PHYSICS AND ENGINEERING PHYSICS

Jean-Paul Villain's impact on my research

J.-P. St.-Maurice

Institute of Space and Atmospheric Studies

Overview

- My E region interactions with Jean-Paul
  - Cyclotron modes or just gradients?
  - Slow to ultra slow modes: a pulling of HAIR echoes?
- Our F region debates
  - The great spectral width conundrum
  - The interesting anomalies
    - Narrow fast spectra
    - Divergent F region echoes: oh la la!

Some of our E region debates

The great E region cyclotron debate

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 92, NO. A11, PAGES 12,327–12,342, NOVEMBER 1, 1987

HF Radar Observations of *E* Region Plasma Irregularities Produced by Oblique Electron Streaming

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Data obtained with the Applied Physics Laboratory HF radar located in Goose Bay, Labrador, have been used to determine the characteristic features of high-latitude ionospheric irregularities at decameter wavelengths. In this paper, we describe a set of four events exhibiting particular characteristics. These observations took place in the postmidnight sector at *E* region altitudes. The scanning capabilities of the radar indicated that arclike regions of irregularities were moving approximately along *L* contours with a drift velocity of the order of 200 m/s or less. For periods of a few minutes to a few tens of minutes, localized regions of irregularities exhibiting high Doppler velocities (350 to 650 m/s) and large signal to noise ratios appeared within the radar arcs. Among the high Doppler velocity signals, two distinct types have been identified. Both types can be present simultaneously. One type is distributed between 320 and 550 m/s and has an average value of 445 m/s, while the other is distributed between 500 and 650 m/s and has an average value of 580 m/s. If one assumes the lower of the high-velocity signals to be the ion acoustic velocity C_s, the higher velocity can be interpreted as electrostatic ion cyclotron (EIC) waves produced by NO^+ ions. These EIC waves follow perfectly the dispersion relation established from the fluid approximation $\omega_r = (\Omega_i^2 + k^2 C_S^2)^{1/2}$. The radar echoes with low Doppler velocities are associated with irregularities produced by the gradient drift instability which presumably was operative at the top of the *E* layer. We suggest that magnetic field-aligned drifts combined with the subcritical perpendicular electron drifts are responsible for the production of both the EIC waves and the ion acoustic waves that were observed.

