Modeling the ISR spectrum perpendicular to B - Magnetoionic effects

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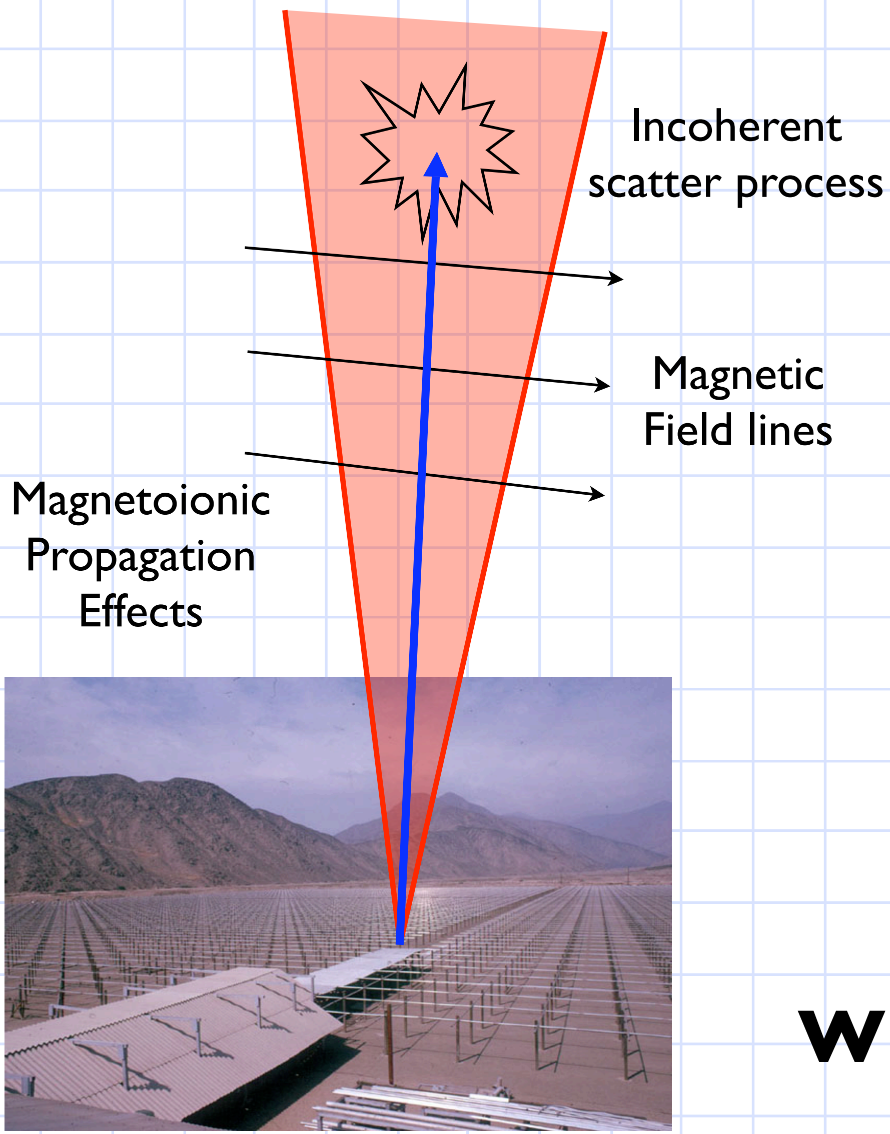
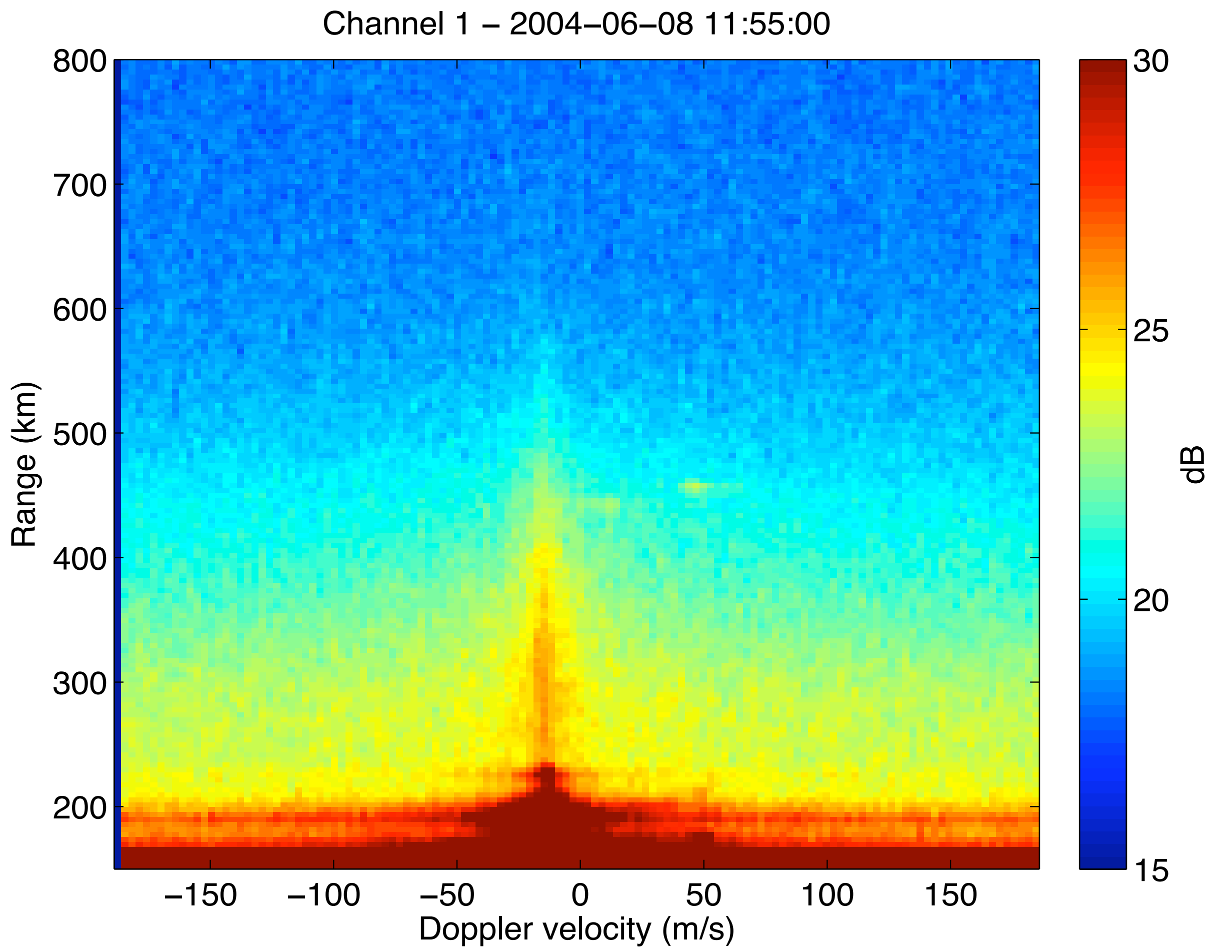
Jicamarca ISR measurements perp. to B



- Phasing Jicamarca antenna perp. to B, we can measure:
  - Drifts:
    - Old days, using the phase of the pulse-to-pulse correlation (Woodman & Hagfors, 1969).
    - Modern times, using Kudeki et al (1999) spectral technique (Doppler shift of ISR signal).
  - Densities: using the "Differential phase" technique introduced by Kudeki et al (2003).

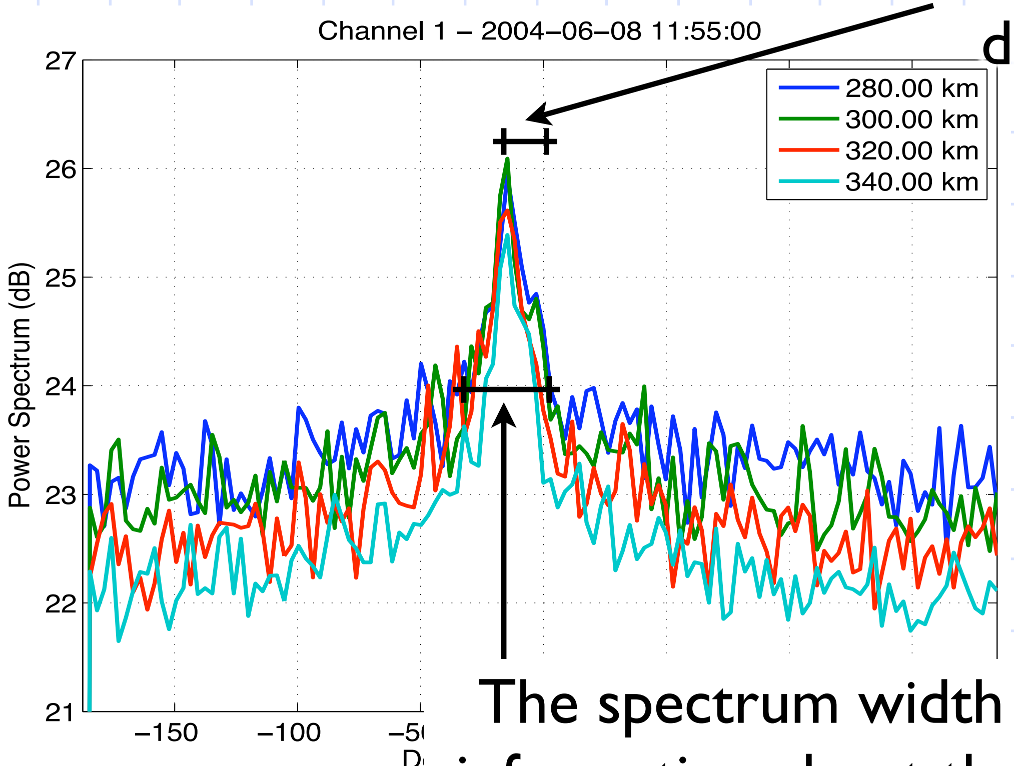
What about temperatures?

