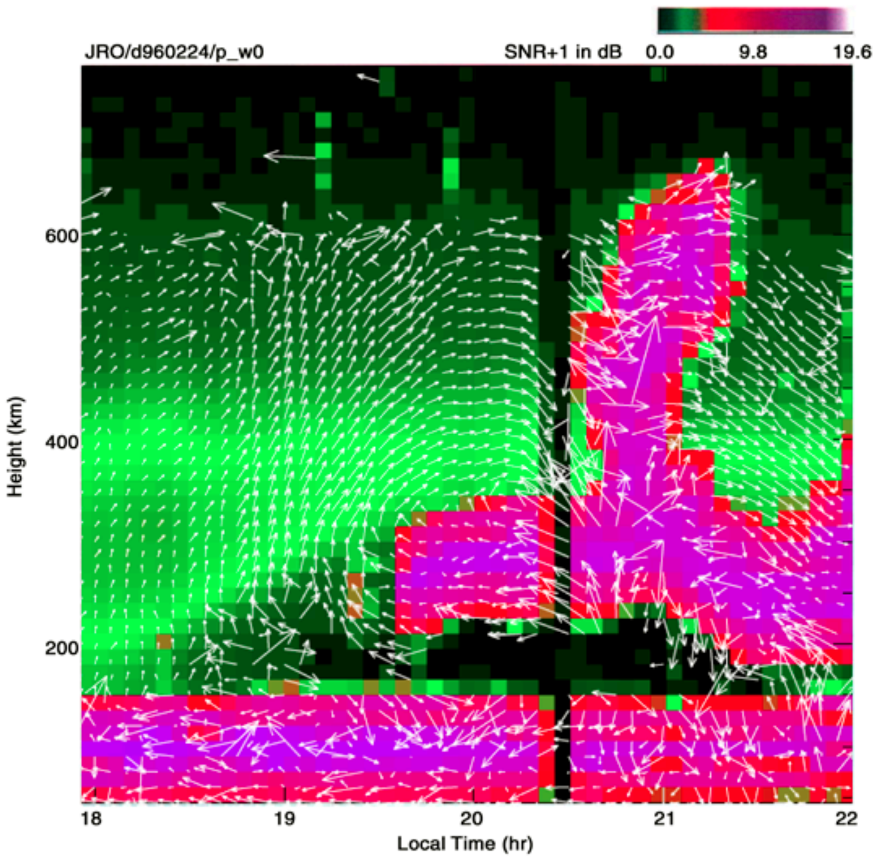
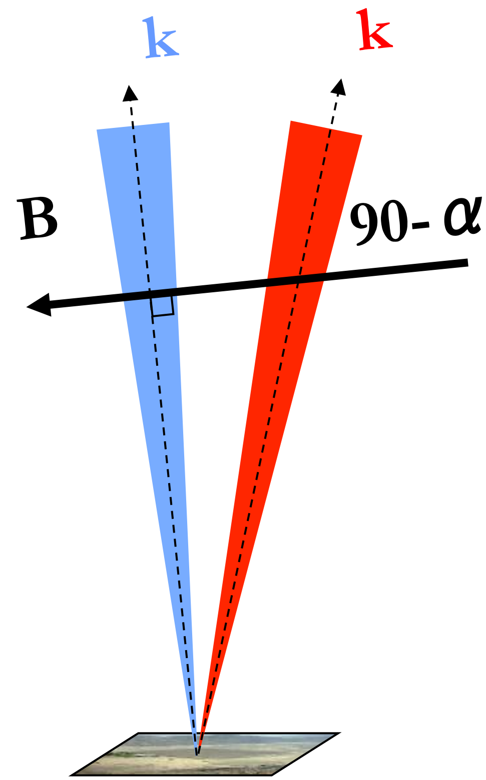
Radar Observations of the Equatorial Atmosphere/ Ionosphere





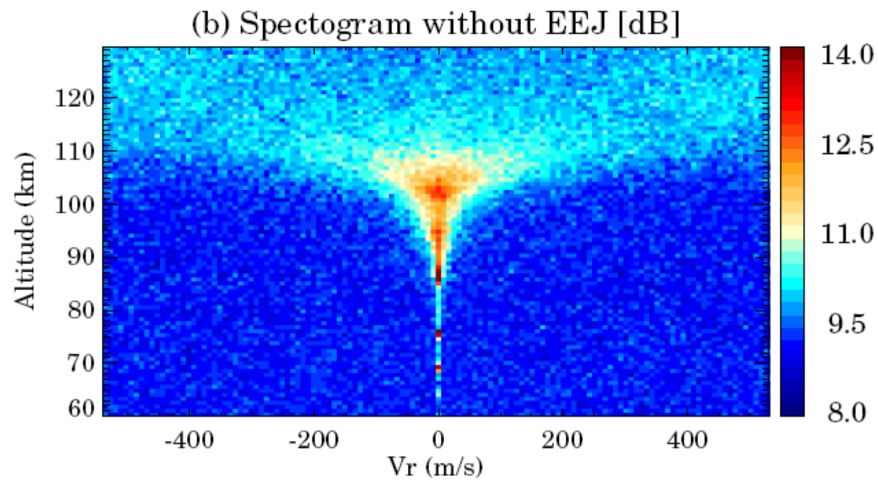
J. L. Chau et al.

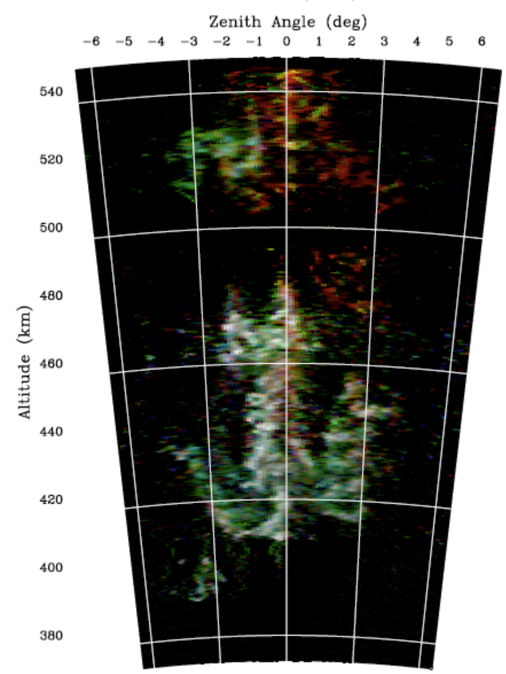
[1]Radio Observatorio de Jicamarca, Instituto Geofísico del Perú, Lima

Nagoya University – March 24, 2010

Outline

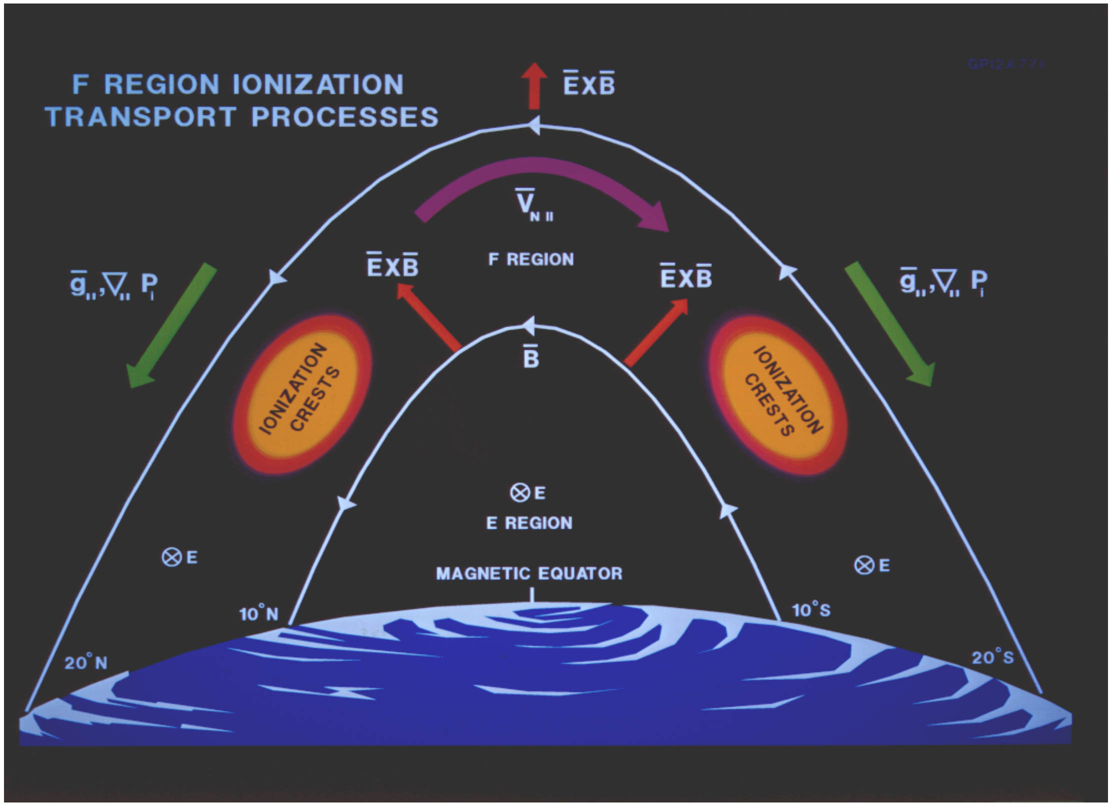
- The Equatorial Ionosphere
- The Jicamarca Radar
- Incoherent scatter techniques
- Coherent scatter techniques
  - MST Technique
  - Radar Interferometry
  - Aperture synthesis radar technique