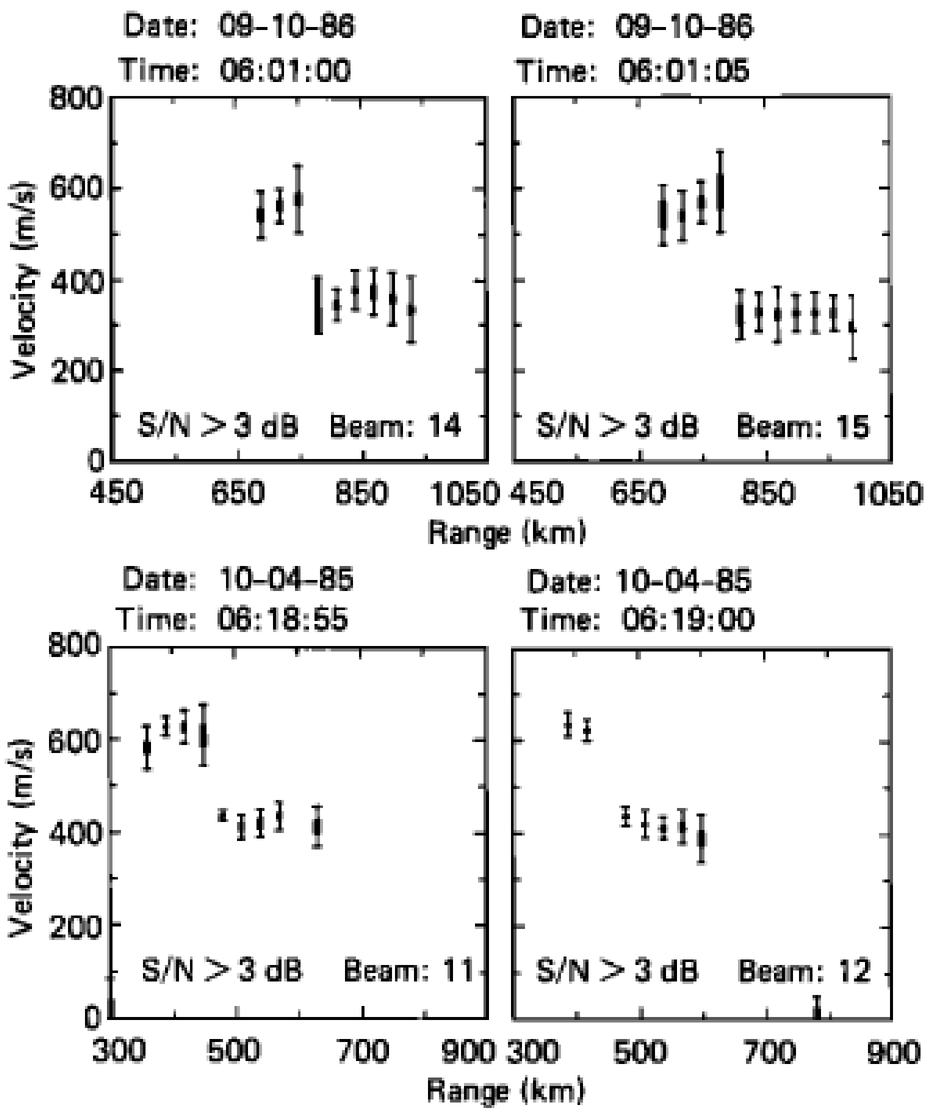

Fig. 7. Example of transition between both kinds of high Doppler velocities observed as looking along a single beam. The absolute value of the velocity is plotted as a function of range from the radar for the selected beam. Range gates are separated by 30 km. The conventions to plot the velocity with its error and the half-power are the same as for Figures 3, 4, and 6.

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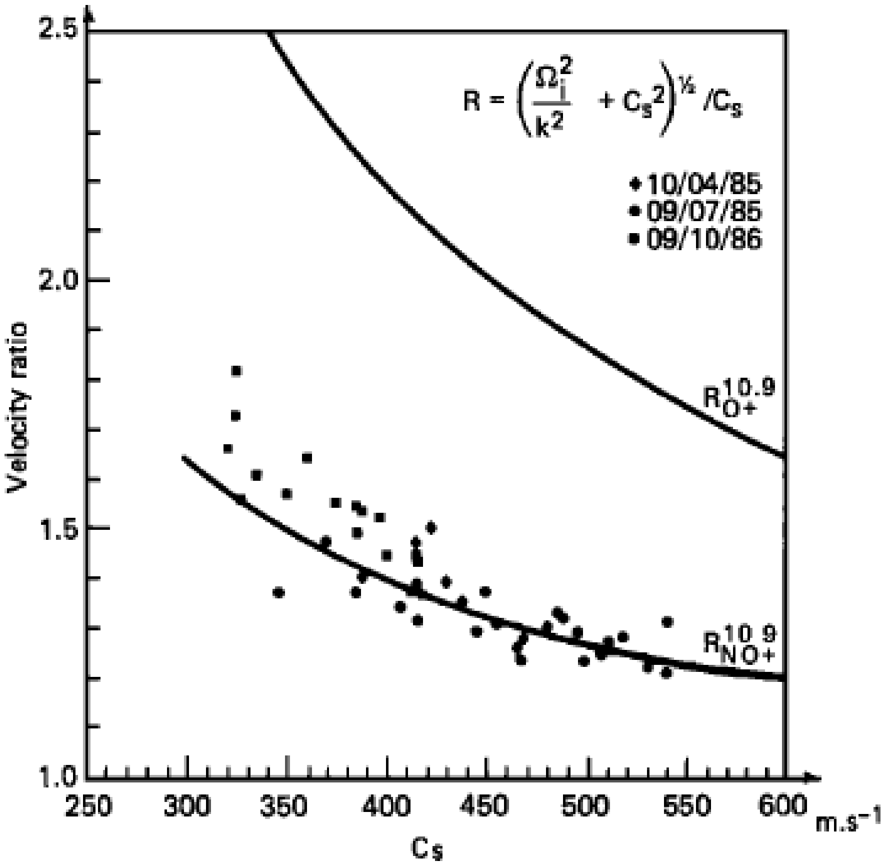

Fig. 9. Ratio between the velocity observed on each side of the gaps, plotted as a function of the lower velocity, assumed to be C_s. The theoretical ratio computed for $k = 0.46$ ($\lambda = 13.75$ m, radar frequency = 10.9 MHz) is plotted for O^+ and NO^+ ions. Excellent agreement is observed between the experimental data points and the NO^+ theoretical curve. Theoretical curves for N_2^+ and O_2^+ would be similar and very close to the NO^+ curve.

sult strongly supports our hypothesis that the lower of the high-velocity waves is associated with ion acoustic modes. It also indicates that high velocities are associated with NO^+ EIC waves.

