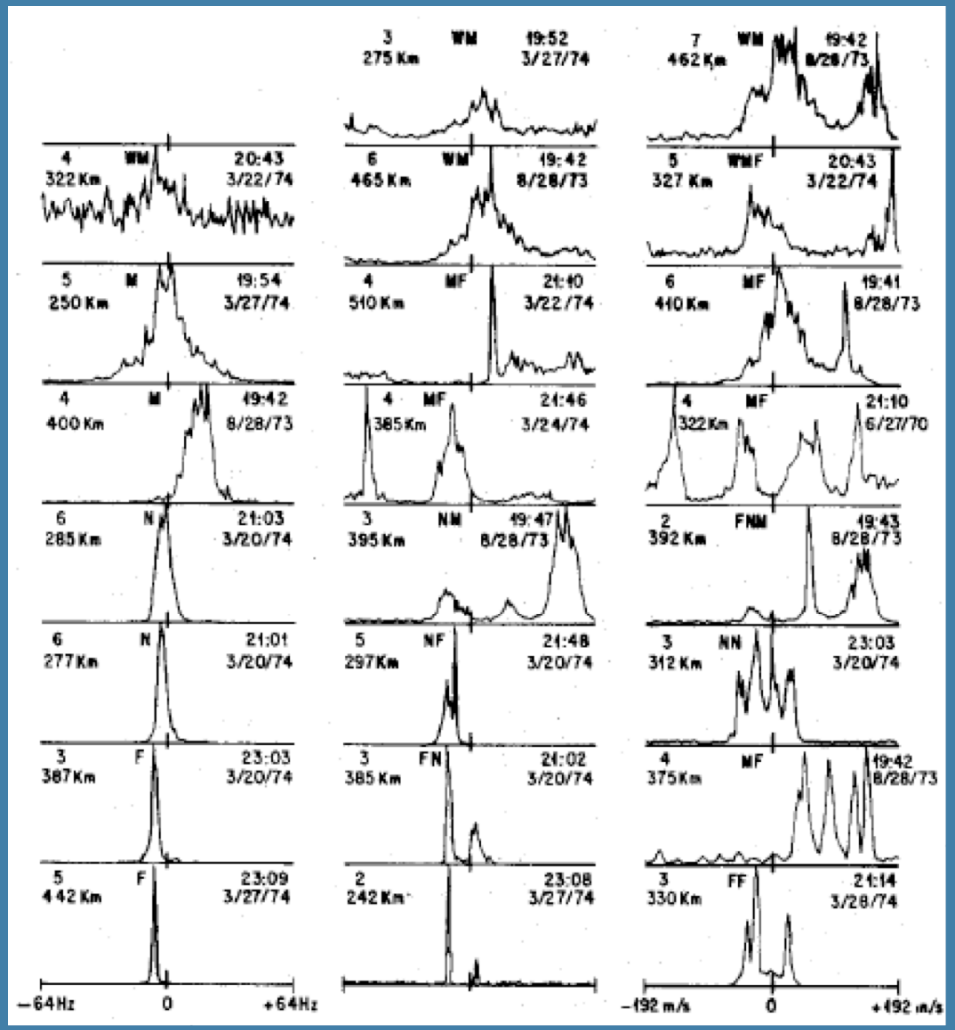
$$\begin{aligned} R(t) &\propto t^2 && \text{short - time} \\ &\propto t && \text{long - time} \end{aligned}$$

# Recipe for getting "k-spectrum" from radar obs. (2)

- theory is only applicable to strongly driven flows in the topside F region thought to occur when the ionospheric interchange instability underlying ESF enters its inertial regime, i.e., statistically homogeneous and isotropic turbulence.
- expected during intense topside ESF events and moderate to high solar conditions.
- shape of the energy and power spectrum of the irregularities can be estimated from inverting the obtained Doppler spectra using different scattering volumes (reconstruction/inversion).

$$\left(\frac{dR}{d\tau}\right)^2 \propto \sum_k \underbrace{\left\langle \left|\mathbf{E}(\mathbf{k})\right|^2 \right\rangle}_{\rightarrow \left|n_k\right|^2} \left(\frac{1-\exp(-2k^2R)}{2k^2}\right)$$

# Morphology of ESF Doppler Spectra



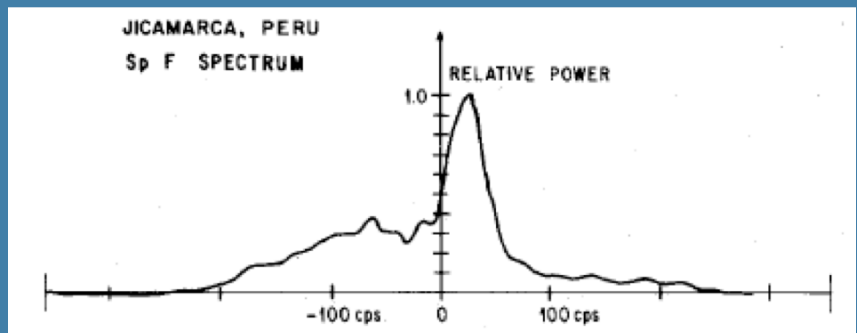




Fig. 5. Sampling record showing the WM type spectrum without frequency aliasing.

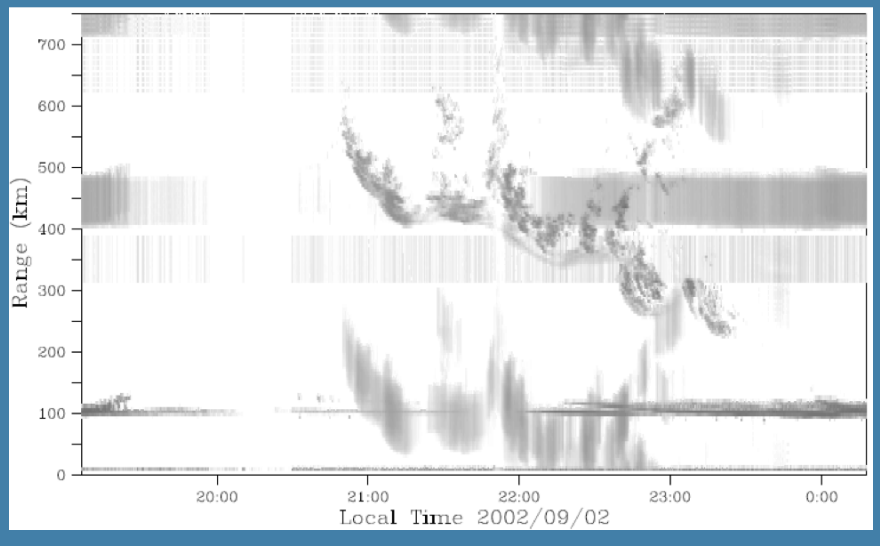
Overspread target!

[*Woodman and La Hoz, 1976*]

# Aperiodic pulsing

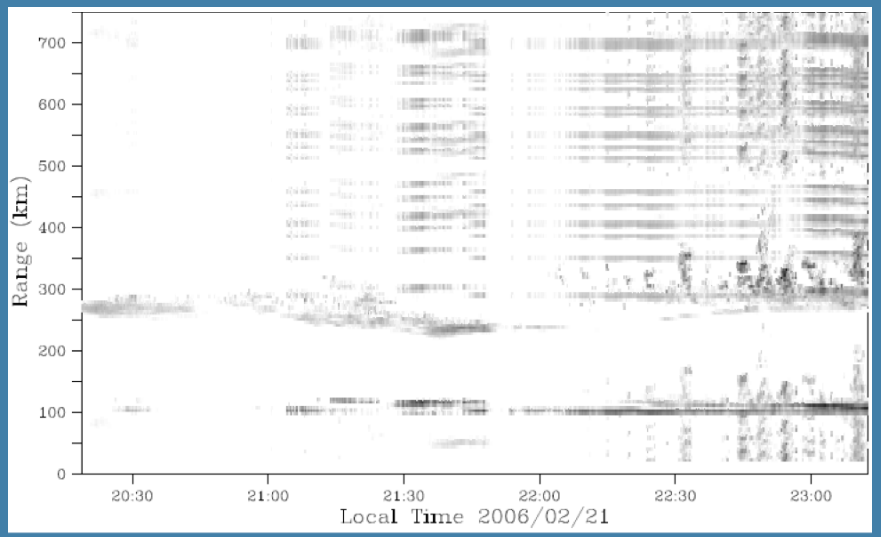
**$PRF_{avg} > f_{Nyquist}$**

- Narrowly staggered pulses
- No multipulse interval repeats in an n-pulse cycle.
- Clutter concentrated on few ranges
- Clutter is always white!