Jicamarca ISR spectrum perp. to B



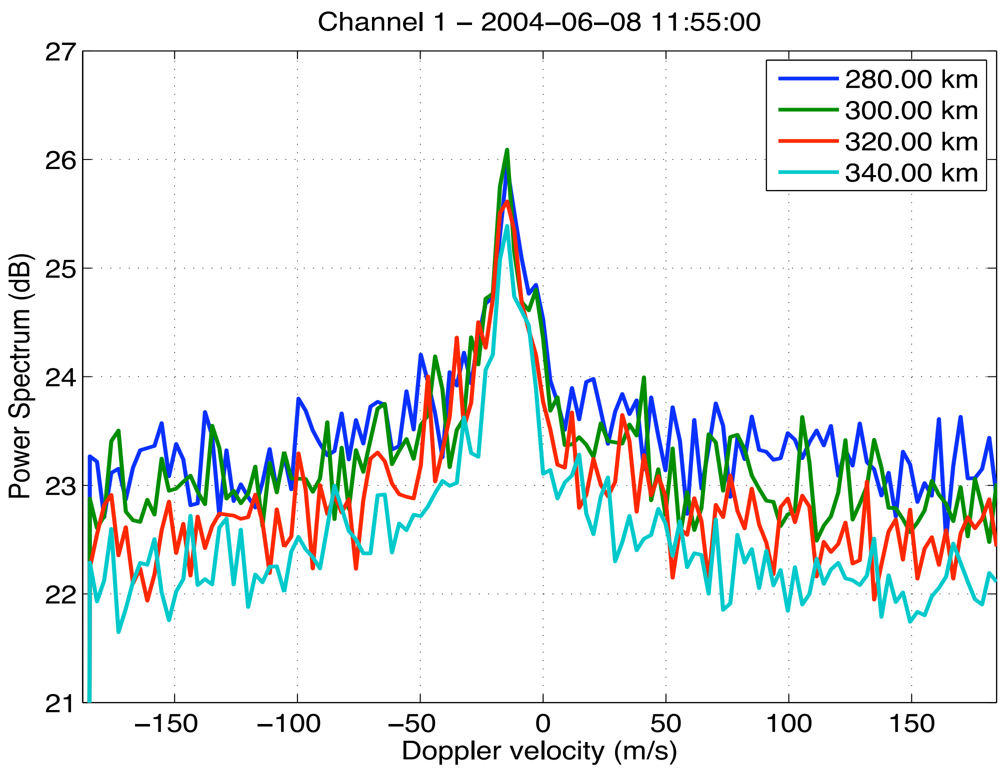
Jicamarca ISR spectrum perp. to B

Doppler shift of the spectrum is a direct measurement of the drift.



The spectrum width should give us information about the temperatures.

Jicamarca ISR spectrum perp. to B



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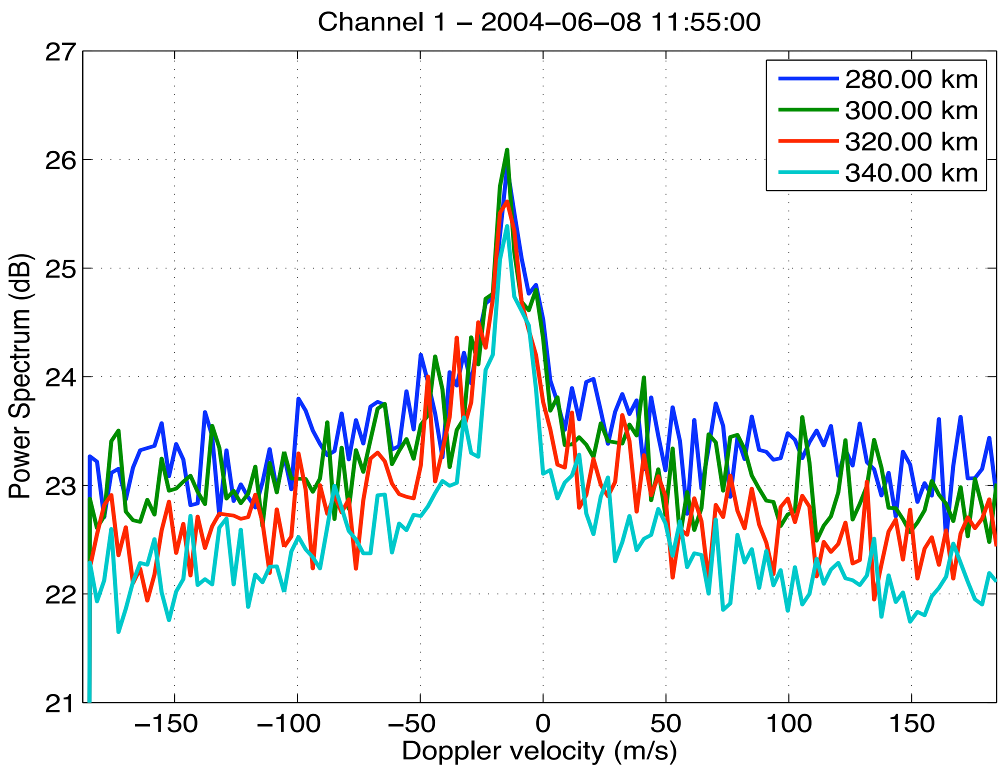
But, the temperatures they obtained were about half of what is expected.

Jicamarca ISR spectrum perp. to B



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But, the temperatures they obtained were about half of what is expected.

The measured spectrum was narrower than what collisionless theory predicts.

Why is the IS spectrum at Jicamarca narrower than what was expected?

Why is the IS spectrum at Jicamarca narrower than what was expected?

Electron Coulomb collision effects (Sulzer & González, 1999)

How do we include the effect of collisions?

- The standard theory of incoherent scatter formulates the spectrum of the ISR signal in terms of the so-called Gordeyev integrals

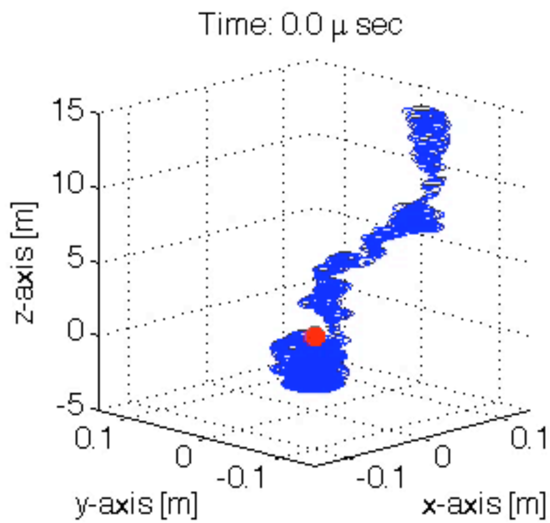
$$\frac{\langle |n_e(\omega,\vec{k})|^2\rangle}{N_e} = \frac{|j(k^2h_e^2+\mu)+\mu\theta_i J(\theta_i)|^2}{|j(k^2h_e^2+1+\mu)+\theta_e J(\theta_e)+\mu\theta_i J(\theta_i)|^2}\frac{2\mathrm{Re}\{J(\theta_e)\}}{\sqrt{2}kC_e} + \frac{|j+\theta_e J(\theta_e)|^2}{|j(k^2h_e^2+1+\mu)+\theta_e J(\theta_e)+\mu\theta_i J(\theta_i)|^2}\frac{2\mathrm{Re}\{J(\theta_i)\}}{\sqrt{2}kC_i}$$

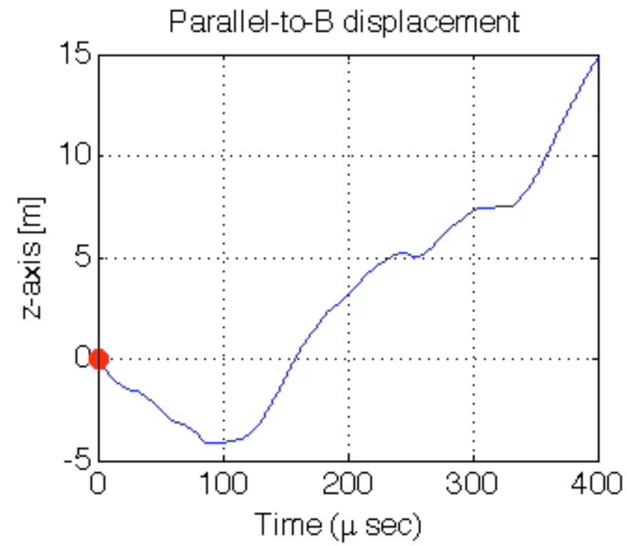
- The Gordeyev integrals can be interpreted as the one sided Fourier transform of the correlation of the signal scattered by a singled-out test particle in a plasma where collective interactions have been neglected.