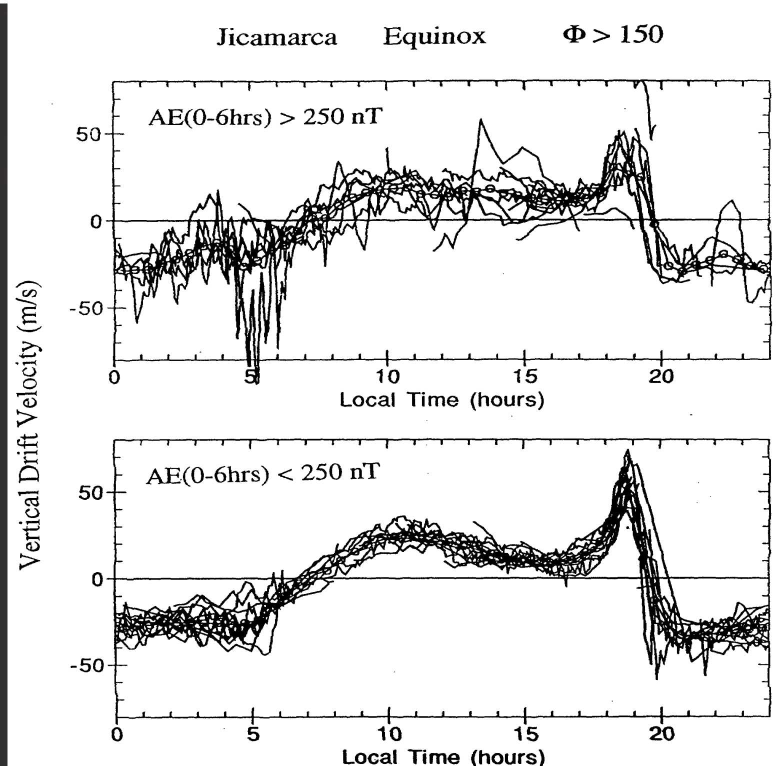




Equatorial Ionosphere

Radio Observatorio de JICAMARCA Radio Observatory





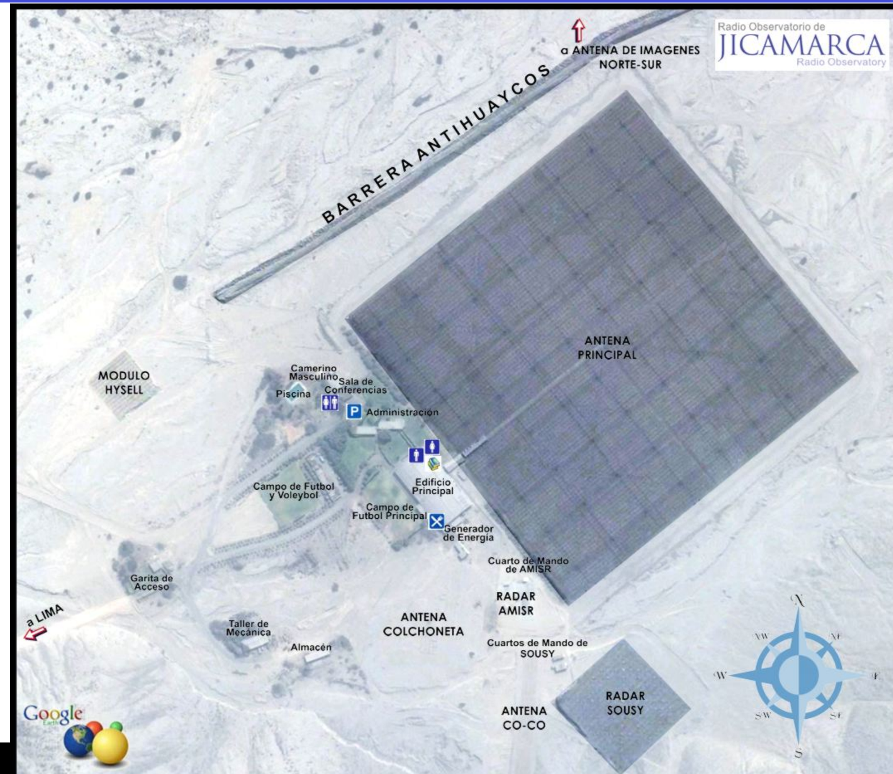
[from *Fejer et al*, 1999]

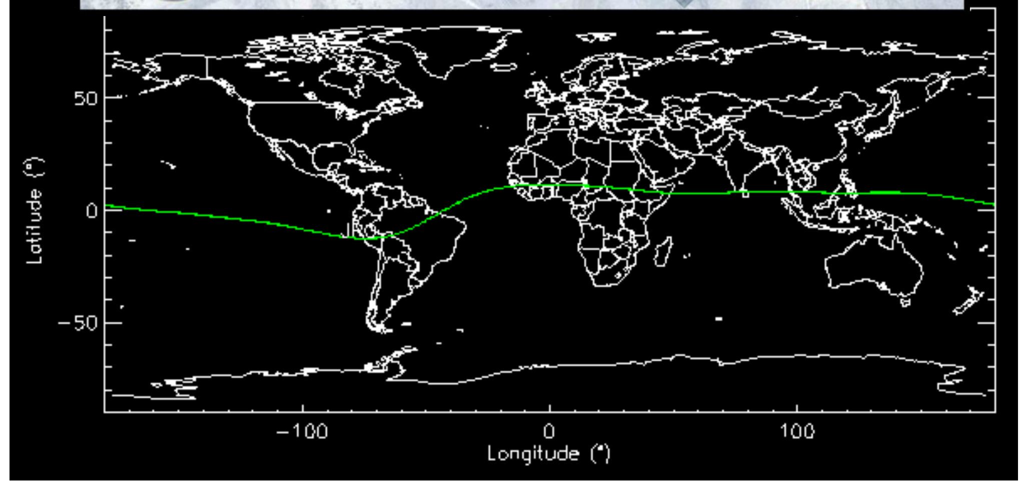
- **B** field is nearly horizontal
- Daytime:
  - *E*-region E is eastward
  - Off-equatorial E maps to F above mag. Equator -> Upward ExB
  - Formation of Appleton Anomaly
- Around sunset, *F* region dynamo develops and competes with *E*, generates PRE and ExB goes downward (E westward)
- At night upward density gradient is opposite in direction to **g**, Rayleigh-Taylor unstable, allowing plasma density irregularities to form.

The Jicamarca Radio Observatory

Radio Observatorio de JICAMARCA Radio Observatory

- Built in 1961 by the US NBS and then donated to IGP in 1969.
- Operating frequency: 50 MHz
- Antenna type: array of 18,432 dipoles, organized in 8x8 cross-polarized modules.
- Pointing directions: within 3 degrees from on-axis. Phase changes are currently done manually.
- Transmitters: 3 x 1.5 MW peak-power with 5% duty cycle.
- Located "under" the magnetic equator (dip 1°).

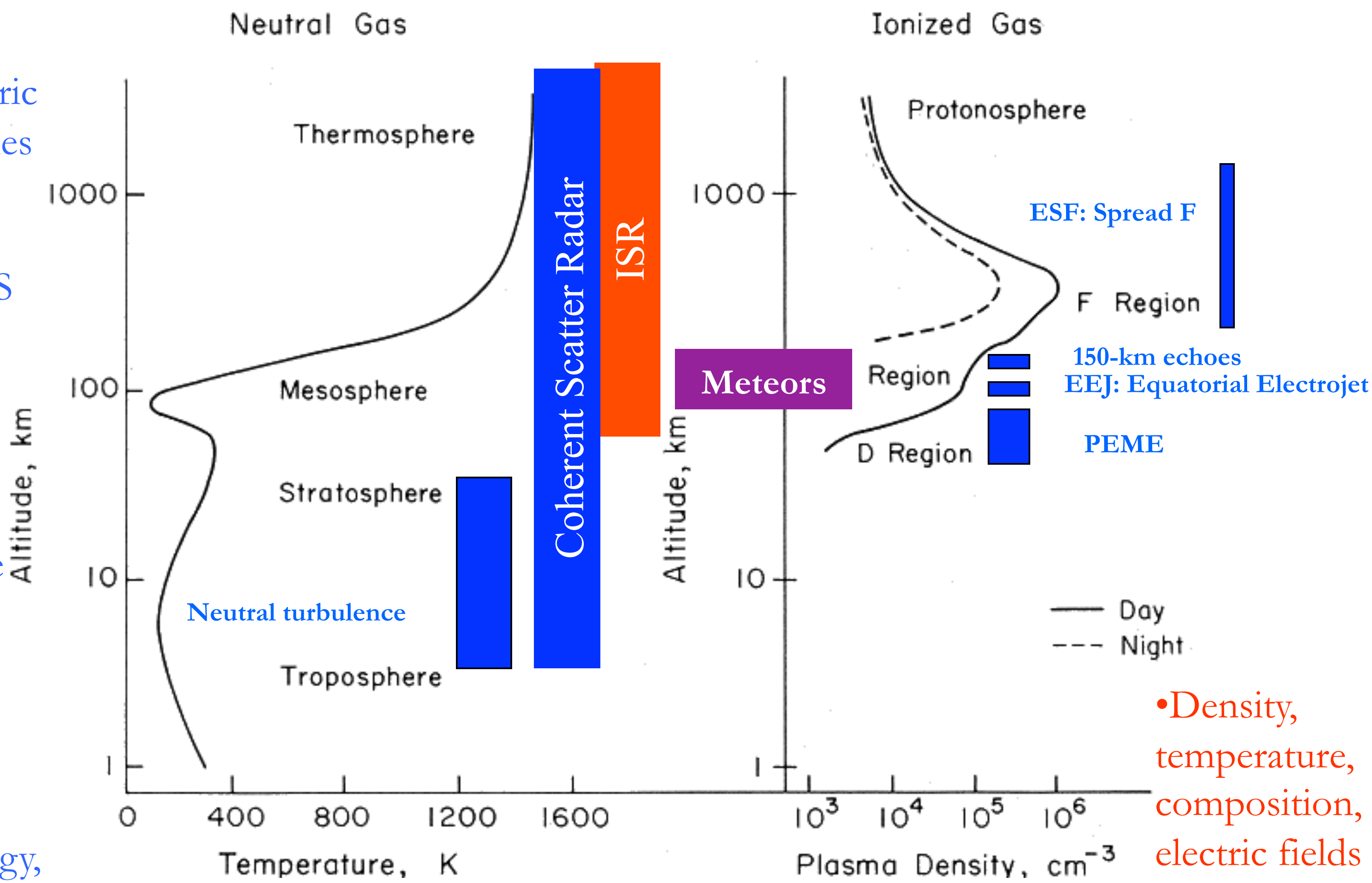




¿What do we study at Jicamarca?