**$PRF_{max} > f_{Nyquist}$**

- Widely staggered pulses
- No multipulse interval repeats in an n-pulse cycle.
- Wide distribution of clutter
- Clutter is always white
- More uniform ACF sampling



# ESF spectra using $PRF_{avg}$ and Periodogram

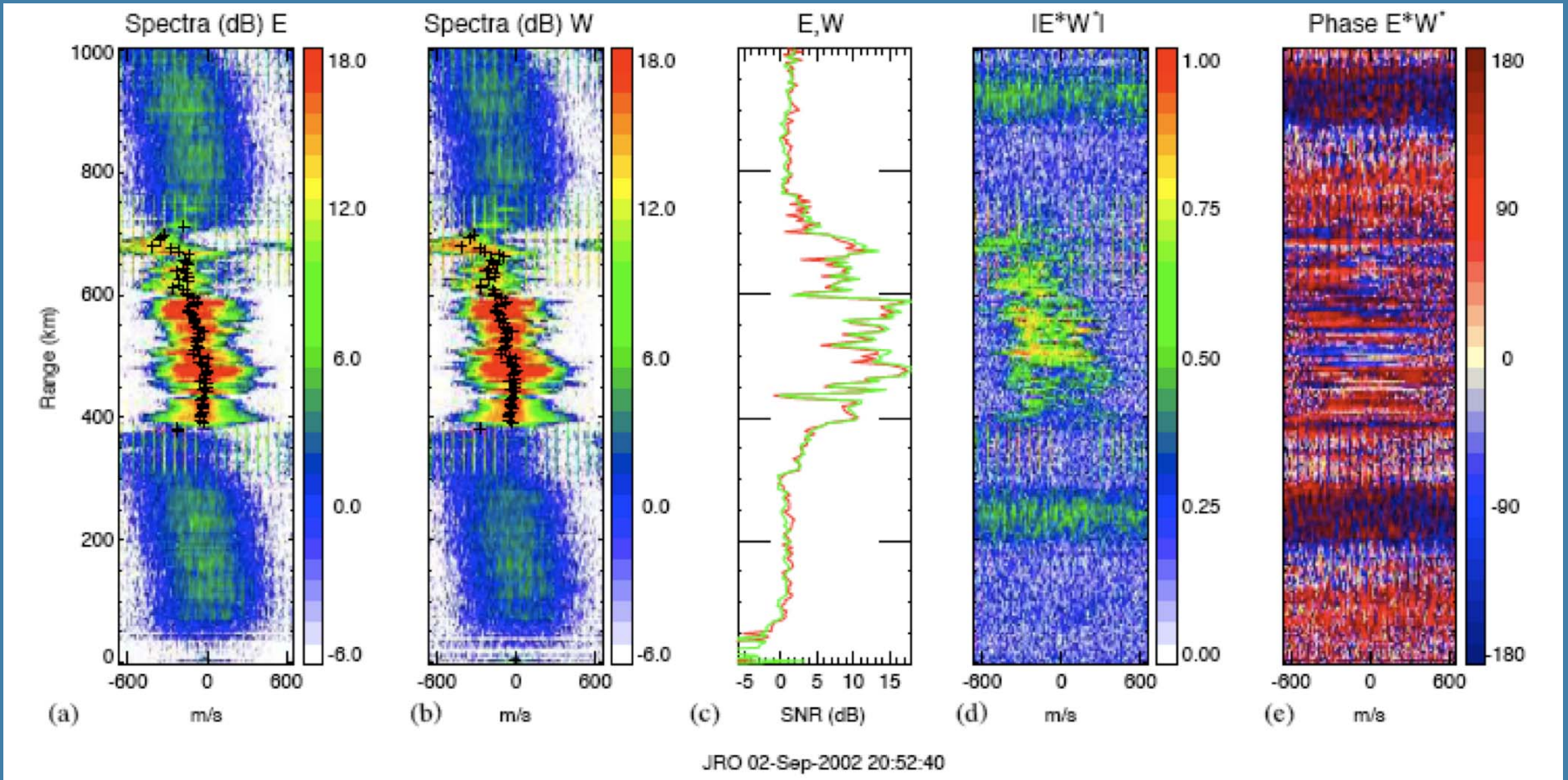
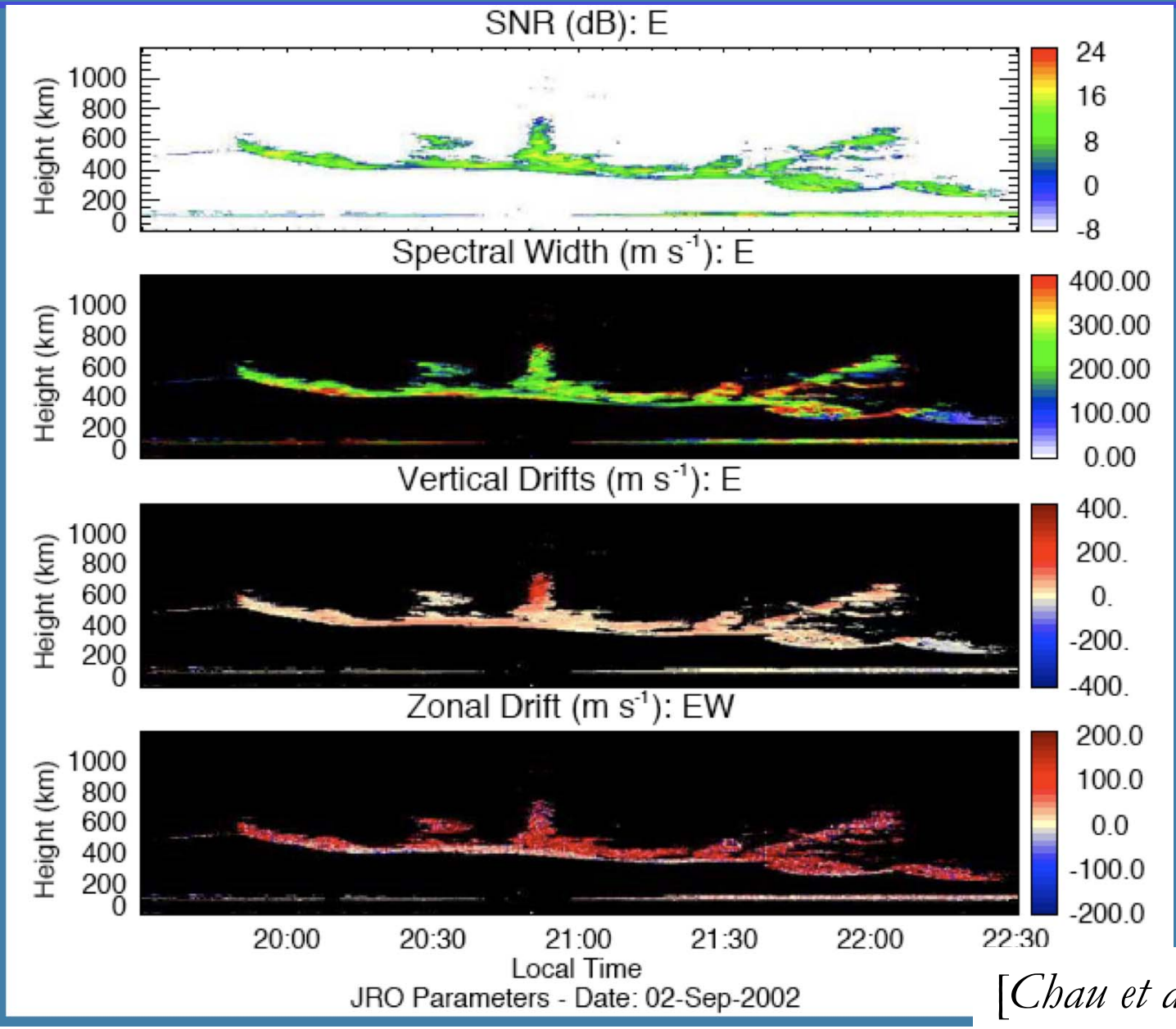



Fig. 1. Example of 20-s spectra and cross-spectra information during the aperiodic experiment at Jicamarca. (a) Spectrogram for the East antenna, (b) spectrogram for the West antenna, (c) mean SNR profiles (East in red, West in green), (d) coherence magnitude, and (e) coherence phase. The spectrograms show the SNR for each frequency bin. The mean Doppler velocities are denoted with plus signs.

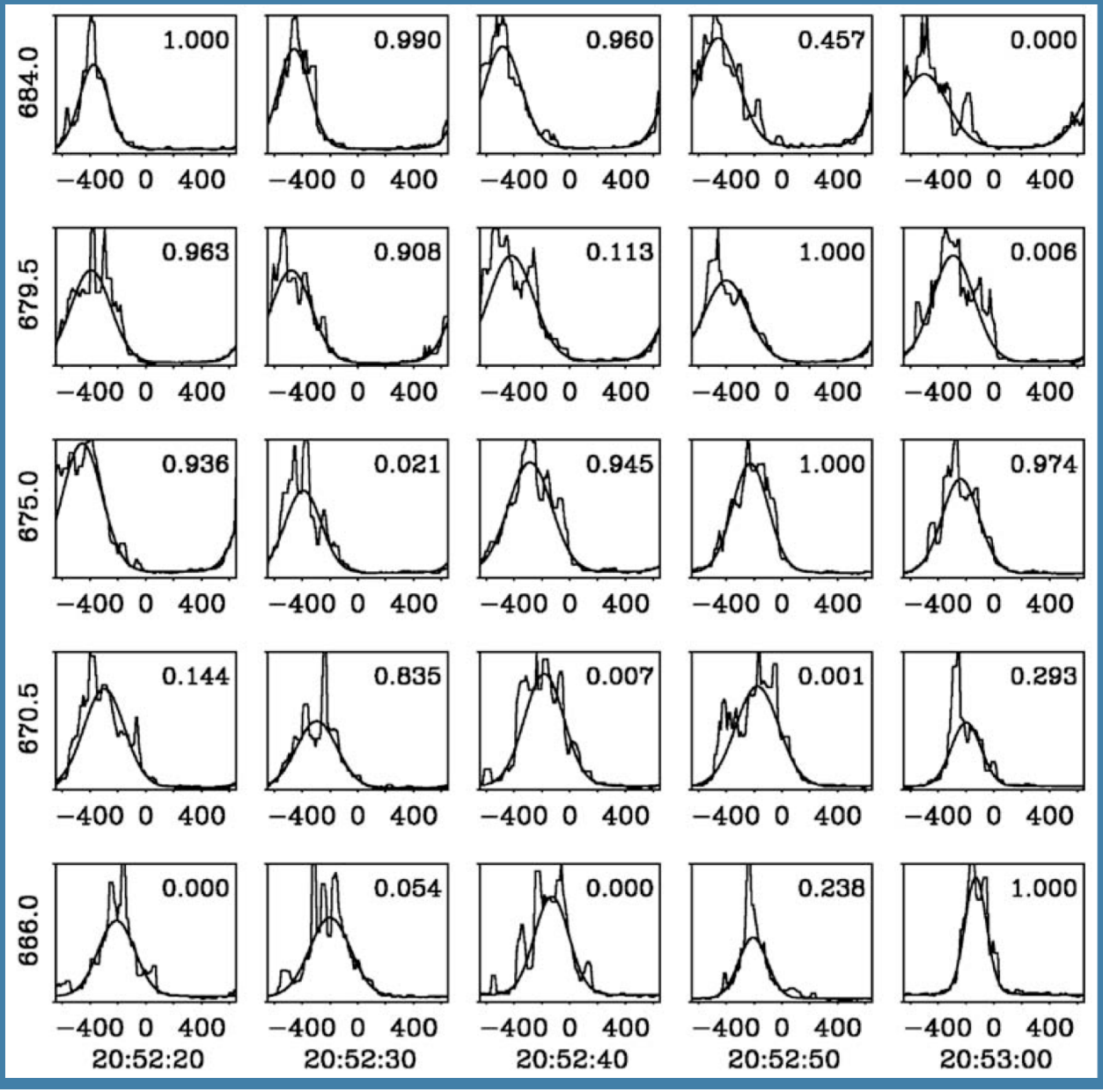
[*Chau et al.*, 2004]