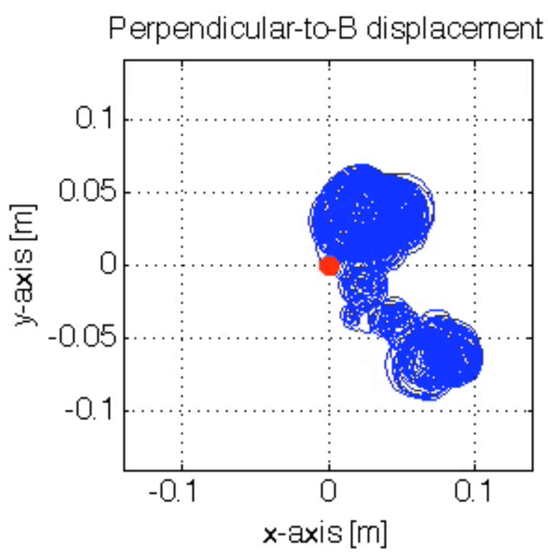
$$J_s(\omega) = \int_0^\infty d\tau e^{-j\omega\tau}\langle e^{j\vec{k}\cdot\Delta\vec{r}_s}\rangle \qquad \langle e^{j\vec{k}\cdot\Delta\vec{r}_s}\rangle = \langle e^{j\vec{k}\cdot(\vec{r}_s(t+\tau)-\vec{r}_s(t))}\rangle$$

- Thus, if the test particle trajectories were known, we could compute the single particle ACFs and corresponding Gordeyev integrals. The effect of collisions is considered in modeling the particle trajectories.

3D charged particle trajectories







O+ Plasma:

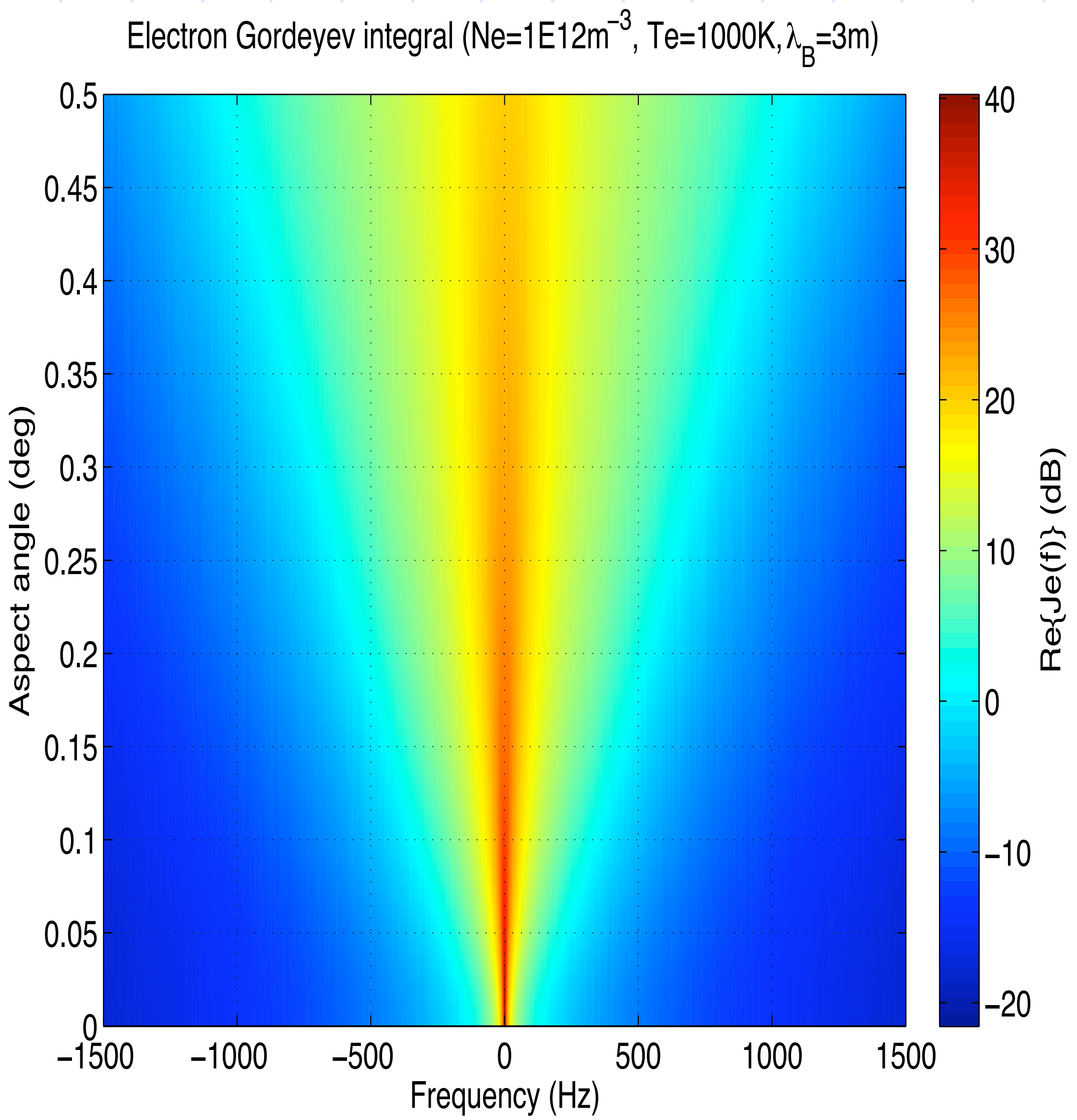
Ne = 10^{12} m^3

Te = 1000 K

Ti = 1000 K

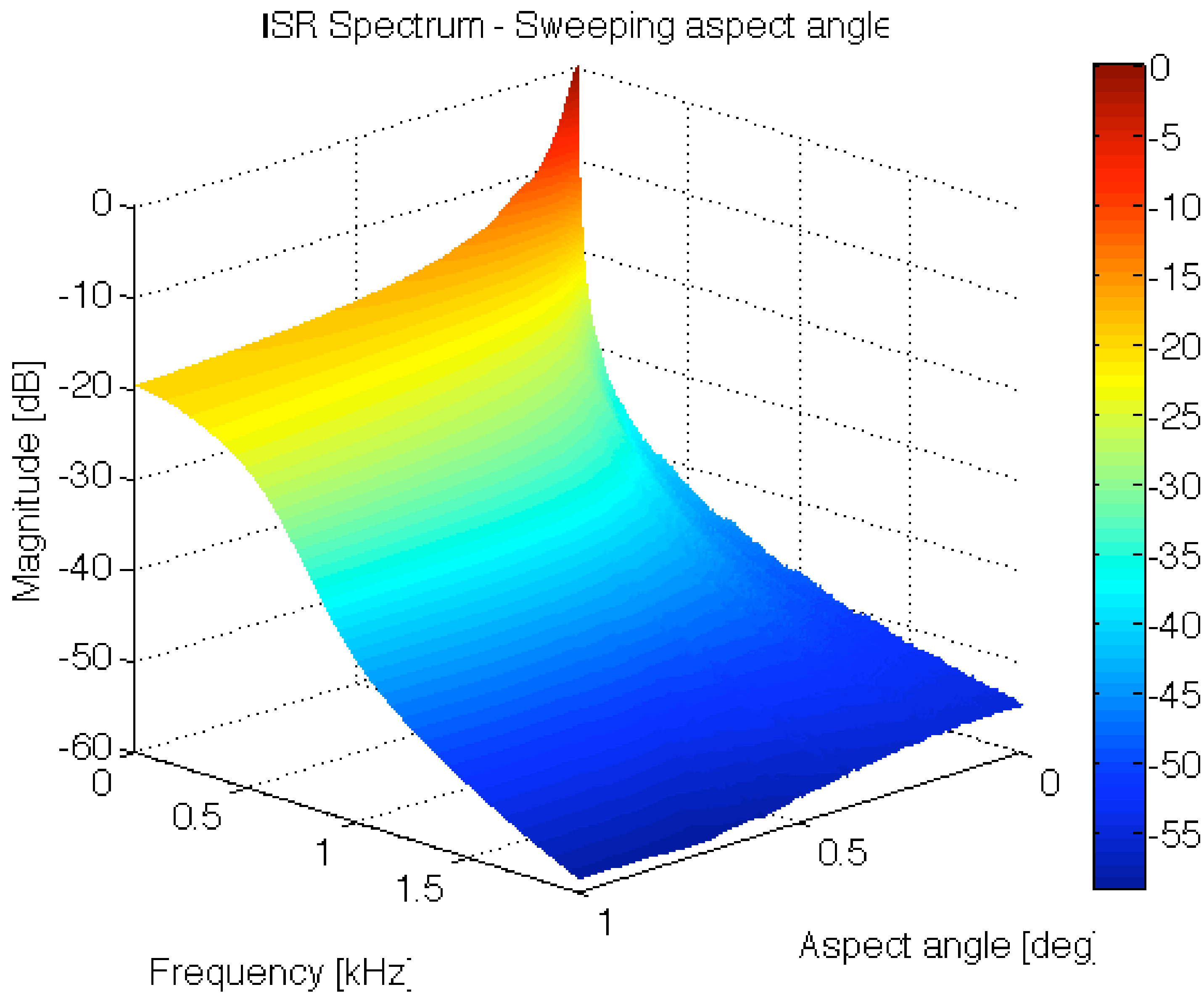
B = 25 000 nT

Database of electron Gordeyev integrals



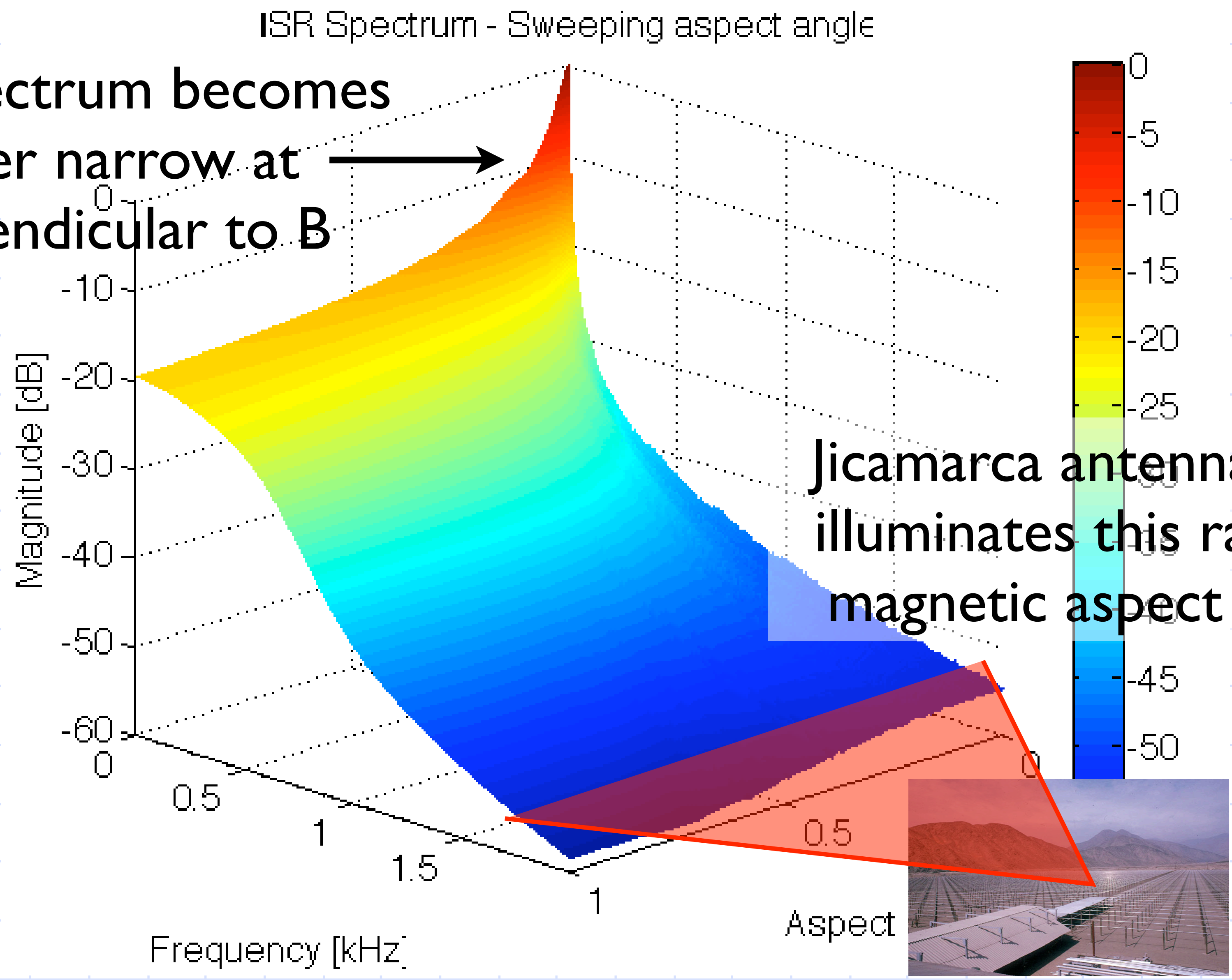
- We have built a library for an O+ plasma that considers
  - 600K < Te < 3000K
  - 600K < Ti < 2000K
  - |B| = 20, 25, 30 μT
  - Ne = 1E11, 1E12, 1E13 m^{-3}
  - Large set of aspect angles from 0° to 90°.
- A web-page with the results is available at http://collisions.csl.uiuc.edu/database/gordeyev/