Radio Observatorio de JICAMARCA Radio Observatory

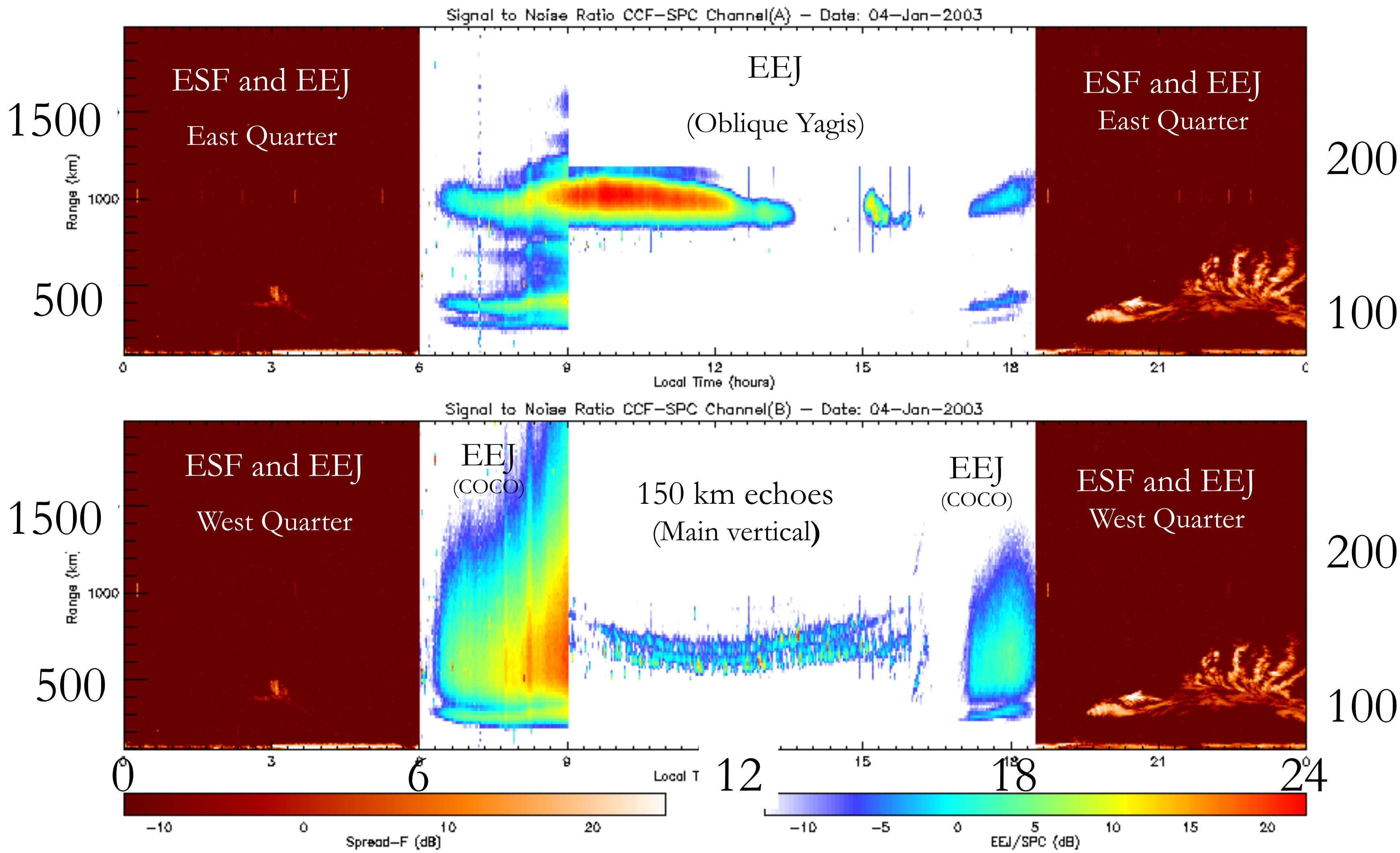
- Ionospheric Irregularities (EEJ, 150-km, ESF).
- SAR, GPS



- Neutral atmosphere dynamics (winds, turbulence, vertical velocities)
- Meteorology, aviation.

- Density, temperature, composition, electric fields
- Modeling, space weather

Equatorial Irregularities (1)
RTIs above 100 km

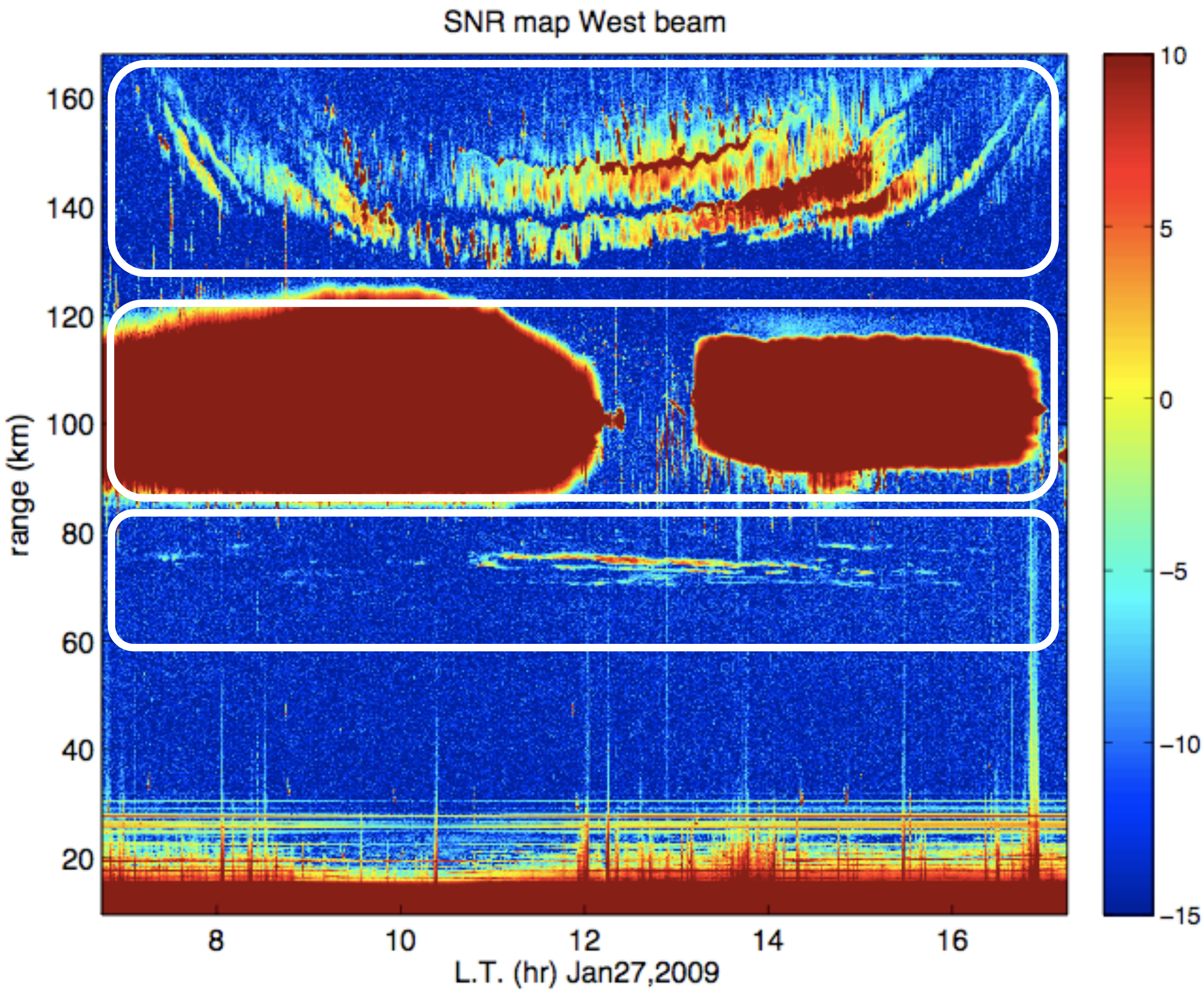


ESF: Equatorial Spread F (nightime)

150-km echoes: Daytime

EEJ: Equatorial Electrojet (all day)