# Range-Time Parameters using $PRF_{avg}$ and Periodogram



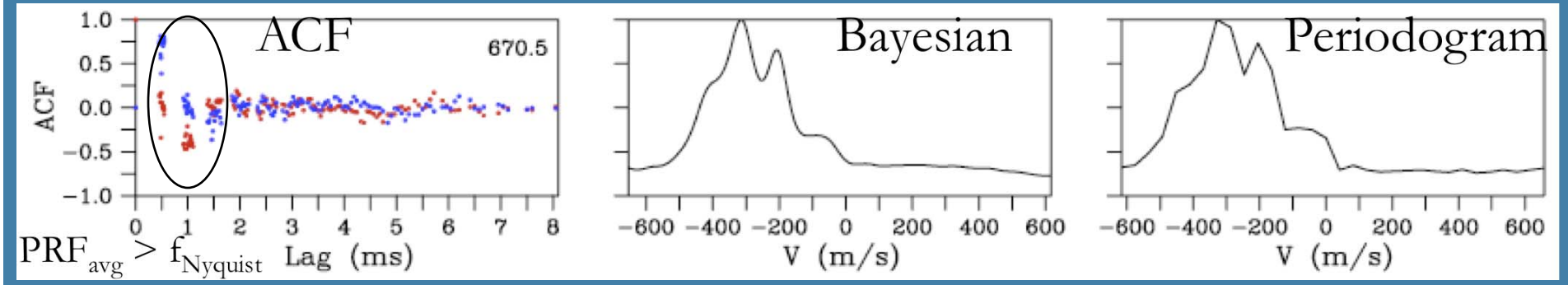

[*Chau et al.*, 2004]

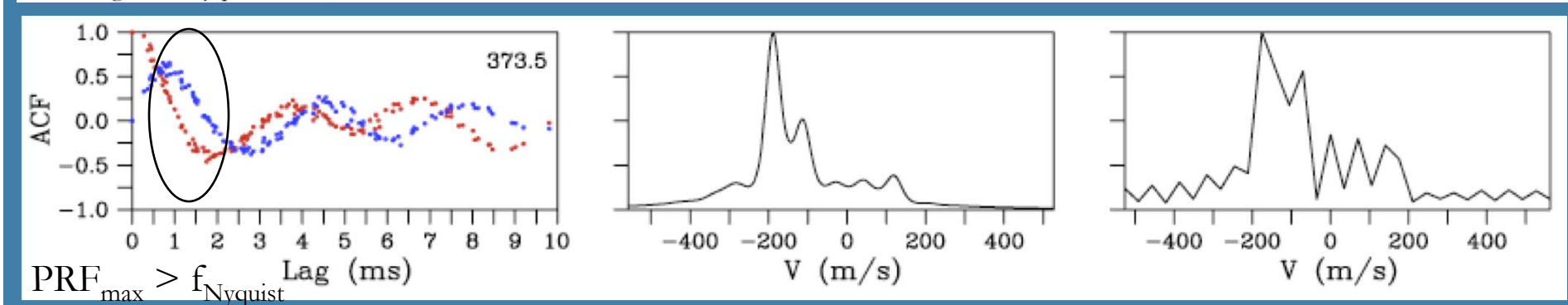
# Measured "aperiodic" spectra vs. Gaussian fitting

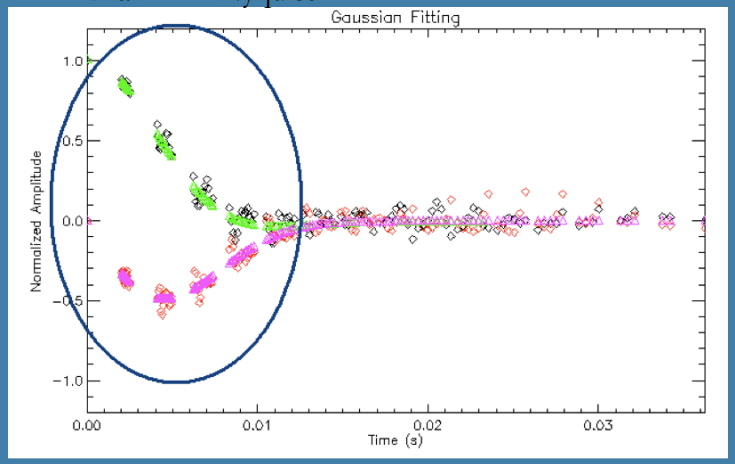



[*Hysell and Chau.*, 2004]

# Measured ACF vs. Spectrum (Periodogram vs. Bayesian)



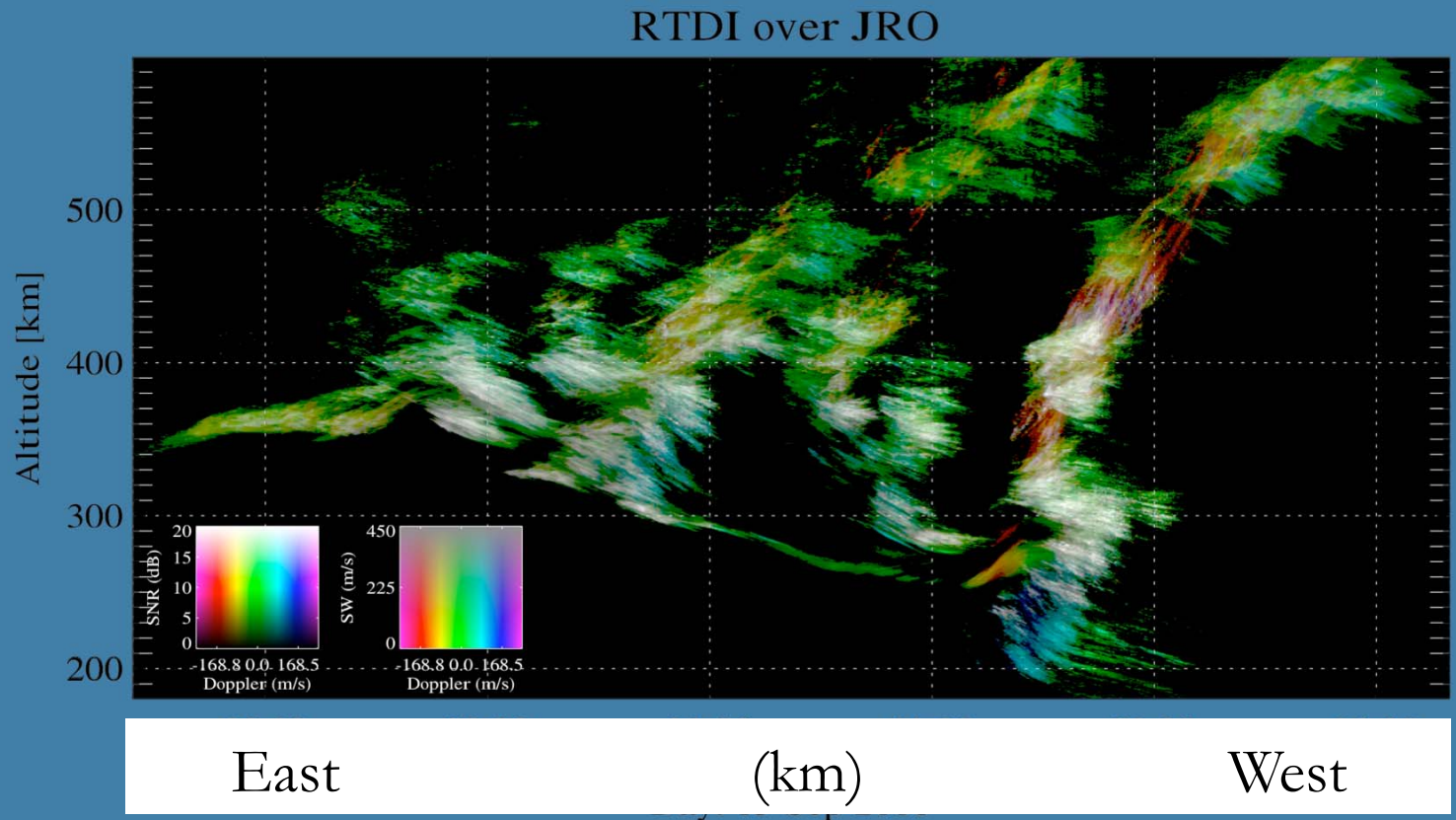

- Note:
  - Non-uniform vs. close to uniform sampling
  - Few lags are required for Gaussian /Lorentzian ACF.