Collisional IS Spectrum



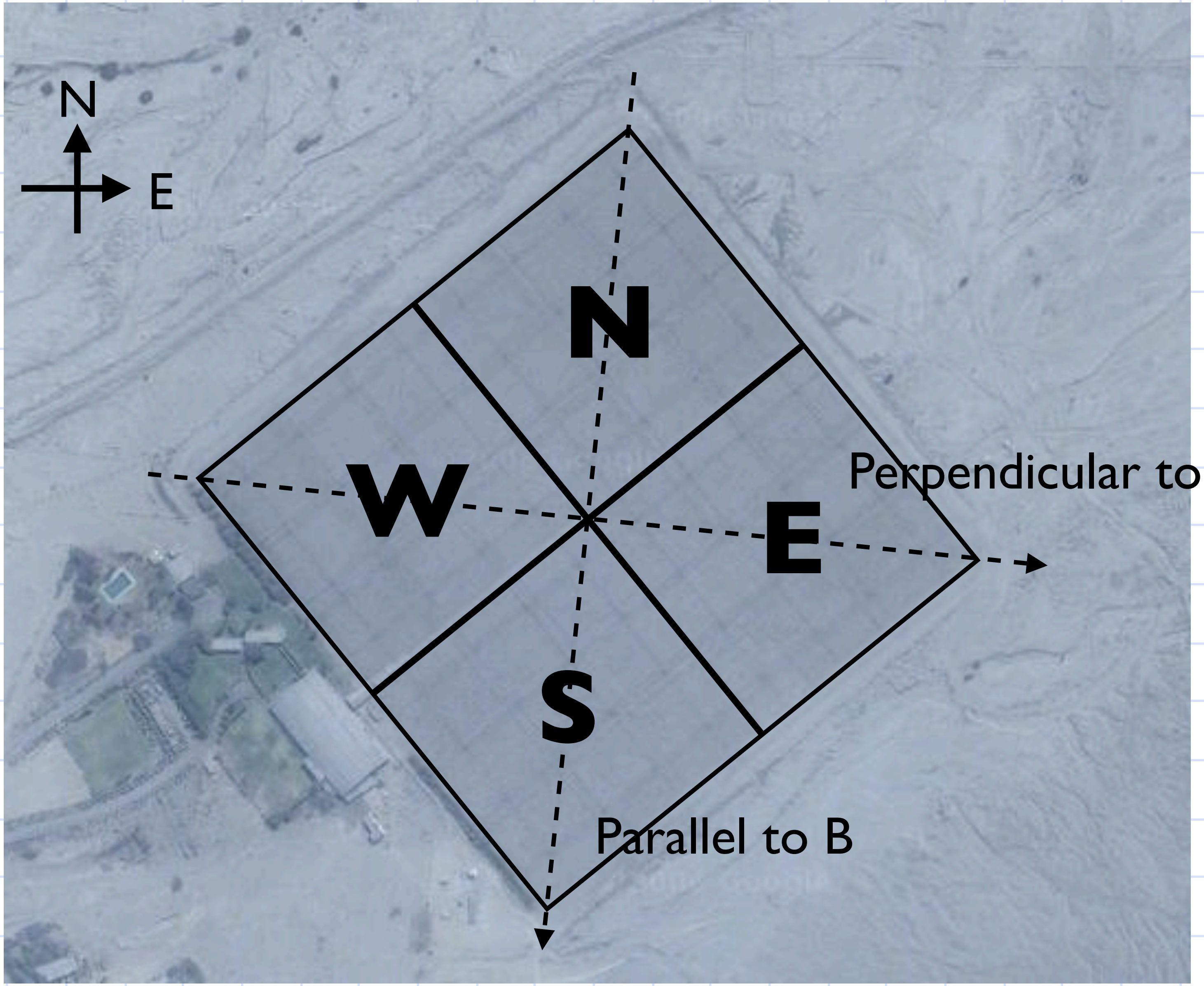
Collisional IS Spectrum

The spectrum becomes super narrow at perpendicular to B

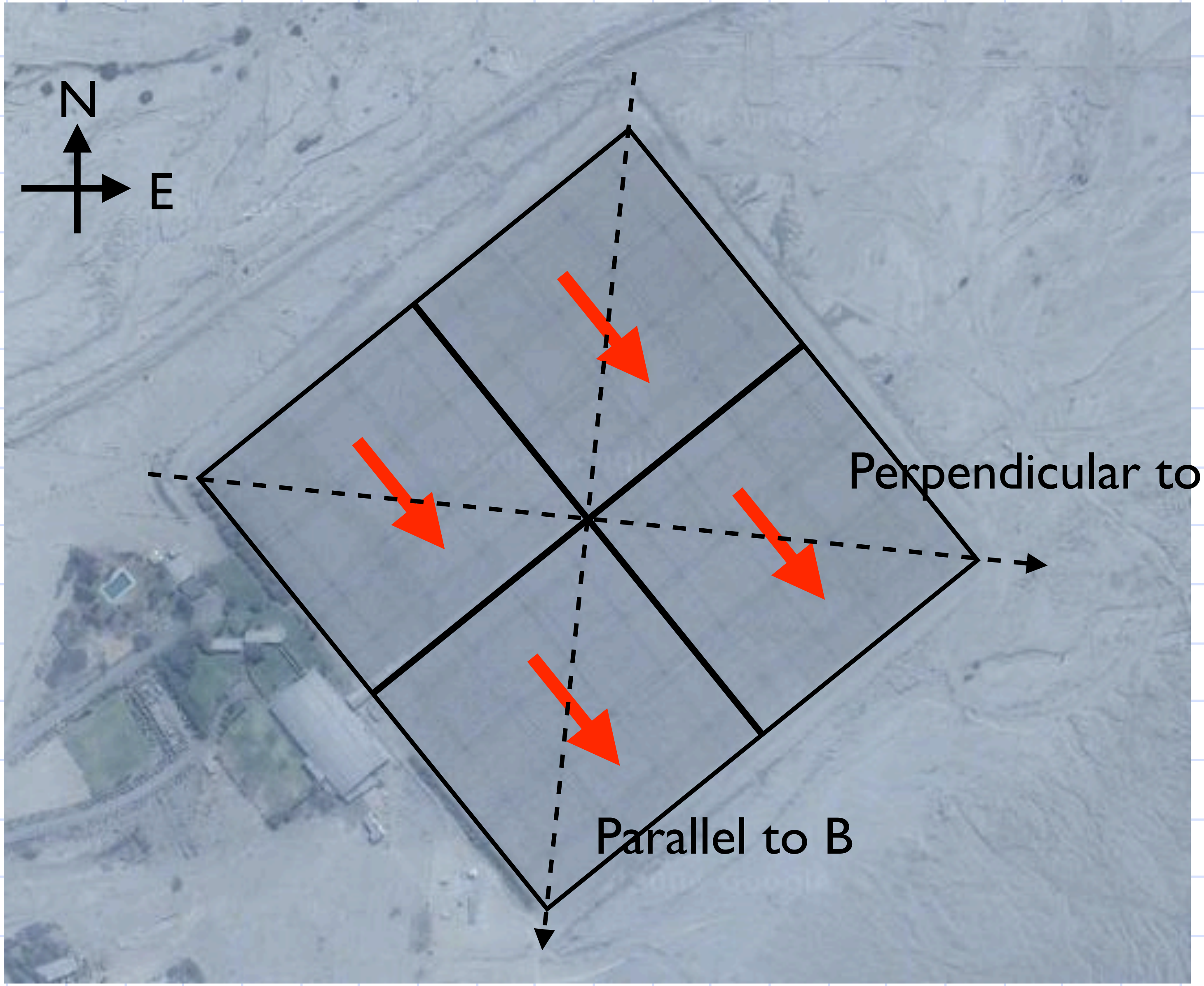


Jicamarca antenna beam illuminates this range of magnetic aspect angles

Application: DVD experiment



Application: DVD experiment



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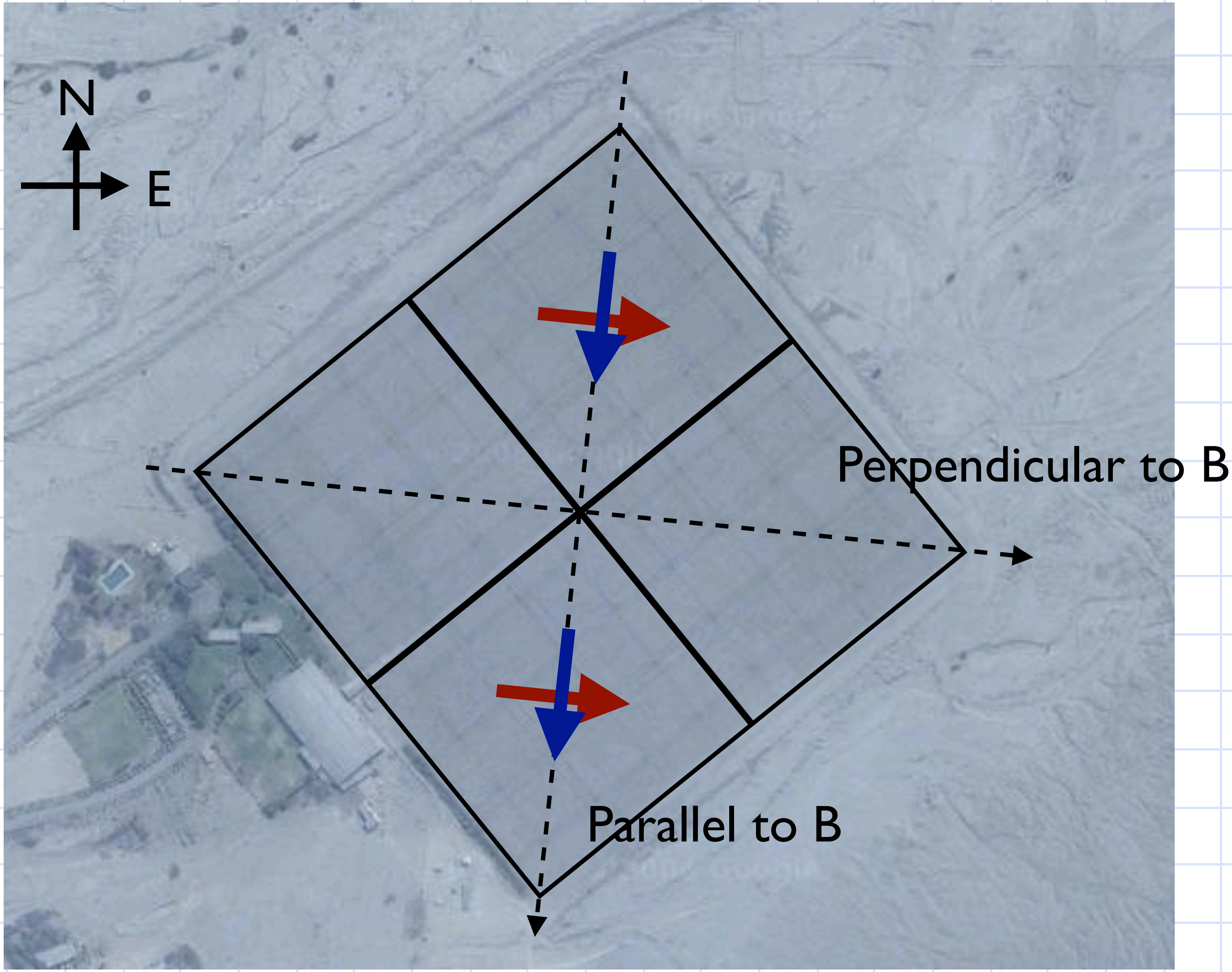
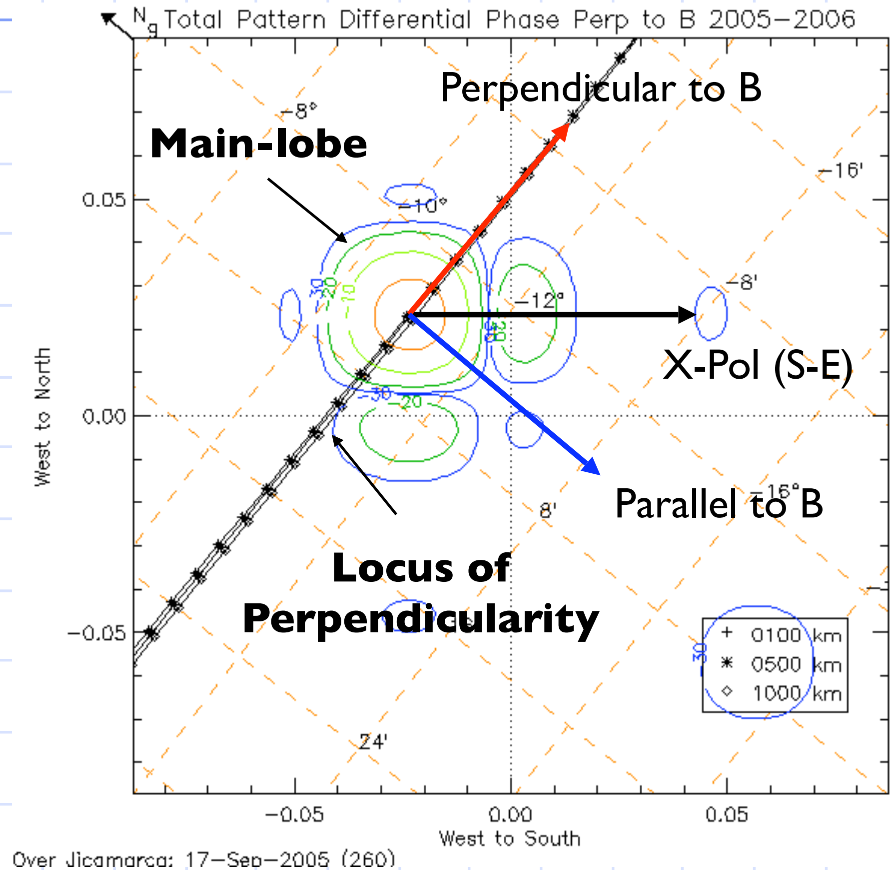
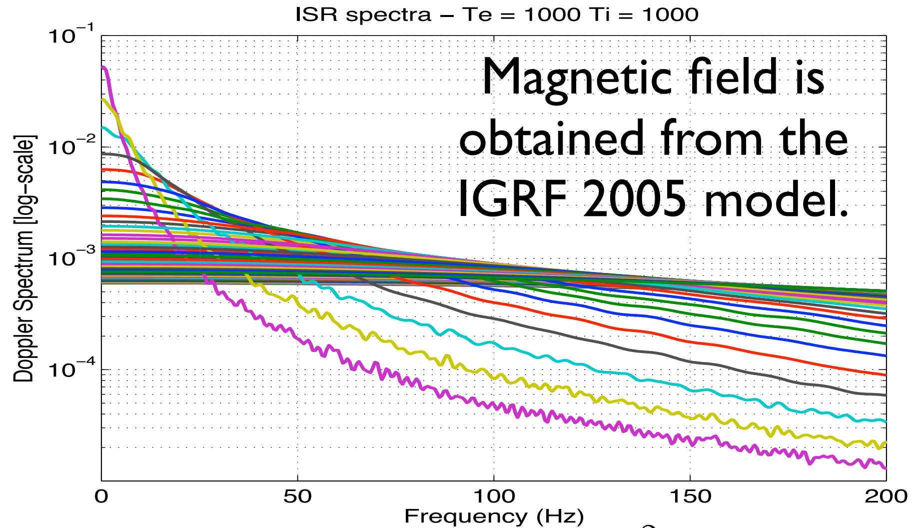