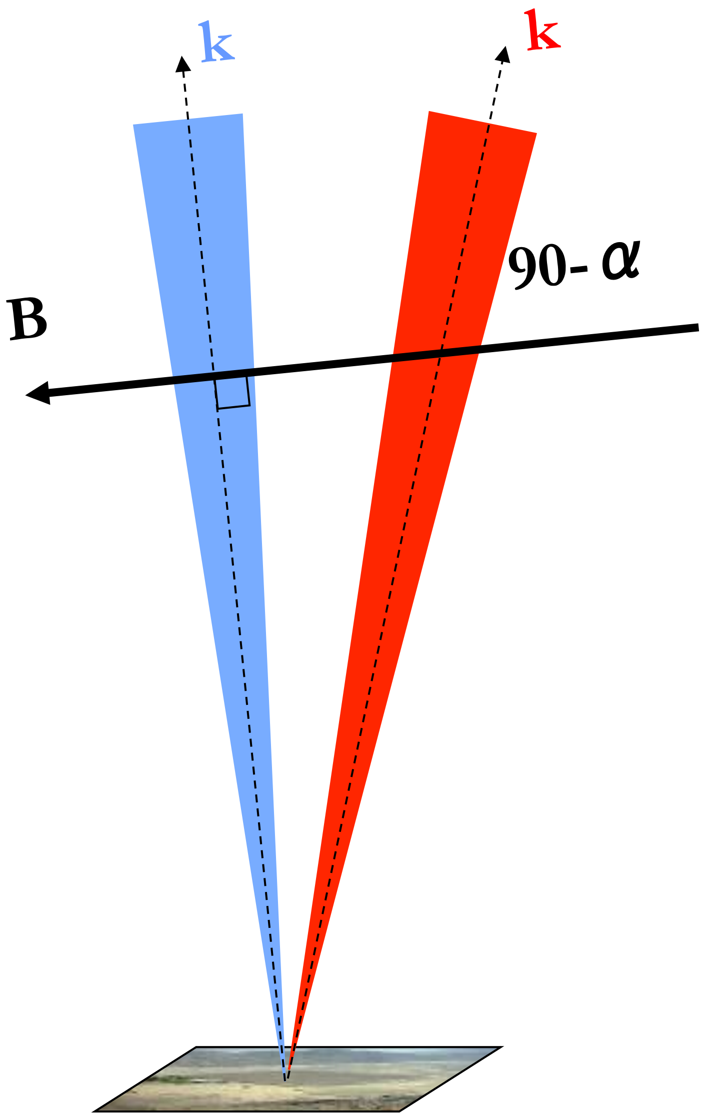
Equatorial Irregularities (2) Below 200 km



- ExB drifts from 150-km first moment.
- Plasma physics from EEJ spectra
- Plasma physics and lower thermosphere winds from non-specular meteor trails
- Mesospheric winds from mesospheric echoes

Incoherent Scatter Techniques

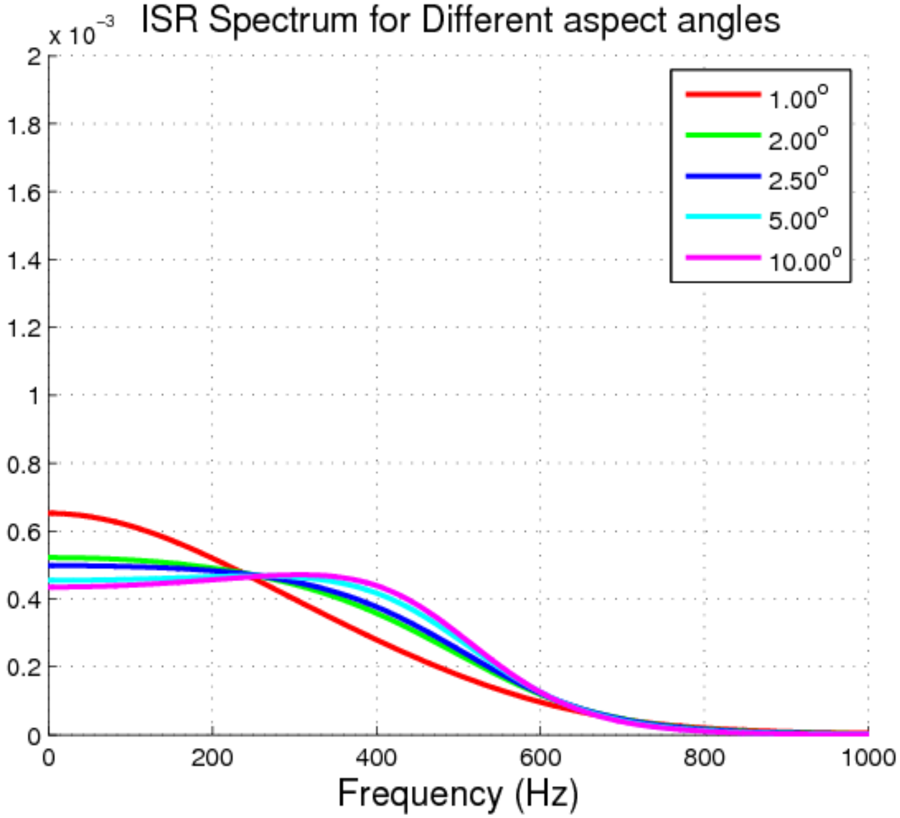
Oblique vs. Perpendicular ISR: Geometry

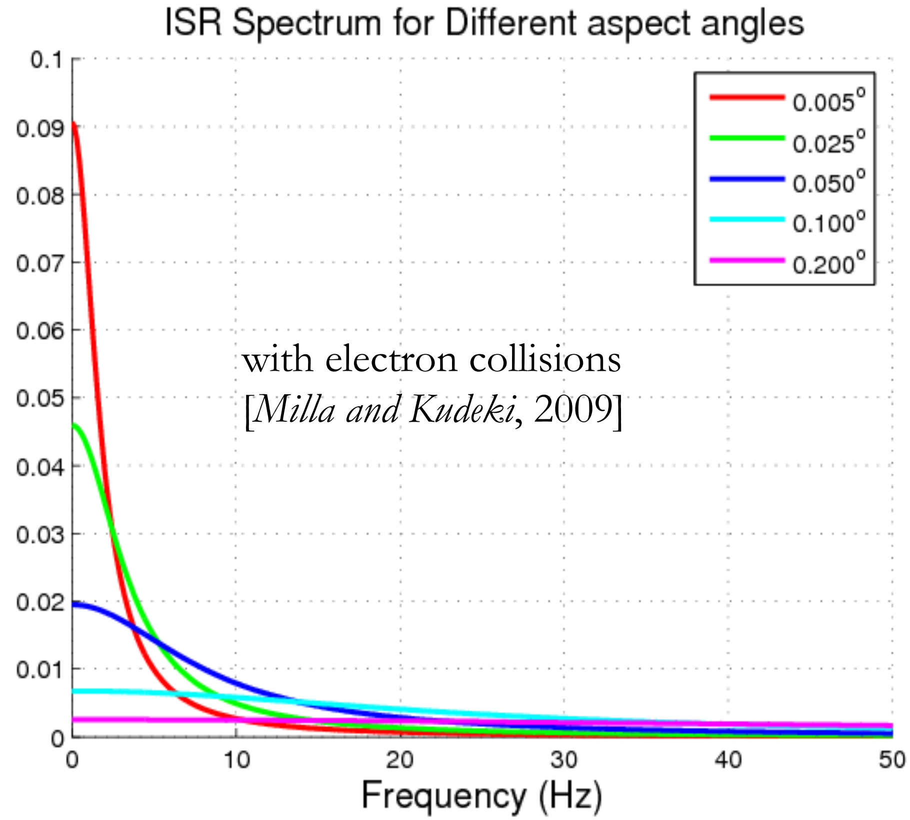


- Depending on α:
  - Oblique: $\alpha > 0$
  - Perpendicular: $\alpha = 0$
- What is the α boundary between modes?
- What are the antenna patterns used?
- What are the differences on ACFs and spectra between modes?
- How is the polarization of returned signals?
- How are the modes affected by coherent scatter echoes?
- What can be measured?

Oblique vs. Perpendicular: Spectra

Radio Observatorio de JICAMARCA Radio Observatory





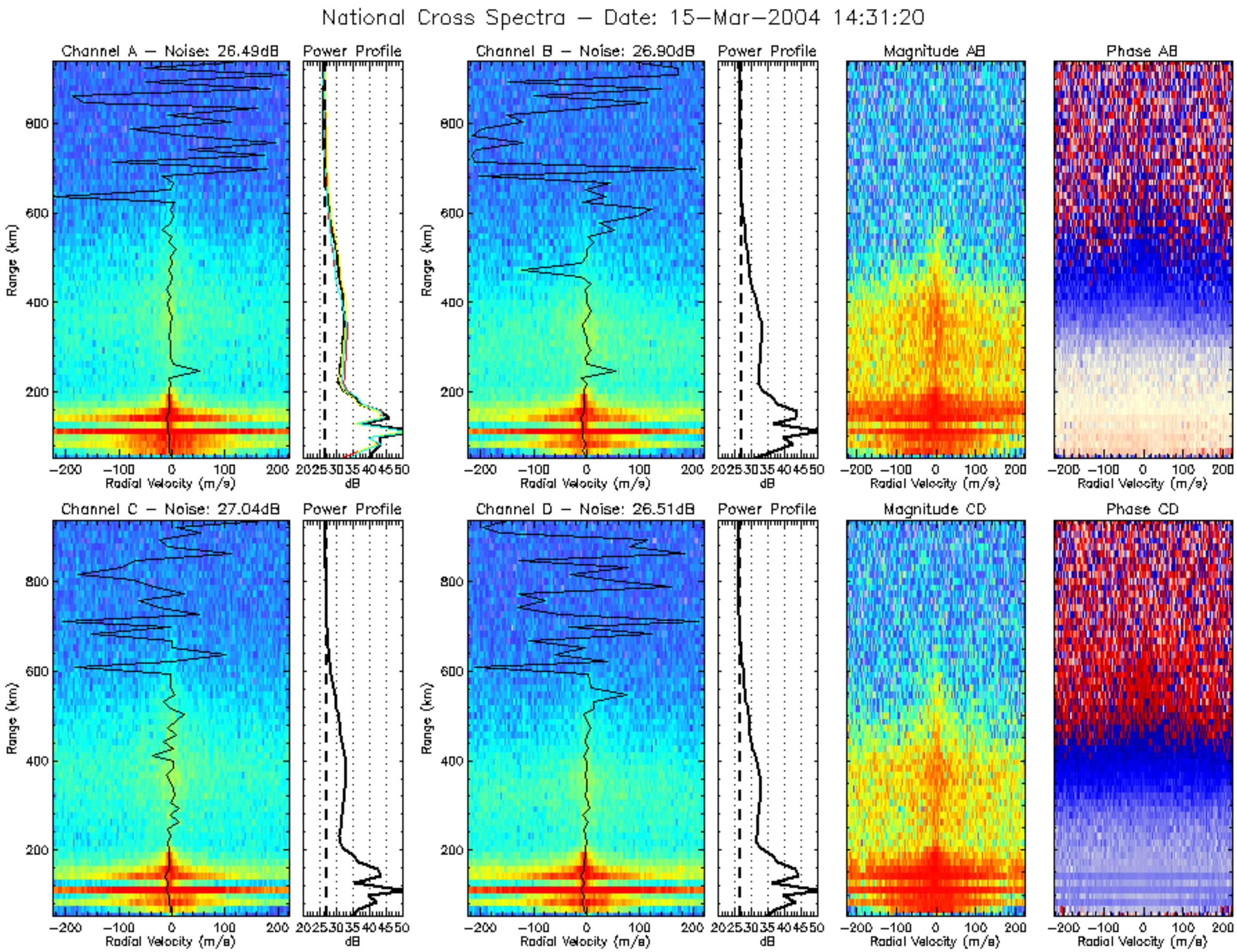
<u>Oblique</u>

- Spectra are wide (>1000 m/s or 300 Hz at 50 MHz) and independent of α within typical antenna beam widths.