[*Hysell et al.*, 2007]

# Radar Imaging at Jicamarca

- Tx using two quarter antennas, phased to have a wide beam in the EW direction.
- 8 digital Rx channels for "imaging". A pair of modules can be used for single baseline interferometry.
- Automated calibration procedure, using beacon on the hill (relative). Absolute calibration from Hydra, meteor-heads, …
- 16-32 "colors" (FFT points)
- ESF images are obtained every 2 seconds and 300 m. The angular resolution is ~0.1-0.2$^{o}$

# ESF RTDI: Slit camera interpretation




- 24-bit modified range time intensity (RTI) plot using Doppler information (RTDI). Extending Hysell's way of plotting radar images, a RTI map is obtained for three Doppler regions centered around: -ve (Red), zero (Green), and +ve (Blue) Doppler velocities.
- It allows, for example, identification of regions and times where (a) there is a depletion channel with different velocity than the surrounding volumes, (b) there is Doppler aliasing or Doppler widening, etc.

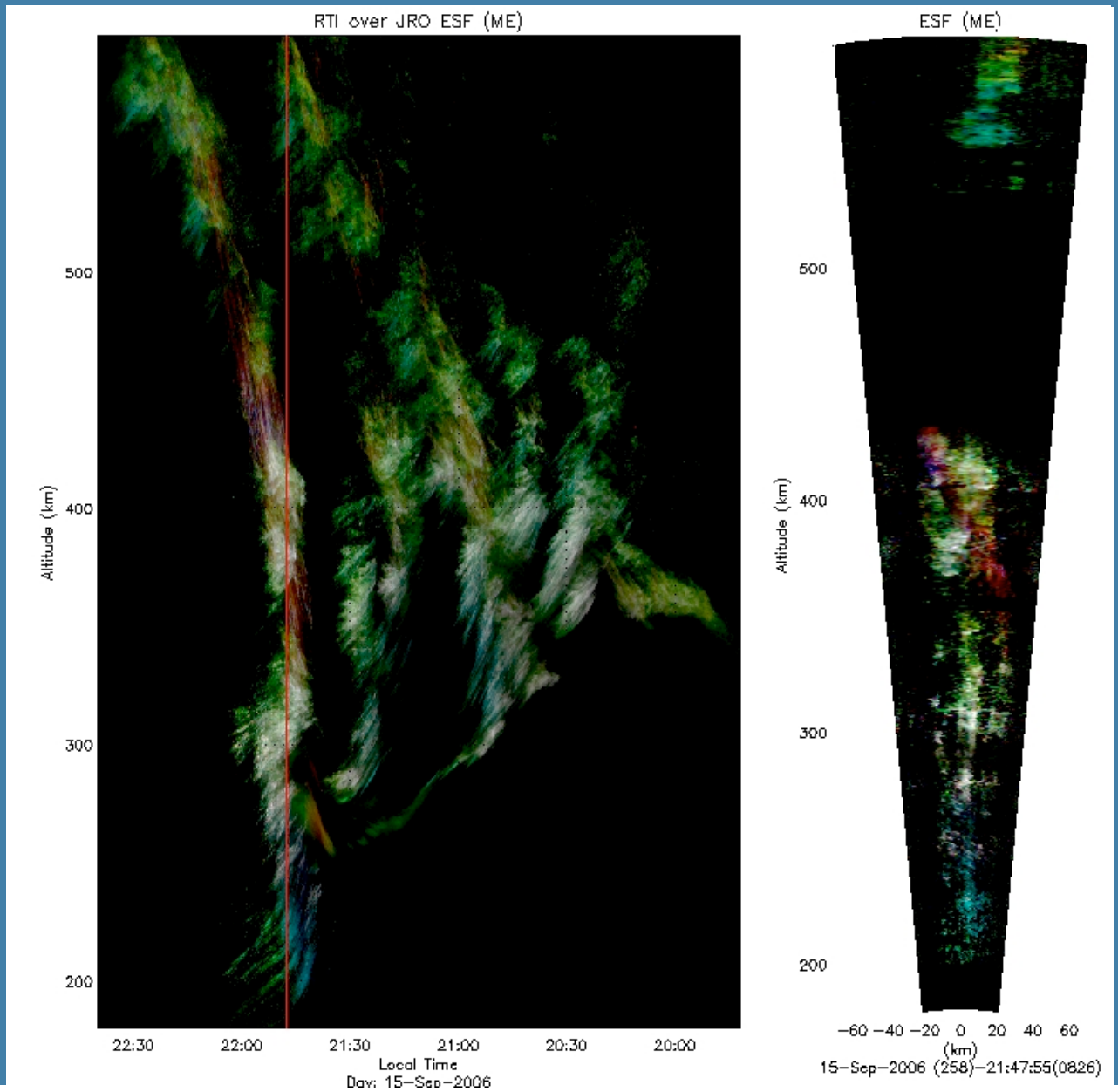
# ESF RTDI + Imaging (1)