Beam-weighted ISR spectrum



- DVD experiment: north and south quadrants of Jicamarca antenna are phased to point perp to B.
- Beam-width: ~1 deg.
- The measured spectrum is the sum of signal coming from different magnetic aspect angles.

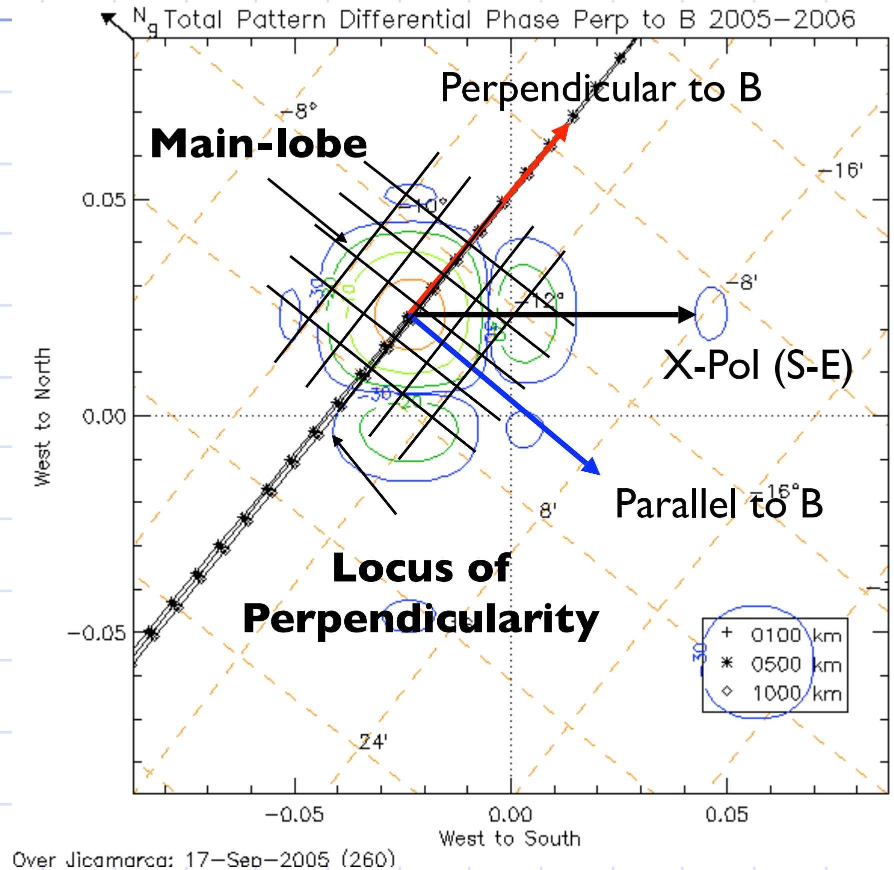


Radar equation:

$$S_\perp(\omega,\tau) \propto \int\int dr d\Omega \frac{|G(\hat{r})|^2}{r^2}$$

$$\frac{1}{T}\sum_n S(-2k\hat{r}, \frac{\omega - 2\pi n}{T}, \vec{r}) \left|\chi(\tau - \frac{2r}{c}, -\frac{\omega - 2\pi n}{T})\right|^2$$

Beam-weighted ISR spectrum



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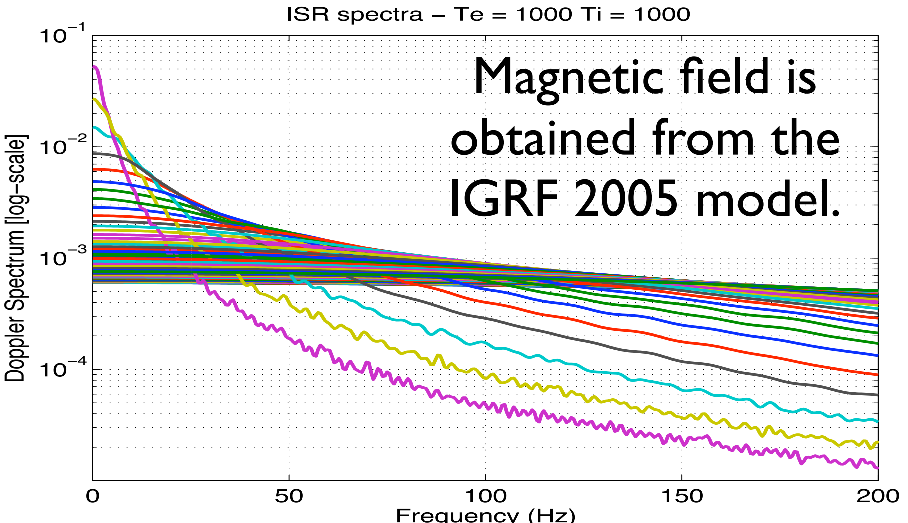