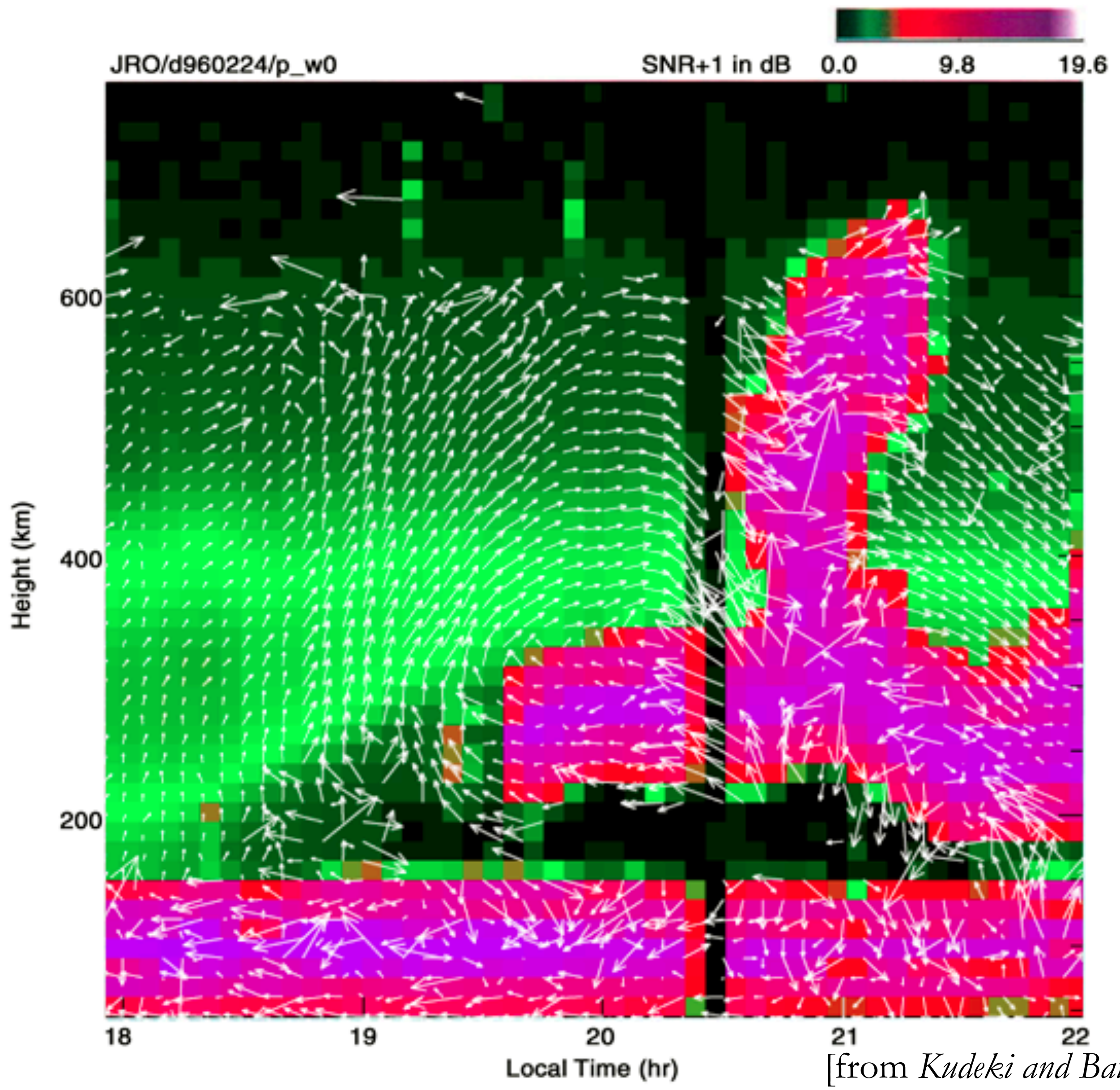
<u>Perpendicular</u>

- Spectra get narrower (less than 150 m/s) for smaller α and change very quickly.
- Measured spectra results from a convolution of spectra with different widths due to finite antenna beam width.

Perpendicular ISR Examples (1): Pulse-to-pulse Spectral Analysis



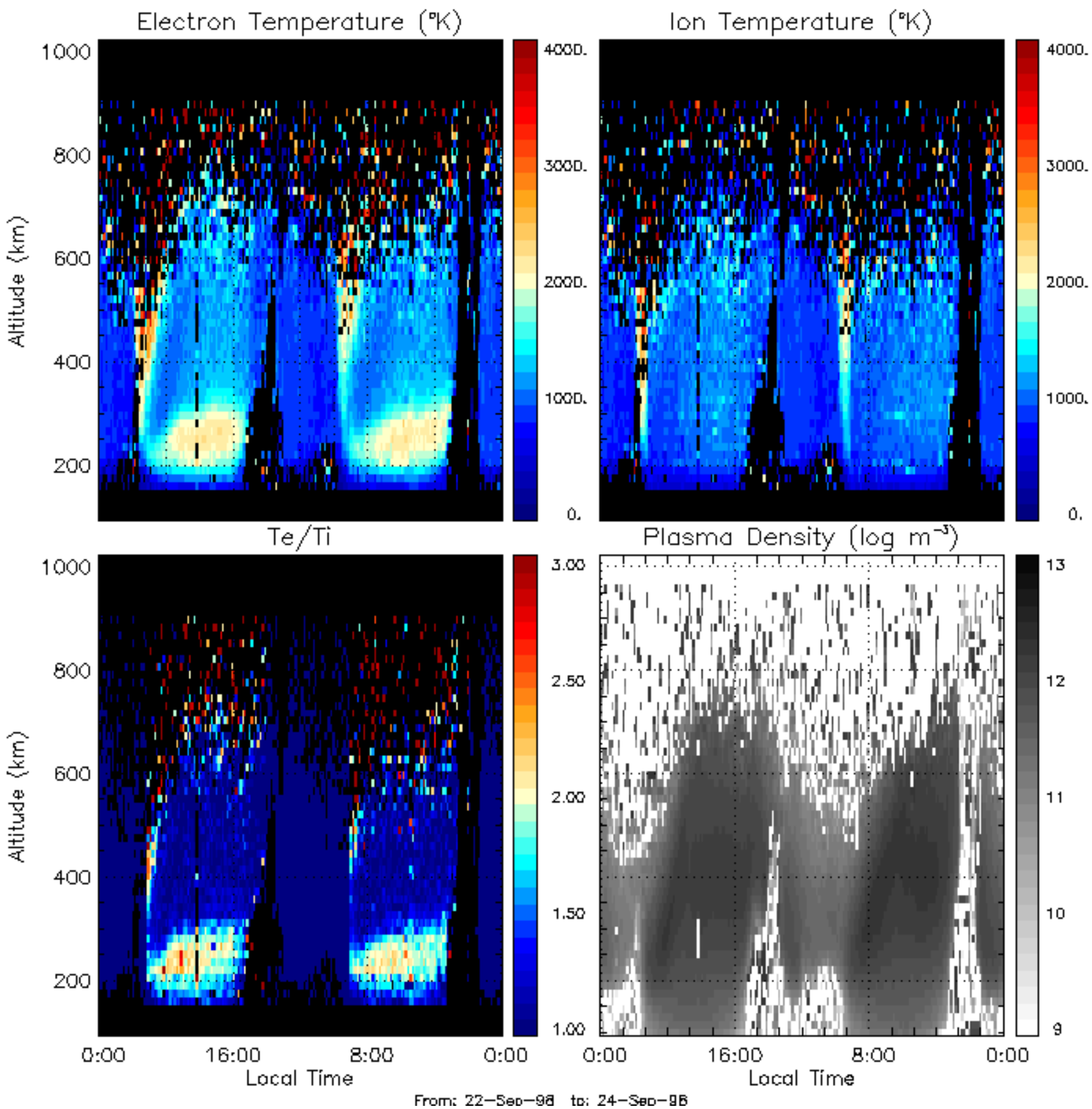
ESF Vortex



[from *Kudeki and Batthacharyya*, 1999]

Oblique ISR Examples (1): Faraday Double Pulse

Radio Observatorio de JICAMARCA Radio Observatory



• This is the traditional mode (since 1960's) to get:
-densities from Faraday rotation and power.
-Temperatures and Composition from ACFs obtained with Double Pulse sequences.
• This mode doesn't use the available duty cycle.
•Composition is hardly obtained.
•After *Sulzer and Gonzalez* [1999] work, temperatures estimates have been improved and the data reanalyzed since 1996.
•e.g., This mode is ideal for studying the Midnight temperature maximum (MTM).