500

400

300

200

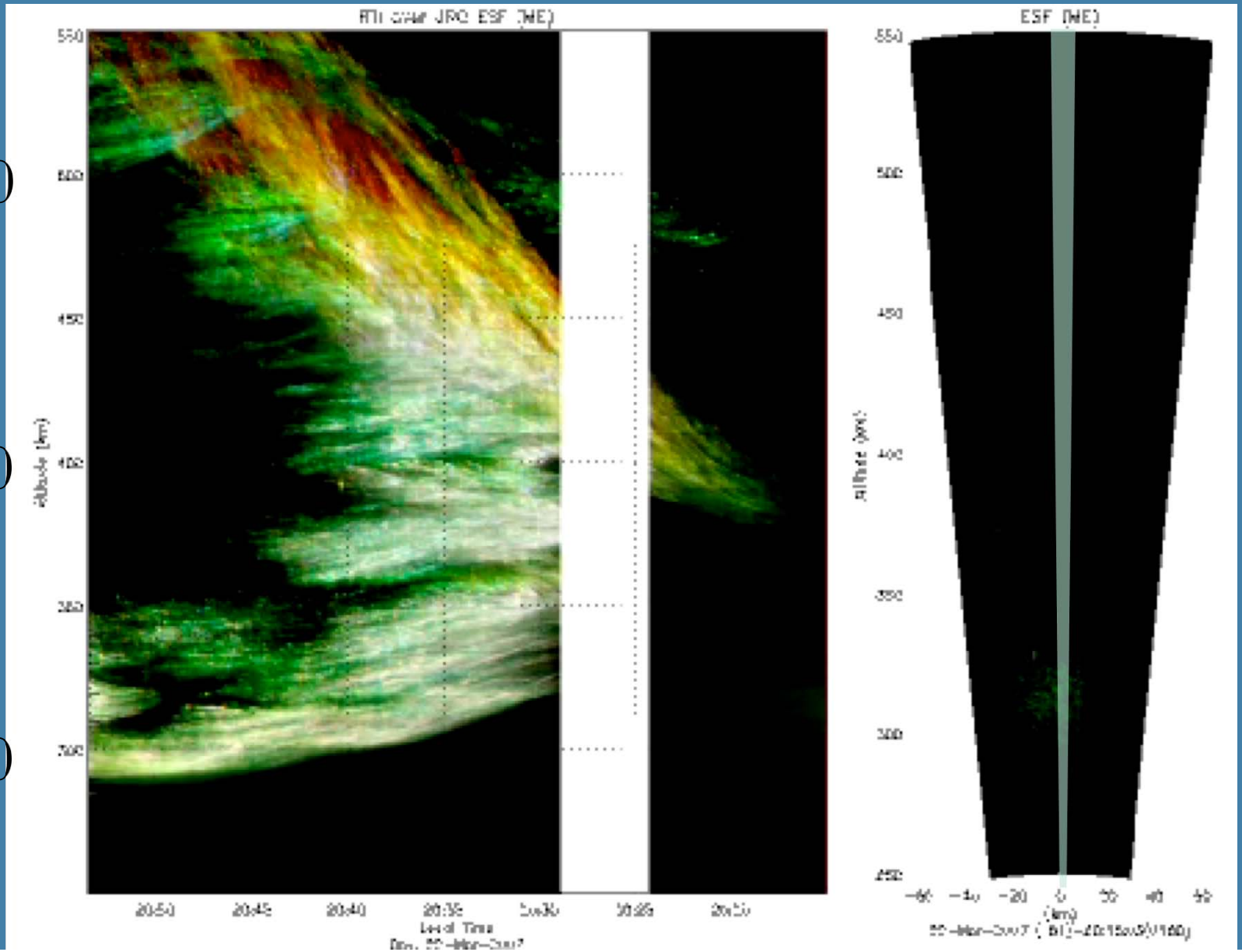


# ESF RTDI + Imaging (2)

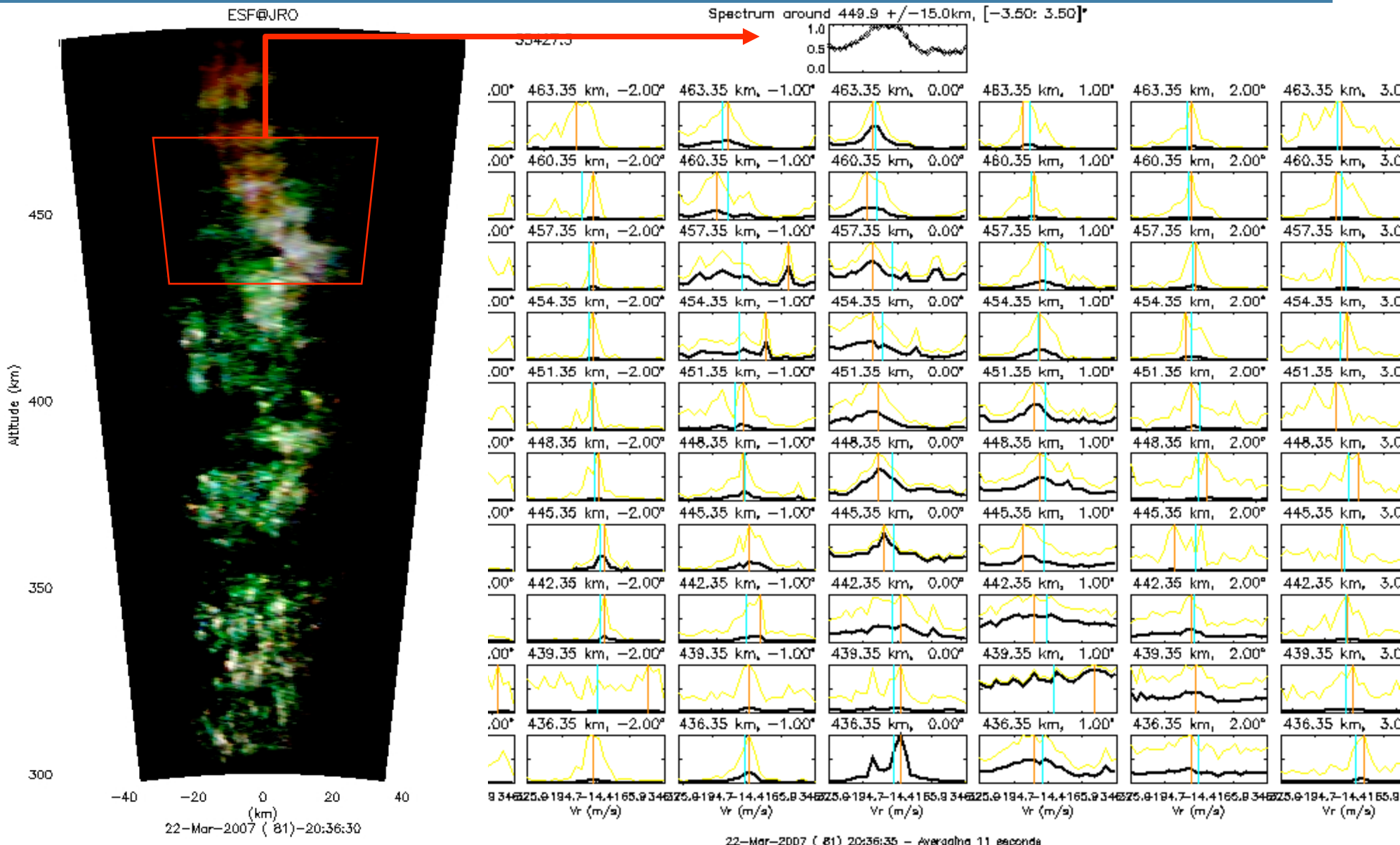
500

400

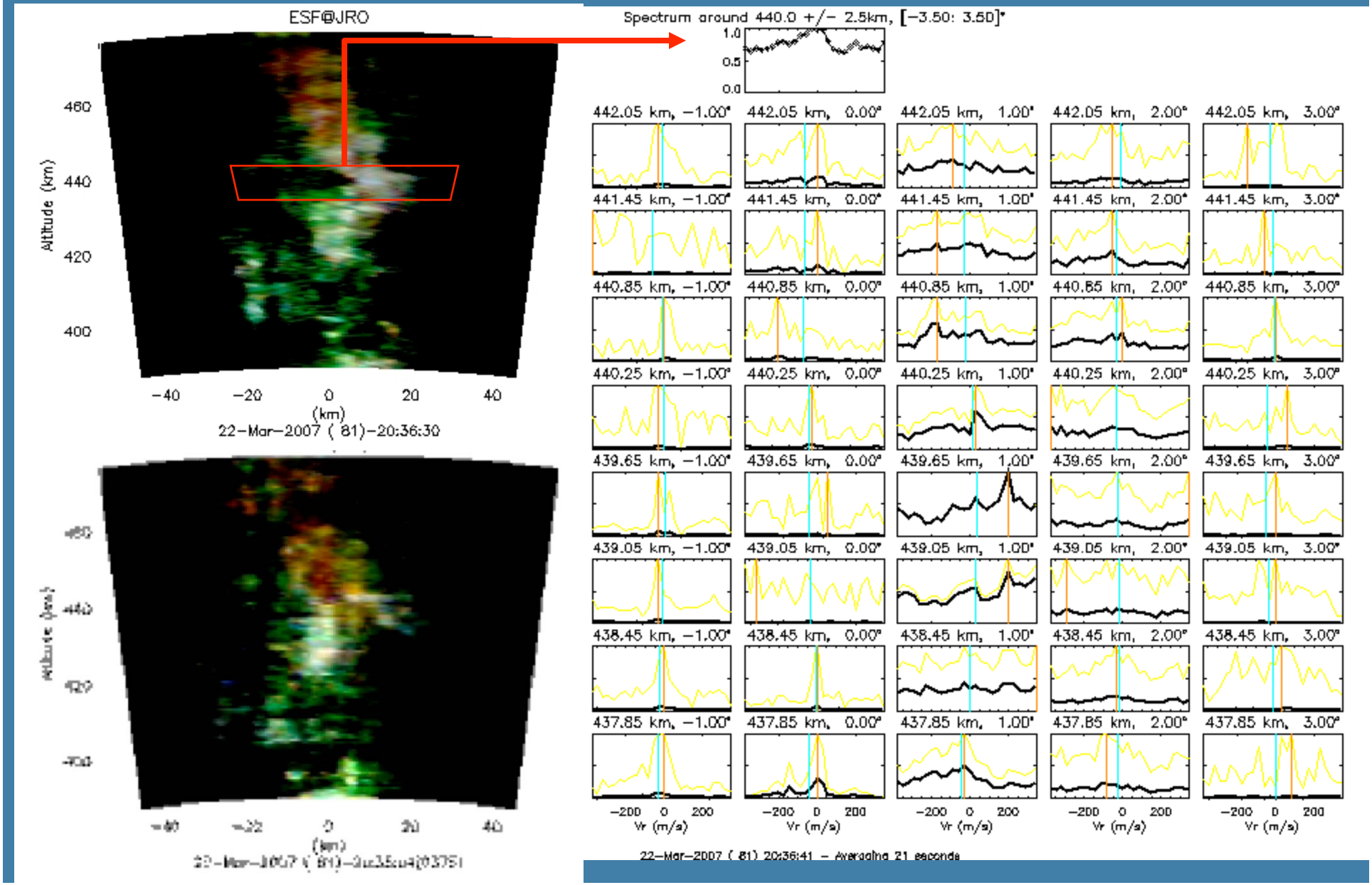
300



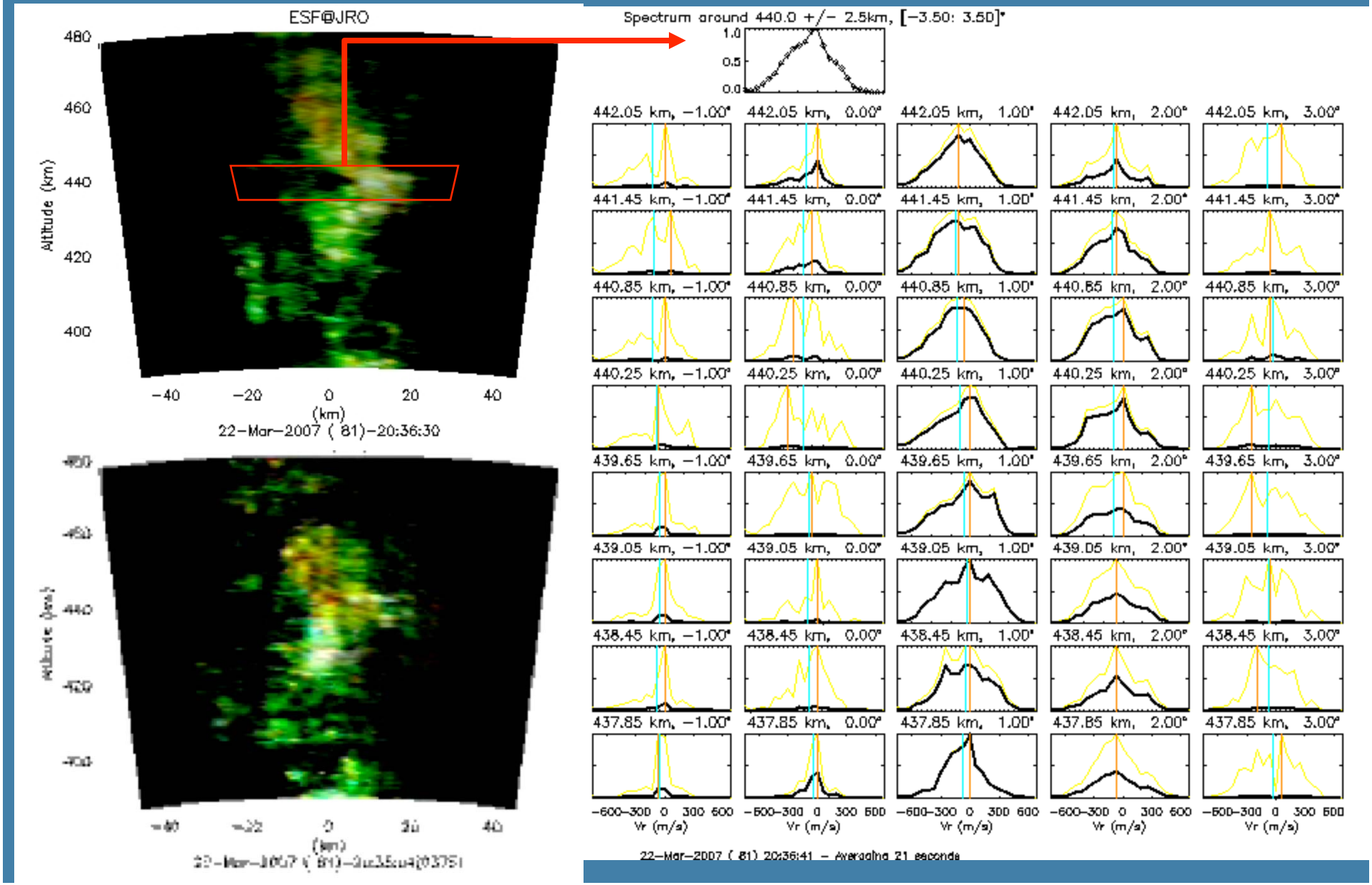
# Spectra cuts from Imaging results



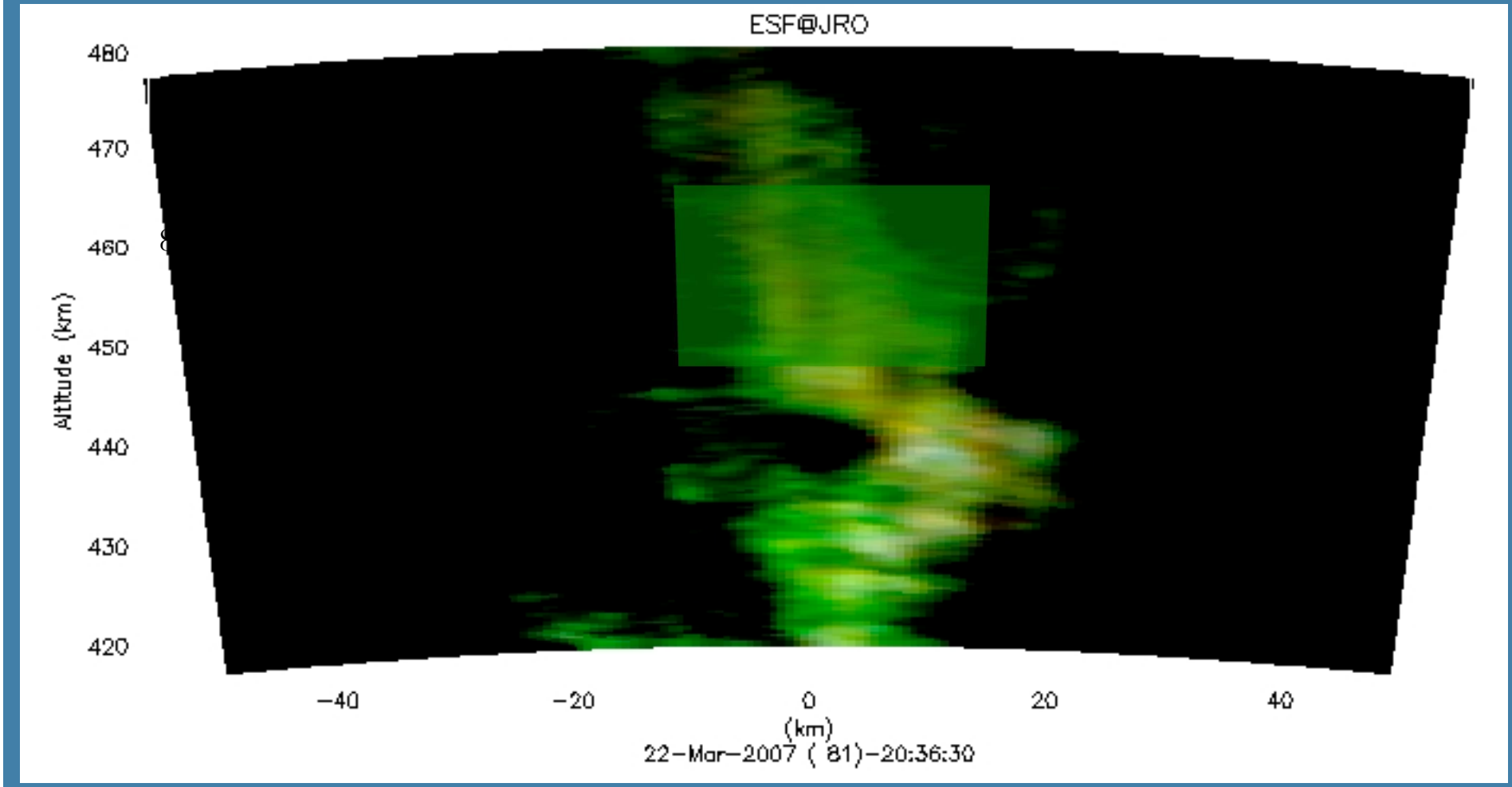