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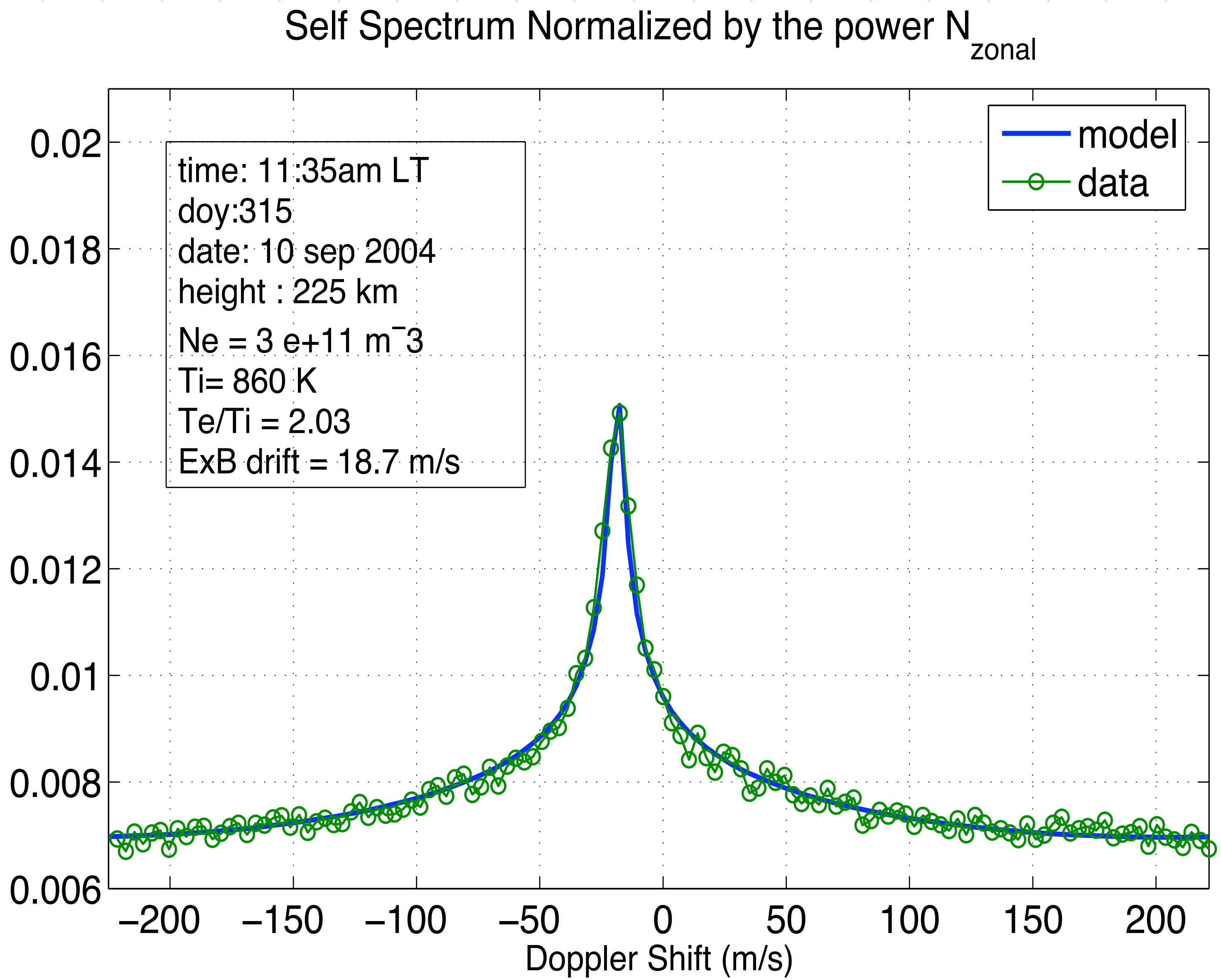
First spectrum fitting



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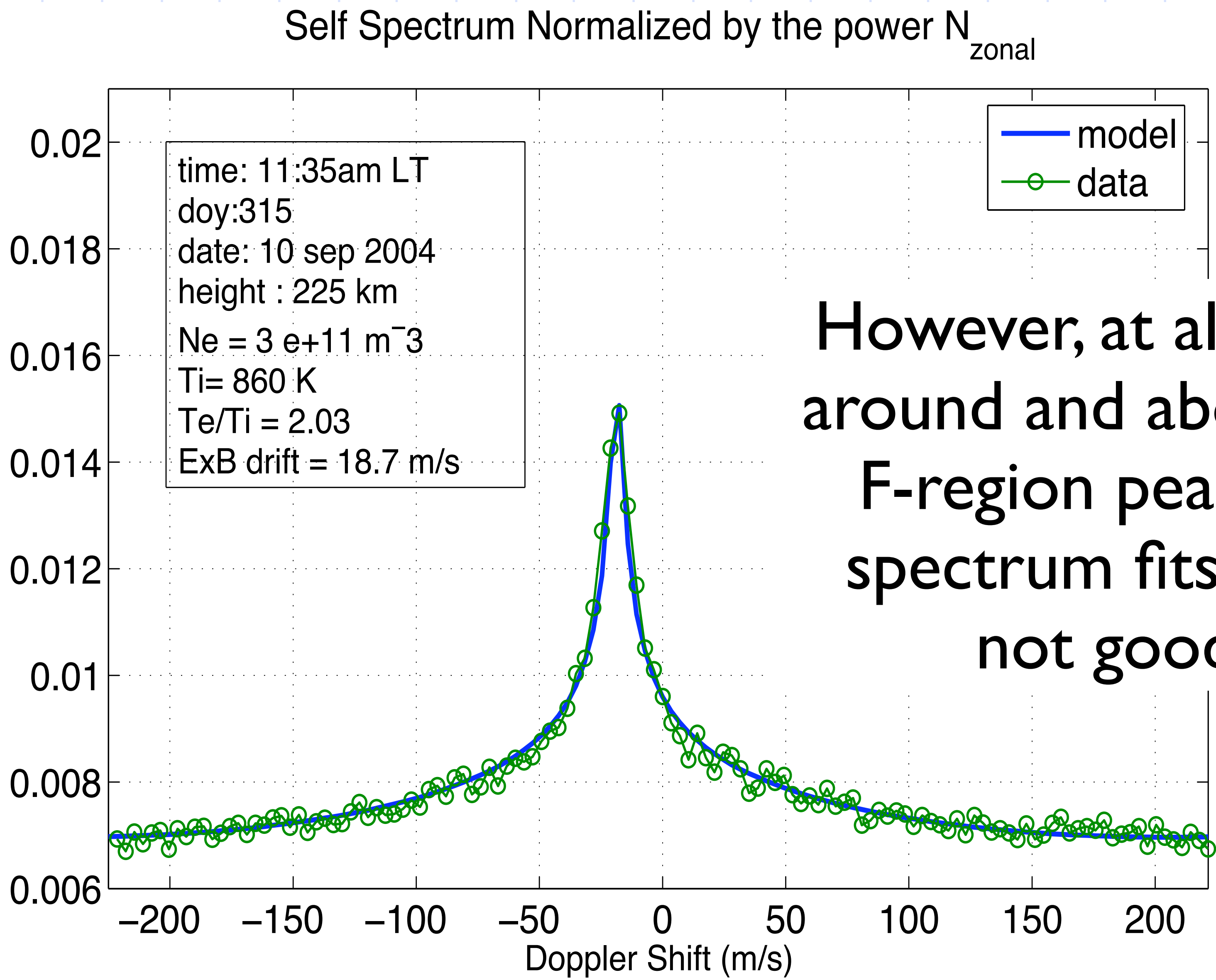
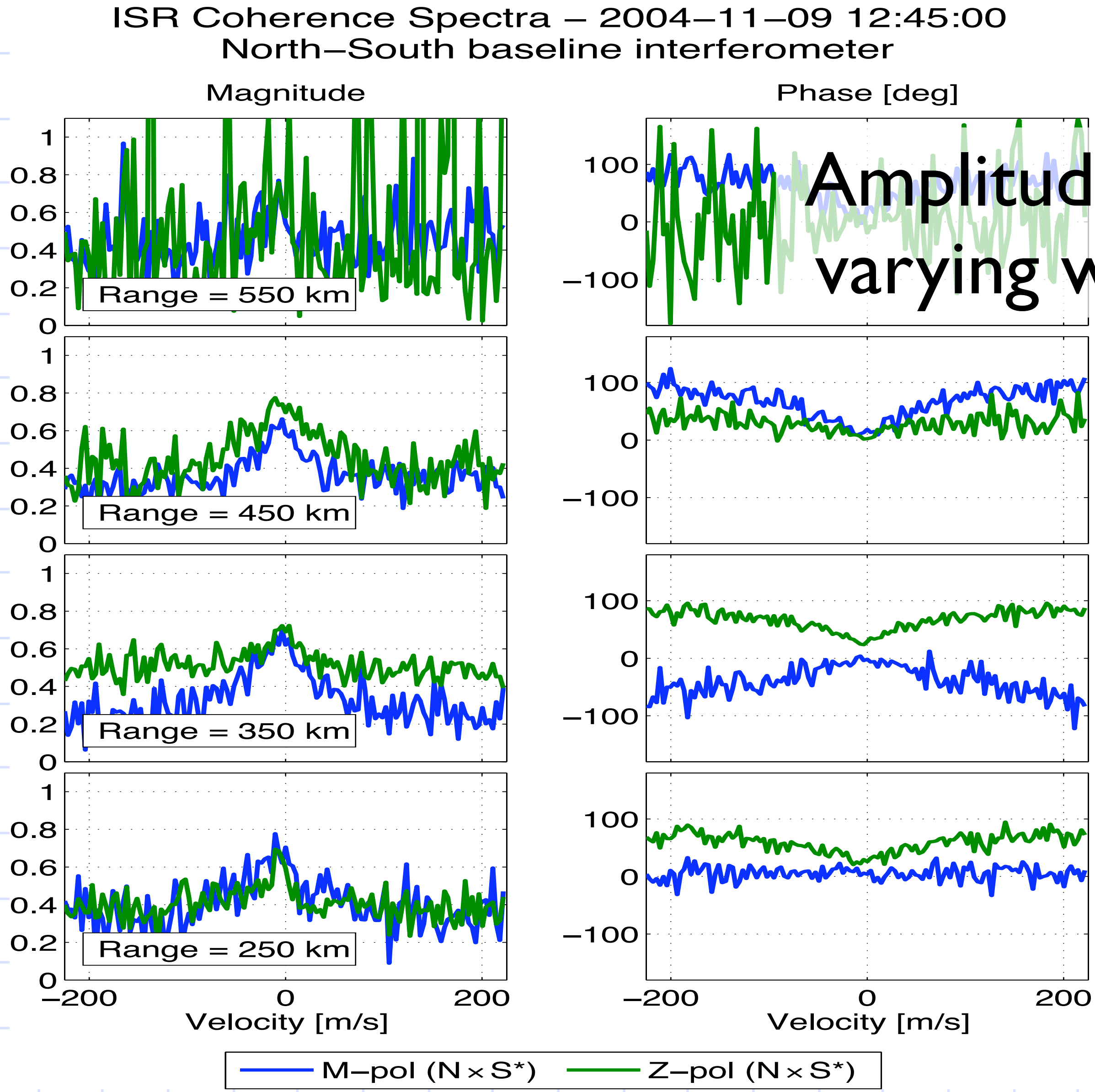