I had 2 problems with this:

1) Should these modes not be Doppler shifted by the plasma drift to the point of not being recognizable?

2) Cyclotron modes in a collisional medium seemed counterintuitive

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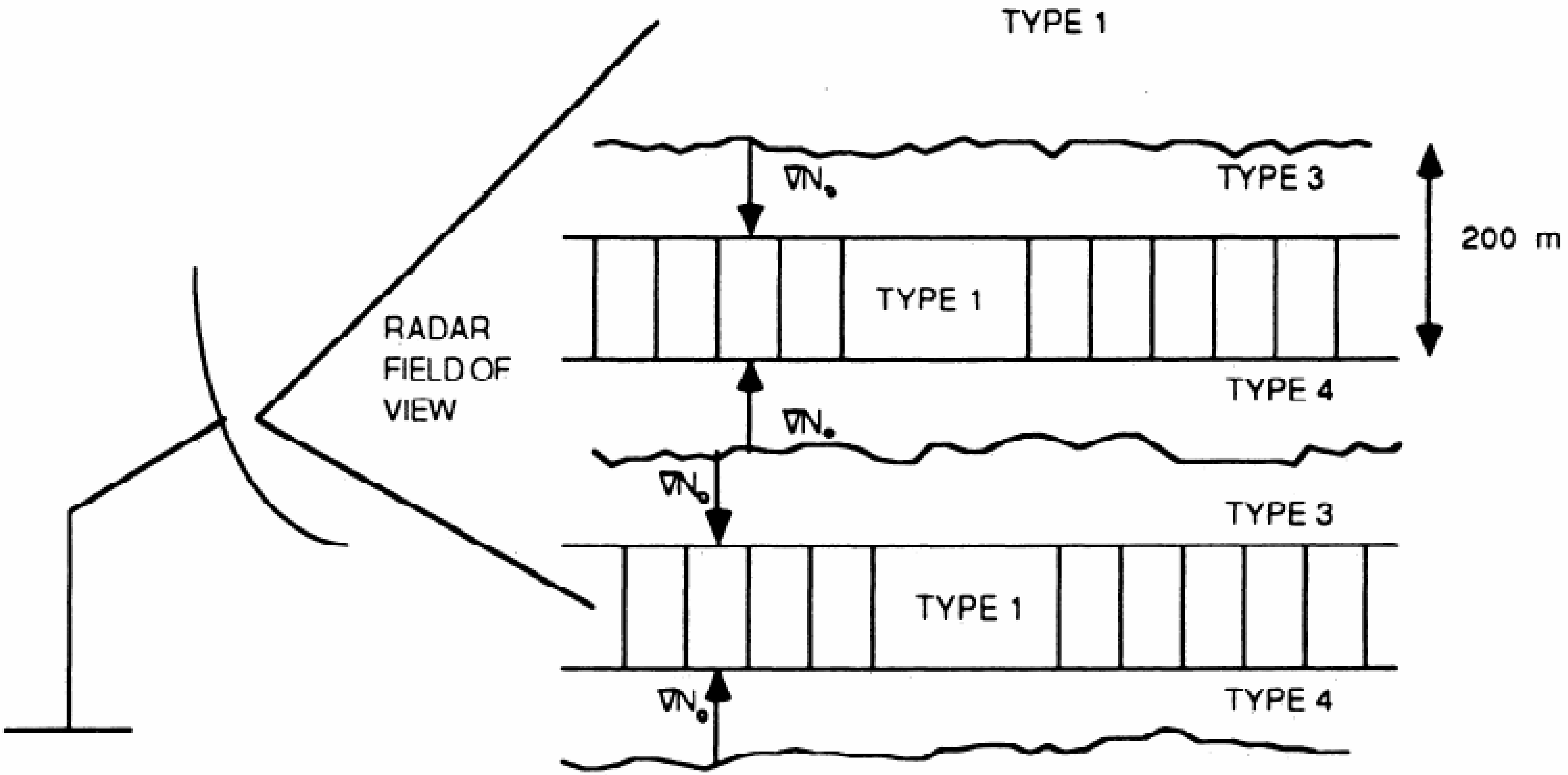
Gradients as an alternative to cyclotron modes