[*Farley*, 1969]

Oblique ISR Examples (2): Hybrid 2 Faraday DP – Long Pulse – Full Profile

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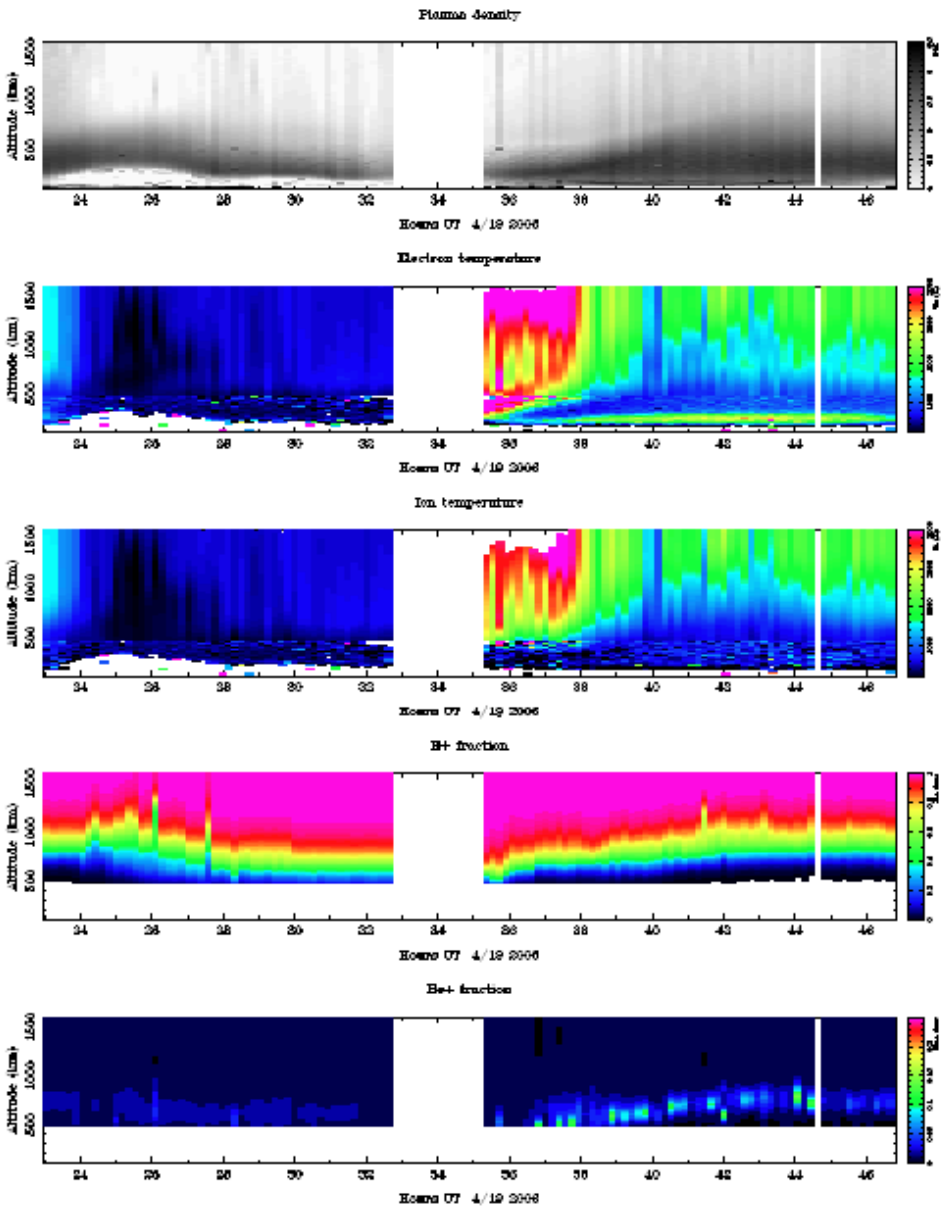


•This modes combines the Faraday DP mode with a long pulse mode, again allowing use of the available duty cycle.

•Altitudinal coverage it is better than previous two modes at the expense of less altitudinal resolution in the topside.

•Similarly it provides:

-Density and temperatures below 500 km

-Density, temperatures and composition above 500 km.

[*Hysell et al.*, 2008]