# ESF Imaging experiment with IPP=600: Frequency aliased spectra



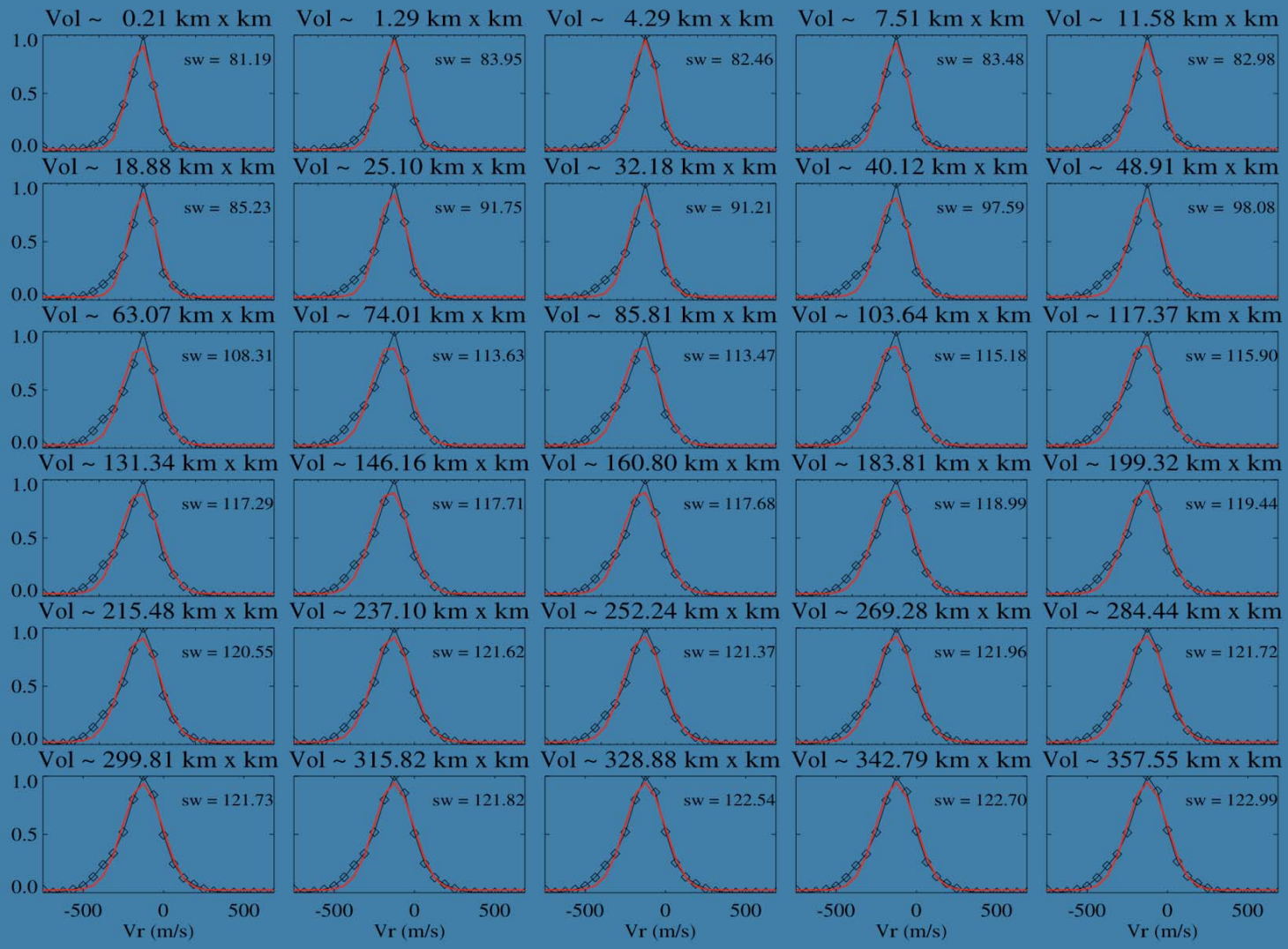
# ESF Imaging experiment with IPP=300: Range aliased, but without frequency aliasing



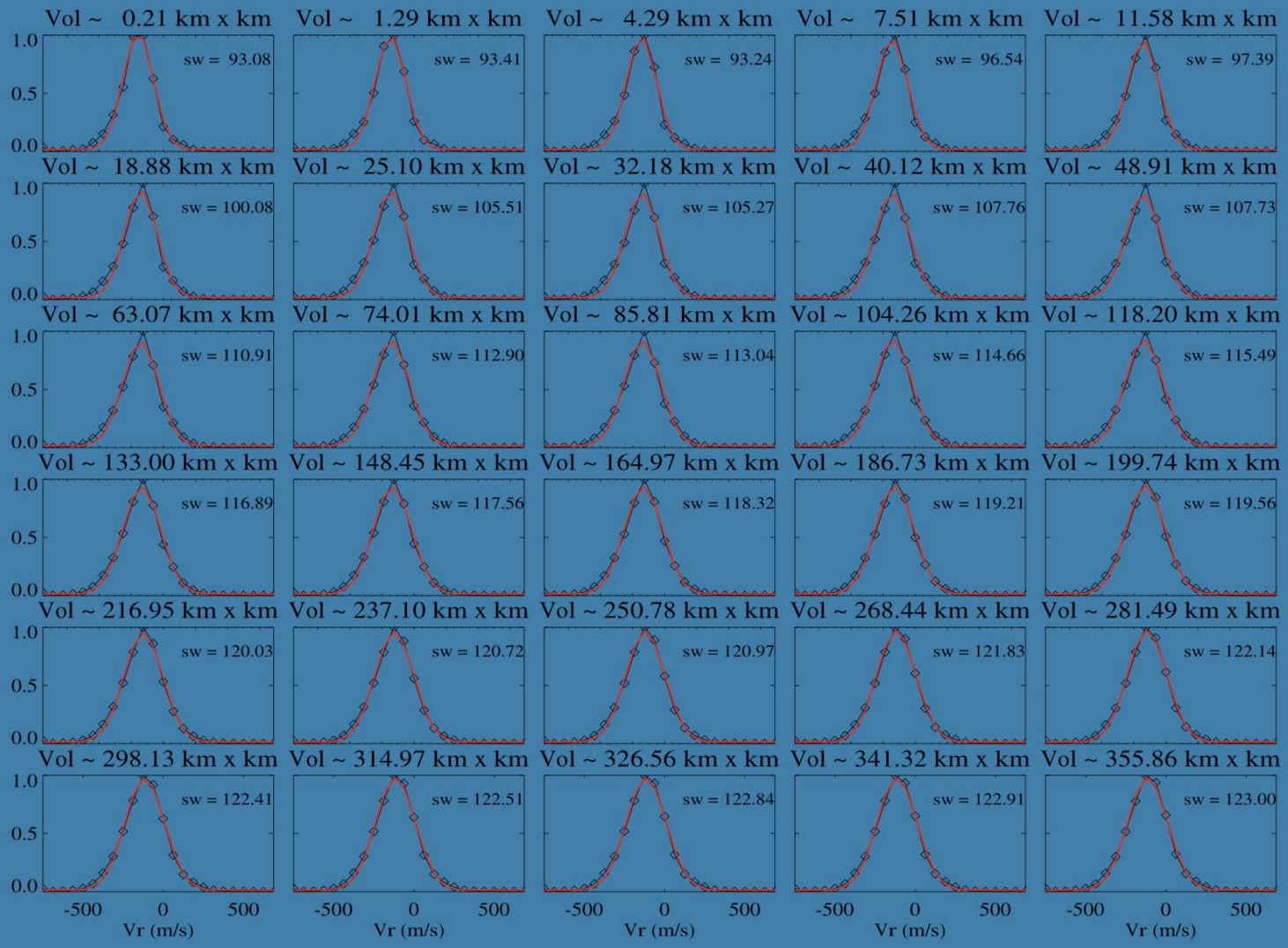
# Frequency spectrum vs. averaging volume