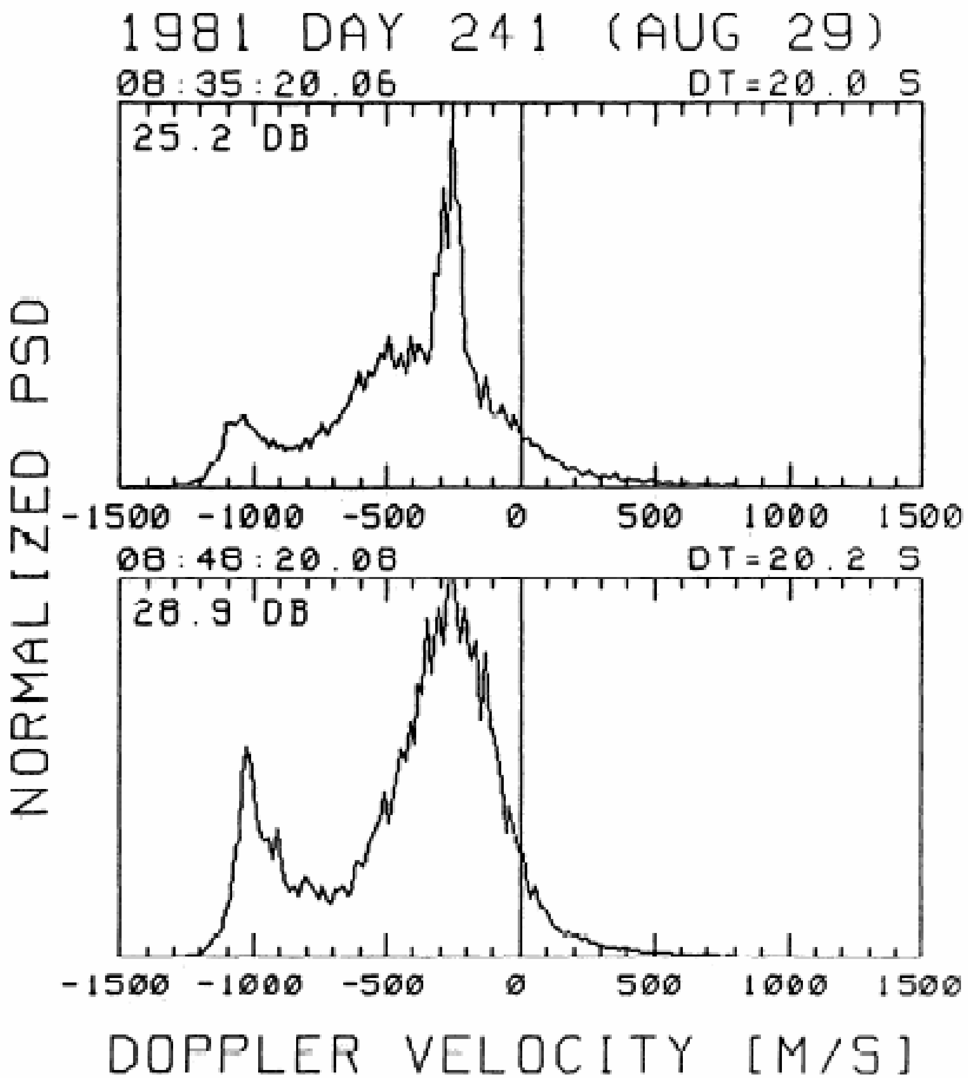
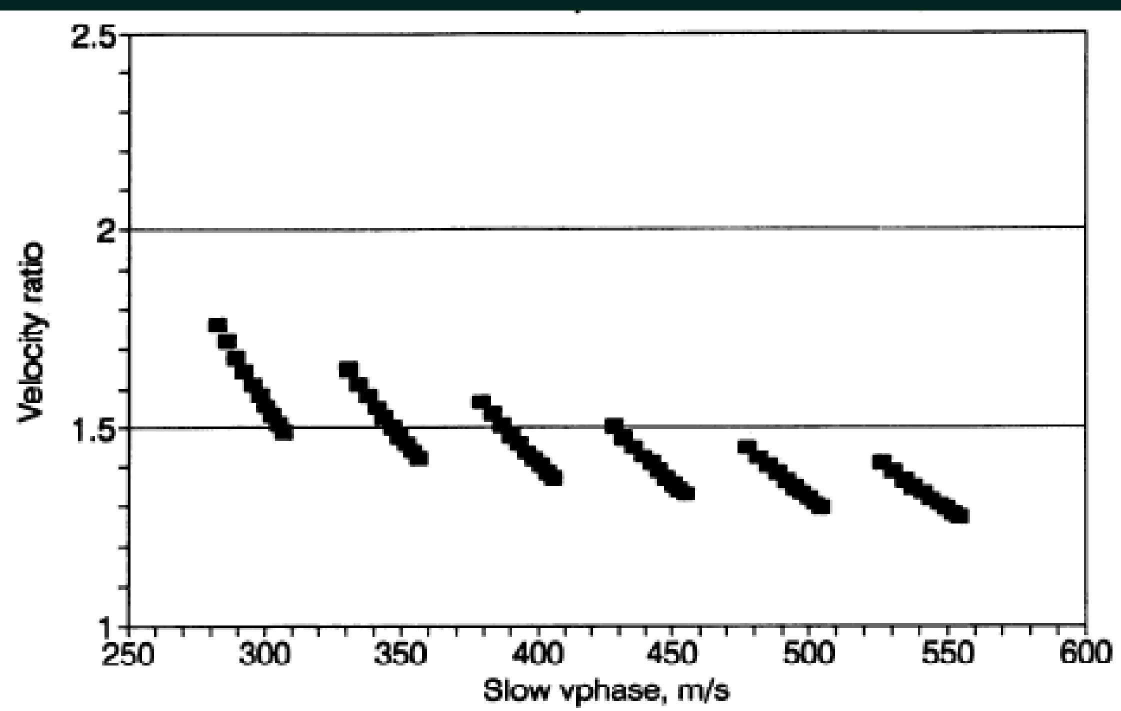