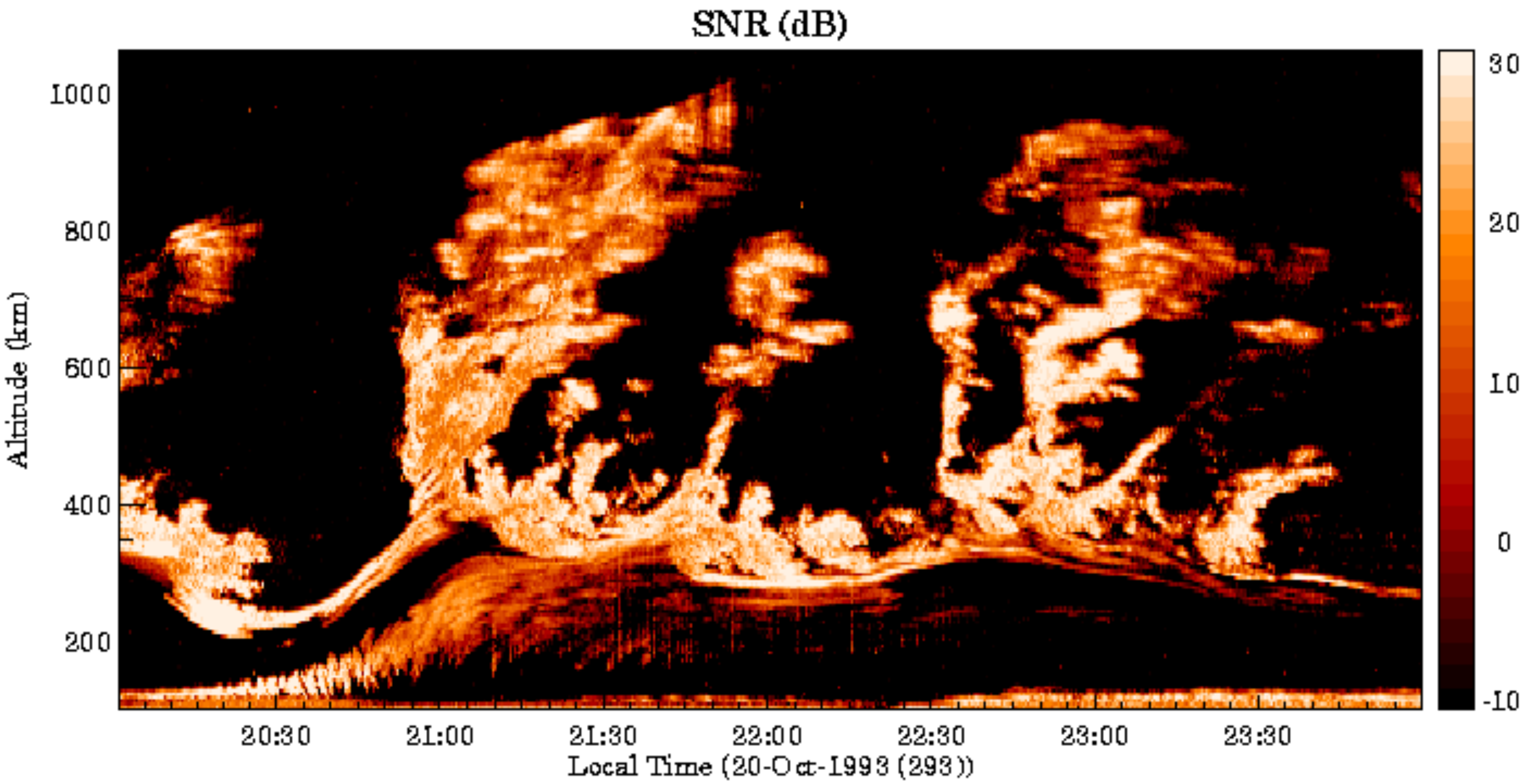
Coherent Scatter Techniques

MST and Radar Interferometry

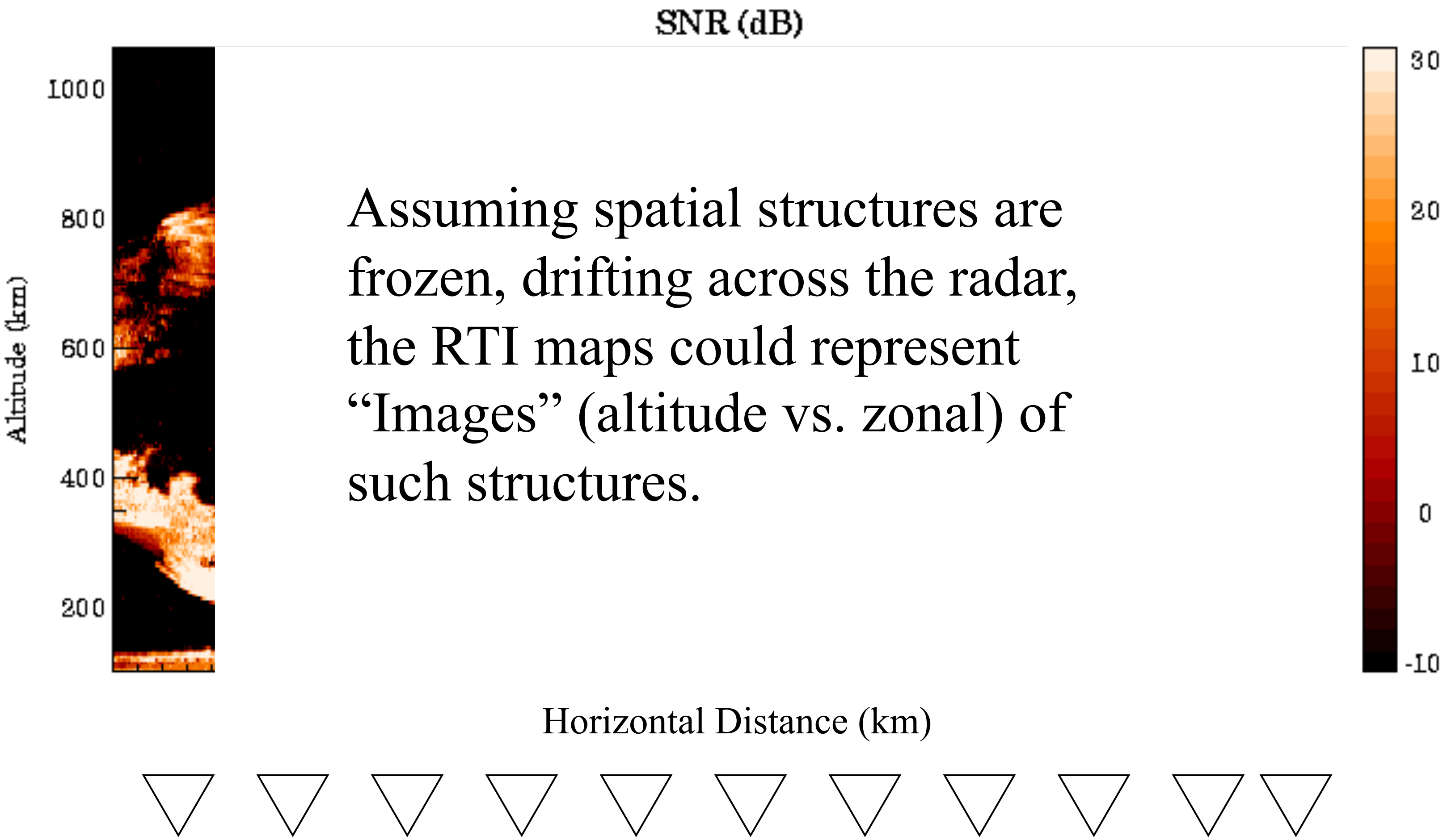
Radio Observatorio de JICAMARCA Radio Observatory

- MST technique
  - To measure neutral winds in the lower atmosphere
  - Improvements in hardware and software (rapid T/R switches, low power capabilities, coherent integrations, pulse compression, pulse-to-pulse analysis).
- Radar Interferometry
  - It uses two or three antennas depending if the target to study is field-aligned or not.
  - To measure target location and angular width (aspect sensitivity). From changes of location as function of time, we can infer horizontal drifts.
  - It has been applied to: EEJ, ESF, meteors, PMSE, sporadic E, lightning, …

Range-Time Intensity (RTI) maps

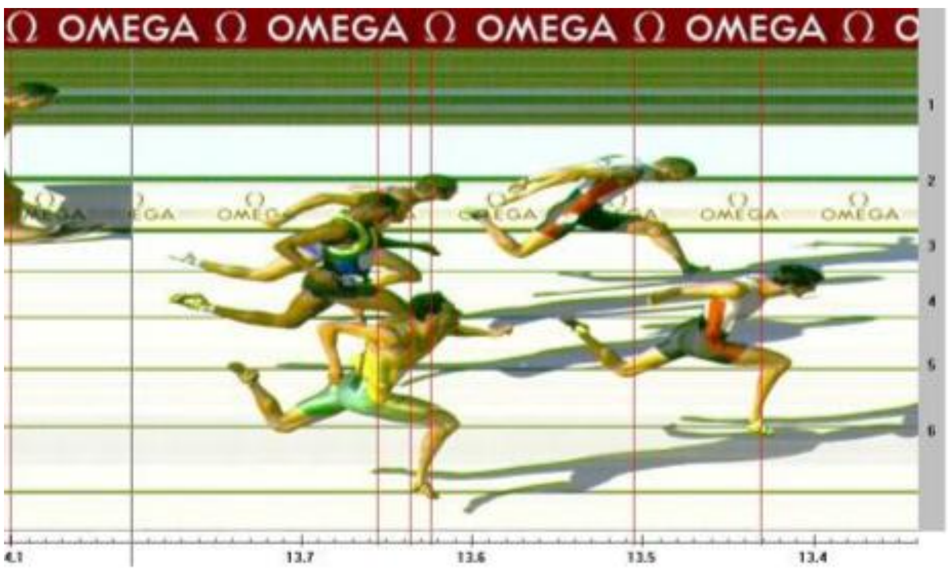


Range-Time Intensity plots as "Images": Slit camera interpretation



Assuming spatial structures are frozen, drifting across the radar, the RTI maps could represent "Images" (altitude vs. zonal) of such structures.

Slit-camera Analogy and Problems



- In some applications like races it is useful
- In many other applications it provides misleading results:
  - Slow structures are stretch out
  - Fast-moving structures are compressed.
  - In general, it is difficult to discriminate space-time features.

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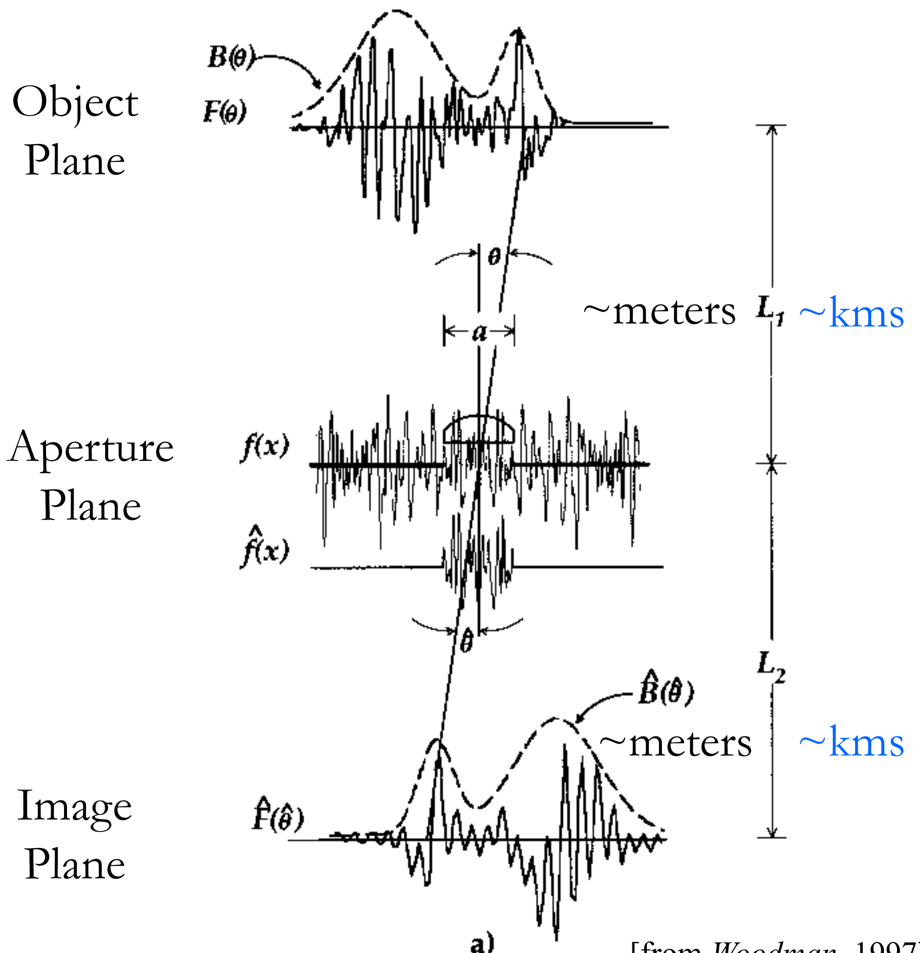
Analogy with an Optical Camera (2) Fourier Operations



[from *Woodman*, 1997]