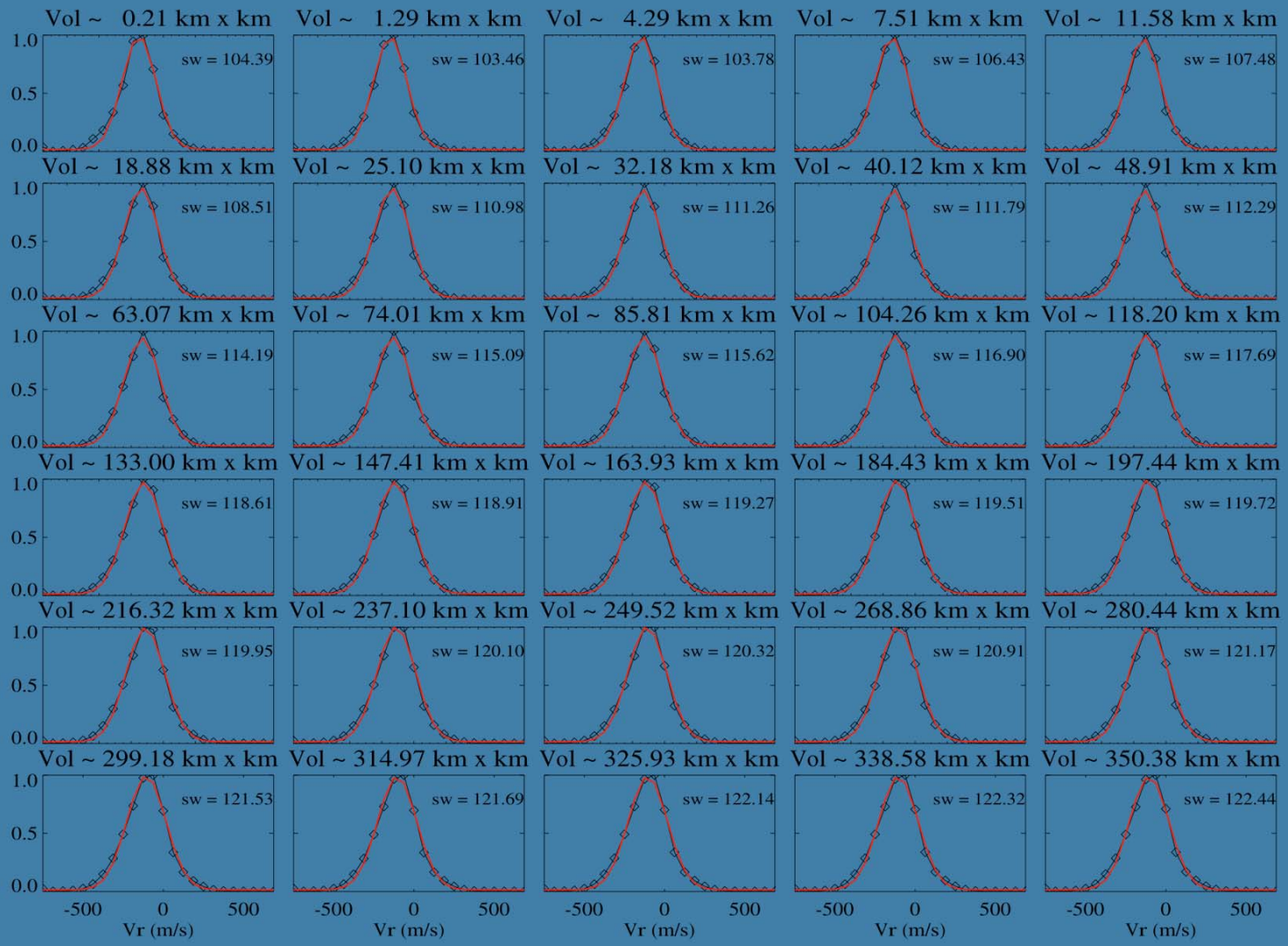
# Frequency spectrum vs. averaging volume (41 s)



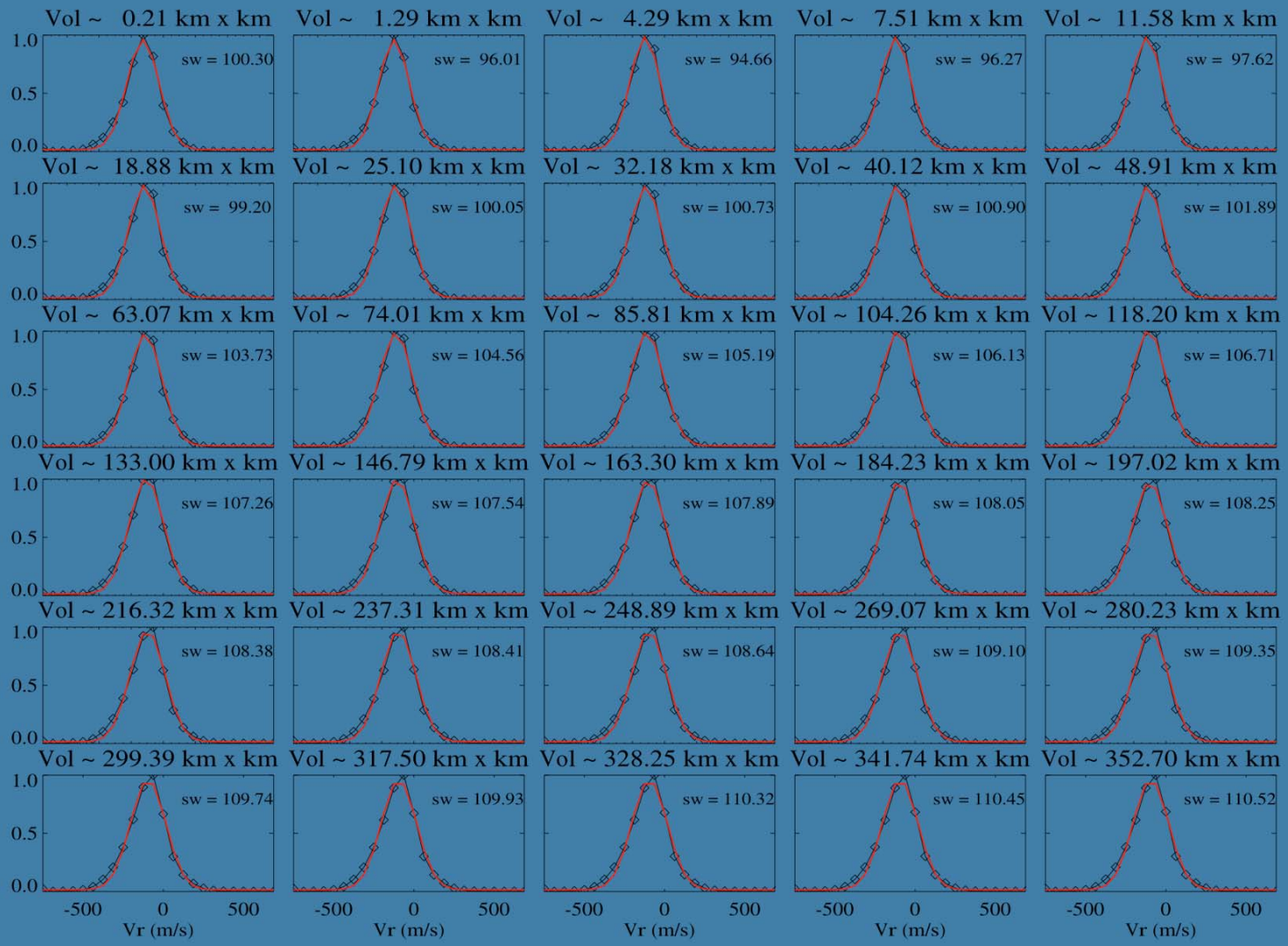
# Frequency spectrum vs. averaging volume (82 s)