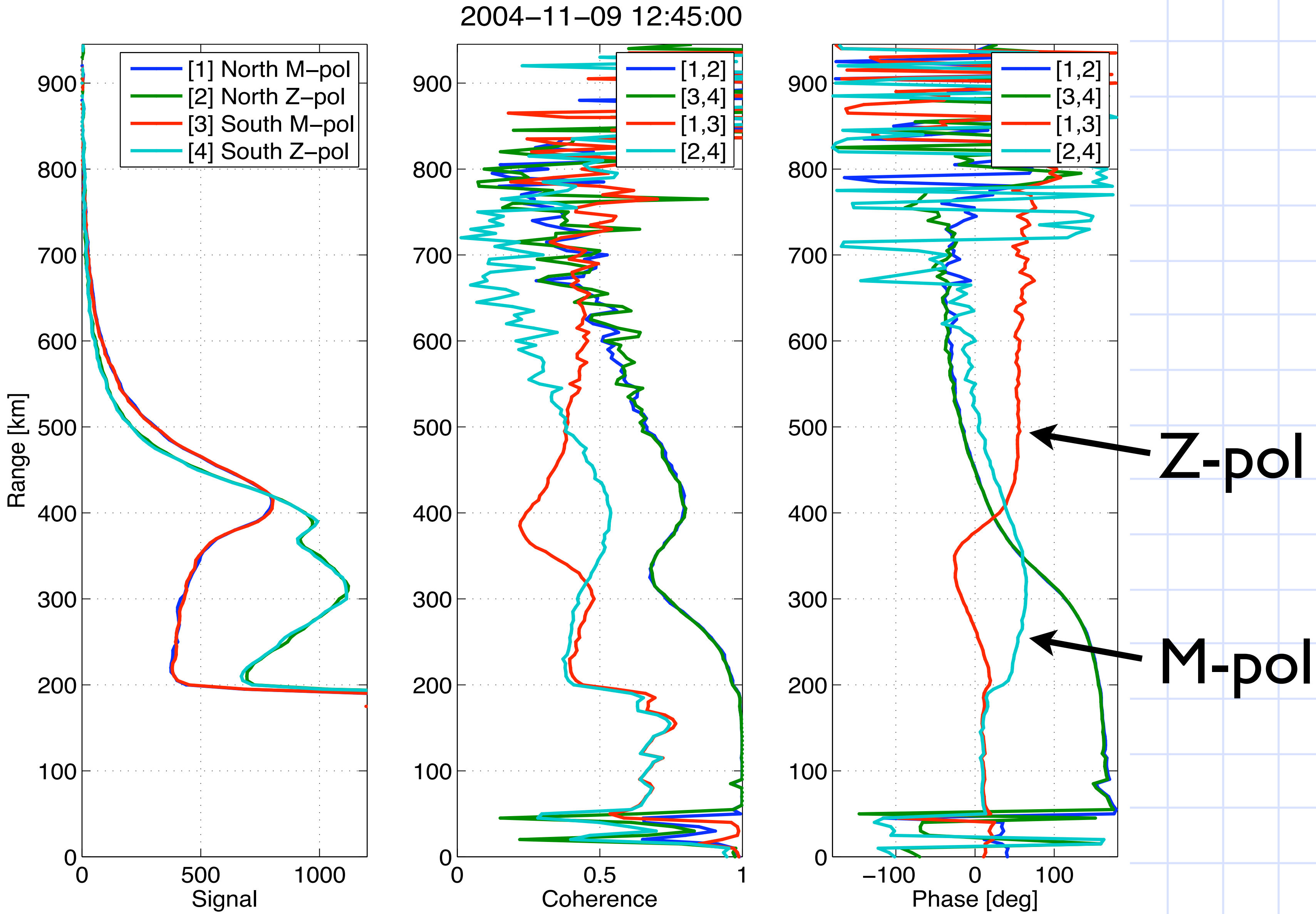
However, at altitudes around and above the F-region peak, the spectrum fits were not good.

Coherence spectrum as function of height



Amplitude and phase varying with altitude

Power and cross-correlation profiles



Why do our model not fit IS spectra measured at top heights?
Why do the interferometric cross-correlation phases vary with altitude?

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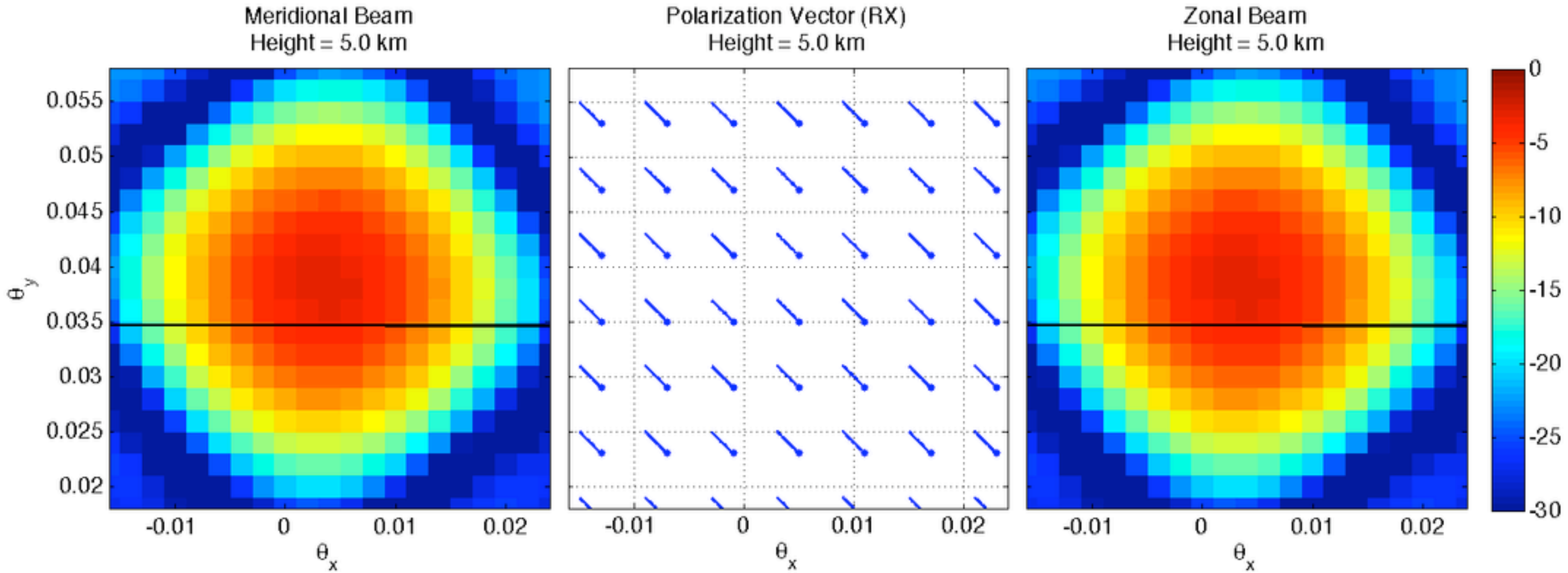
Why do the interferometric cross-correlation phases vary with altitude?

Magnetoionic propagation effects

Beam-shape modified by Magnetoionic propagation effects



Simulation

Conclusions and Future work

- The modeling of the perpendicular-to-B IS spectrum measured by the Jicamarca radar needs to include:
  - Electron Coulomb collisions effects,
  - Beam-weighting effects, and
  - Magnetoinic propagation effects.
- A full-profile spectrum analysis will be required to invert densities, temperatures, and drifts simultaneously.
- We have already developed the tools to model each of the effects, the next step will be to combine them in a single tool to do the inversions.
- Alternatively, radar configurations using perpendicular and off-perpendicular beams are being investigated.