$B(\theta)$ True Brightness

$$B(\theta) \xleftrightarrow{\text{Fourier}} V(r)$$

$$\hat{B}(\theta) = A^2(\theta) * B(\theta)$$

$$\hat{B}(\theta) \xleftrightarrow{\text{Fourier}} \hat{V}(r)$$

$\hat{B}(\theta)$ Estimated Brightness

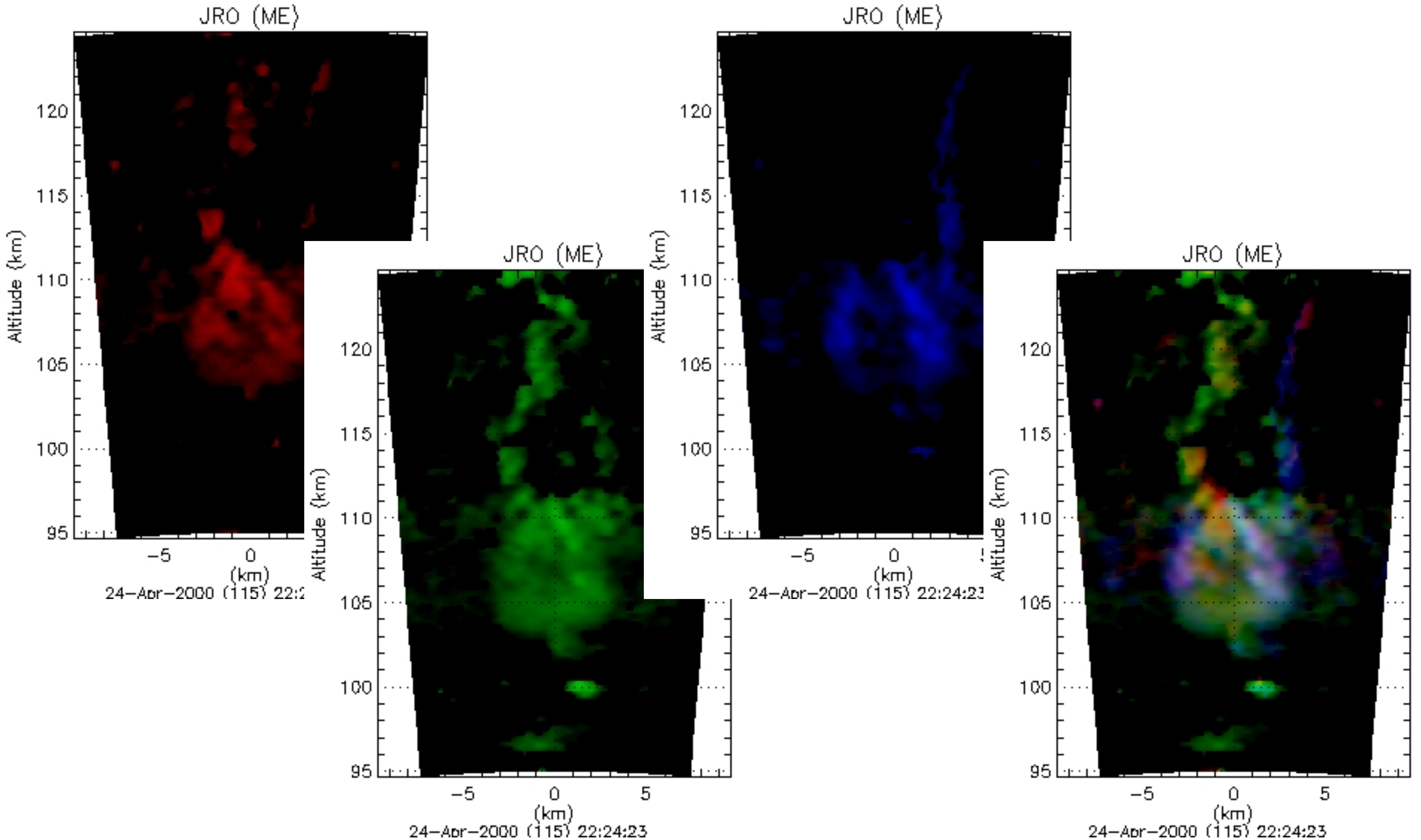
- In radio astronomy: Camera without “flash”
- In radar imaging: Camera with “flash”

Latest examples of ESF Radar Imaging at Jicamarca

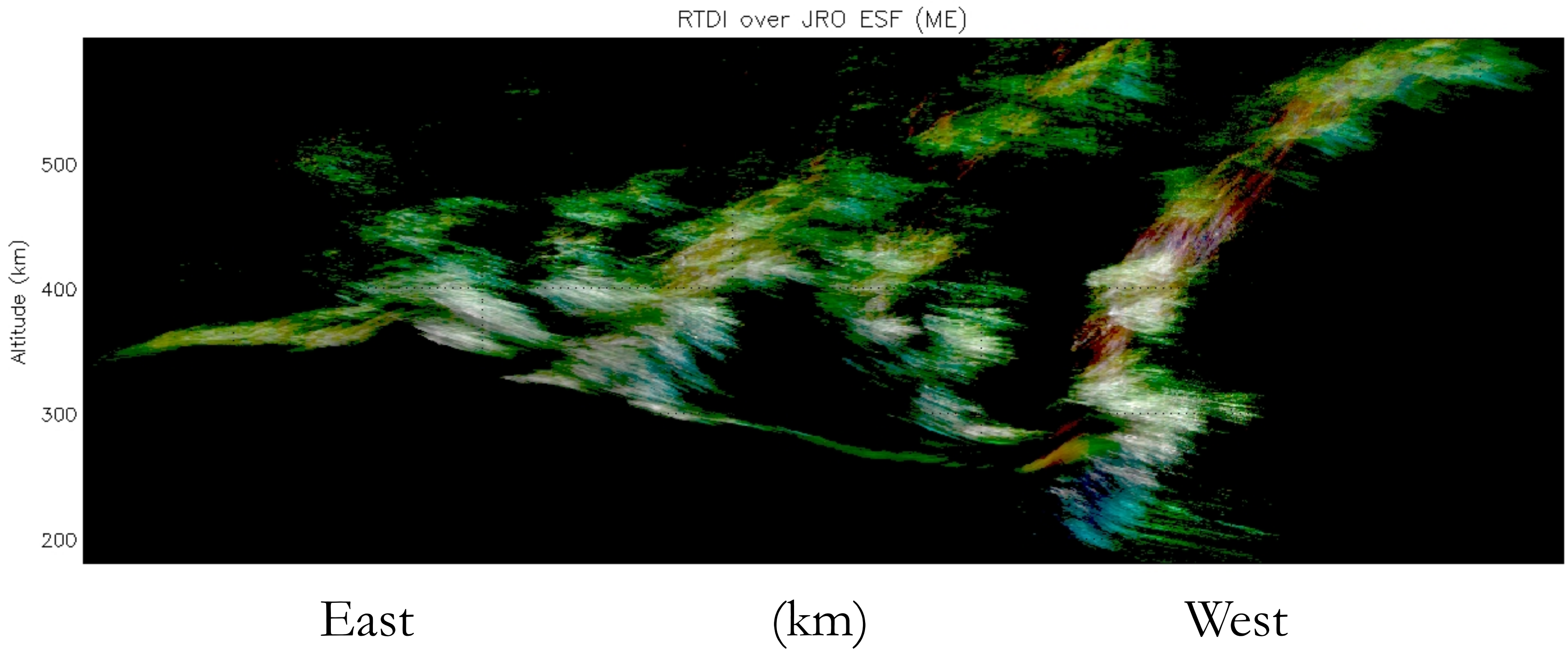
Radio Observatorio de JICAMARCA Radio Observatory

- 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 phase 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°

How to display radar images

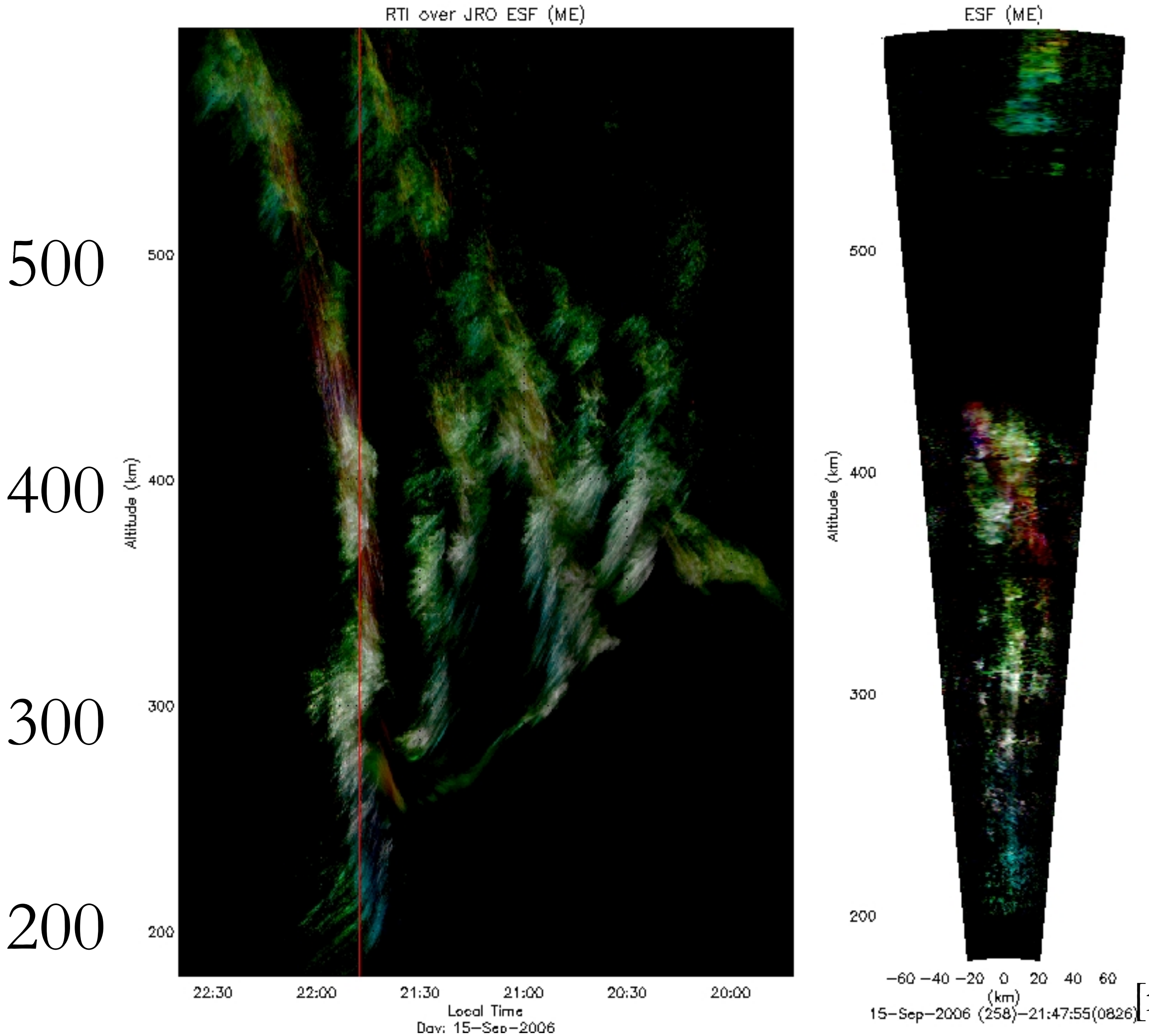


ESF RTDI: Slit camera interpretation



- Typical RTI maps are shown with "false" colors (colors from a pre-defined color table are associated to the signal intensity).
- Here we use Doppler for color. True 24-bit color range time intensity (RTI) plot using Doppler information (RTDI). 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 there is a depletion channel pinching off, Doppler aliasing, Doppler widening, etc.

ESF RTDI + Imaging (1)



[from *Chau et al.*, 2008]

ESF RTDI + Imaging (1)

Radio Observatorio de JICAMARCA Radio Observatory