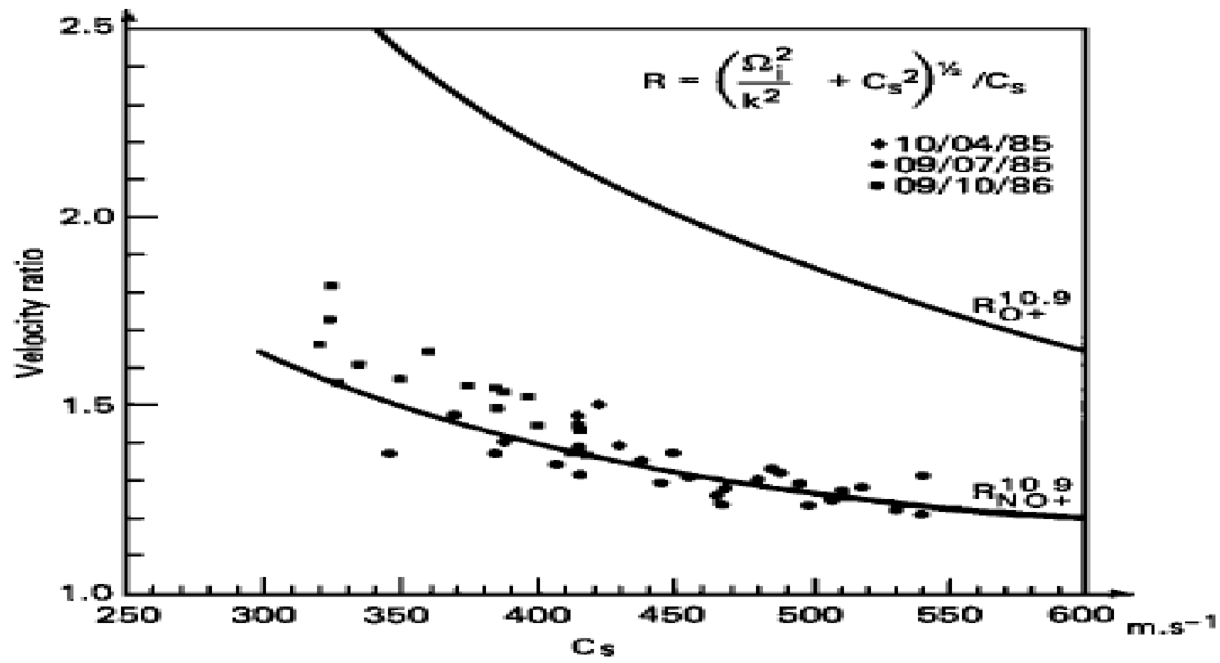