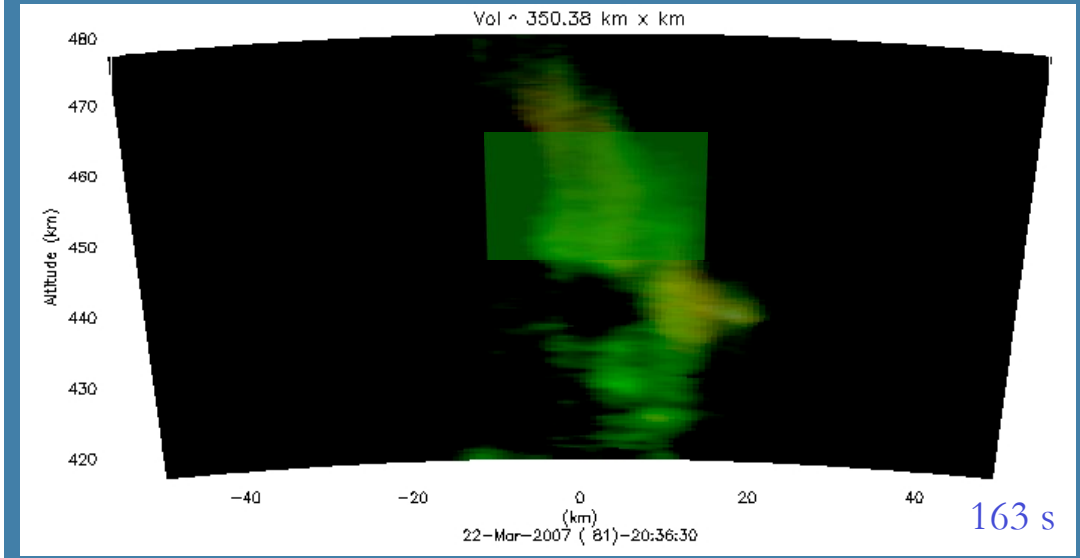
# Frequency spectrum vs. averaging volume (122 s)



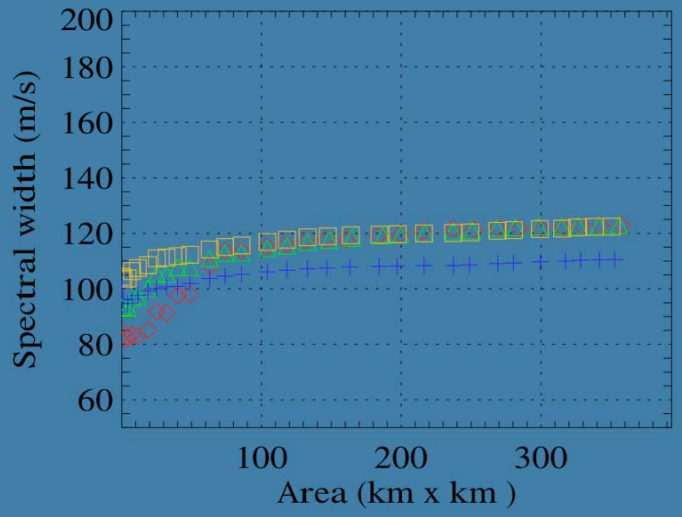
# Frequency spectrum vs. averaging volume (163 s)



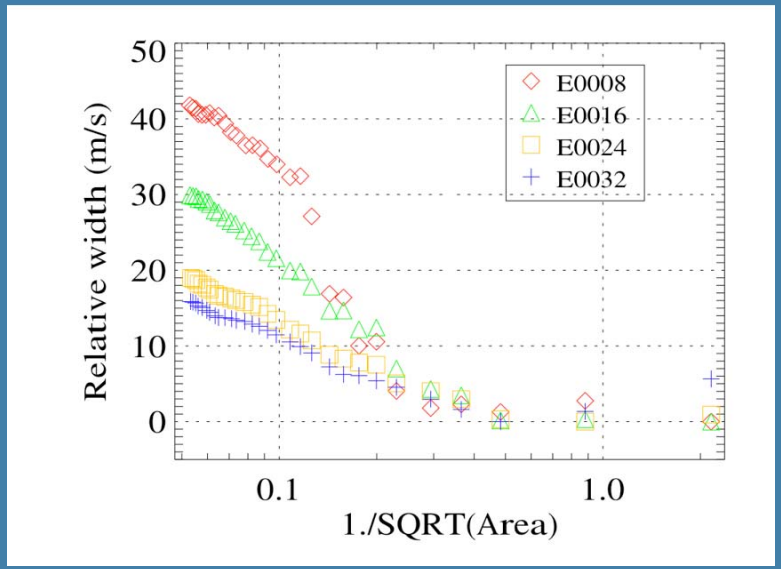
# “k-spectra” for different averaging times



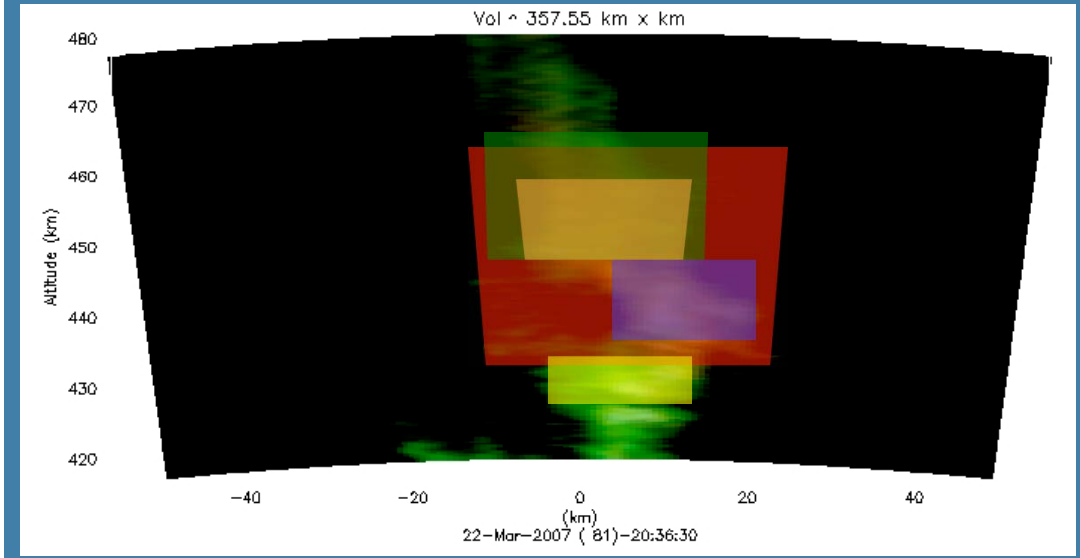

163 s

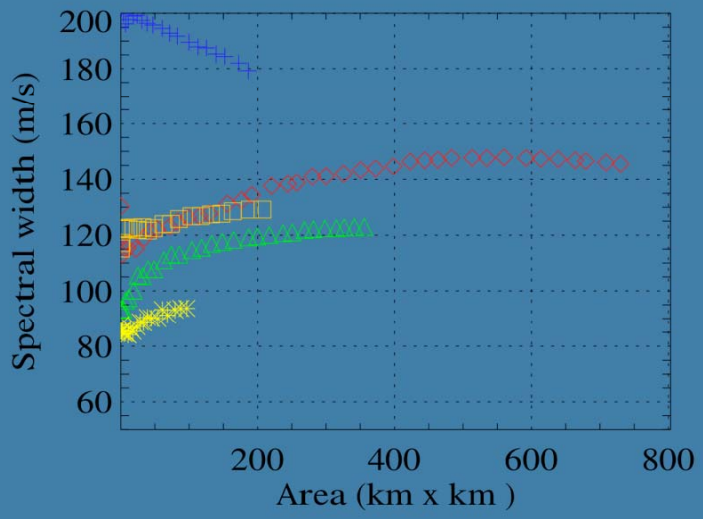



- 1/SQRT(area) ∝ k
- Relative spectral width ∝ turbulence energy within volume
- Are inertial regime flows occurring in this example to do the inversion and get the irregularity k-spectrum?

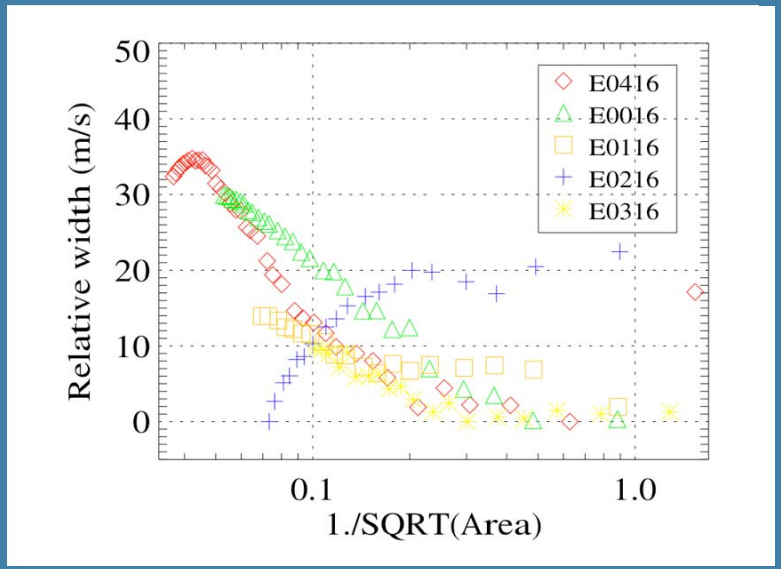


# “k-spectra” for different volumes




- For statistically isotropic and homogeneous turbulence, spectral width will always increase with increasing volume.
- There are regions where these conditions aren’t satisfied (e.g., collisional regime)



# Concluding Remarks

- The combined radar imaging and range aliasing approach give us further confidence that the ground -based radar technique might work.
- Before inverting the results, we need to verify that inertial regime is at work, either wait for the f10.7 to increase and/or have independent satellite passes (e.g., from C/NOFS) for validation and comparison.
- We are developing a general mode that combines both radar imaging and aperiodic pulsing. For the latter only few lags are needed for estimating the expected Gaussian/Lorentzian frequency spectra.