Figure 3. Multiple spectral types observed by a 50-MHz cw experiment during a campaign that took place in August 1981.

Gradients could explain triple spectra the connection between their Doppler shifts and their radar wavelength dependence





We had a tie:

both theoretical interpreta-tions did well

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The mysterious very slow E region modes

Obliquely Propagating Ion Acoustic Waves in the Auroral E Region: Further Evidence of Irregularity Production by Field-Aligned Electron Streaming

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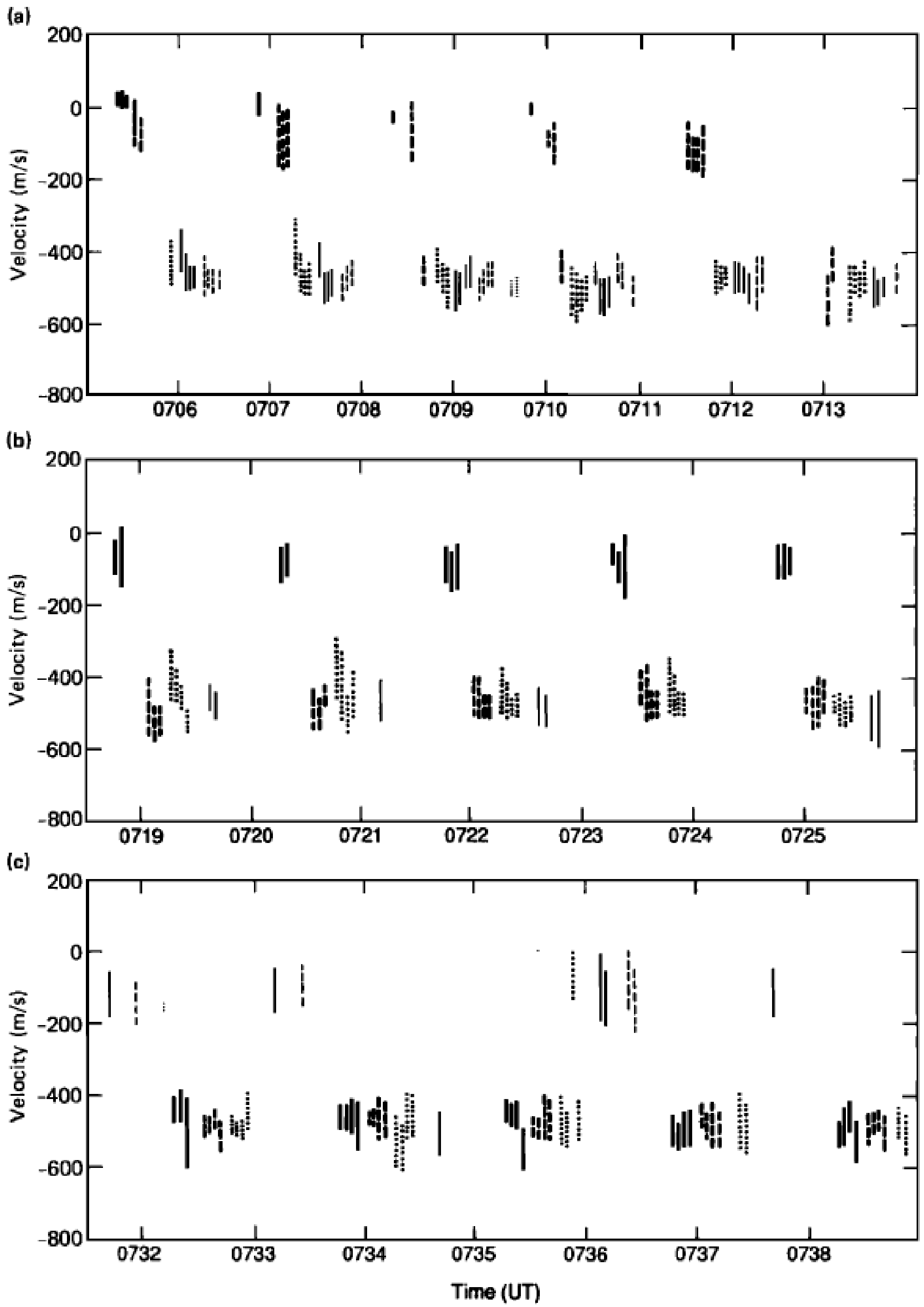

Question raised by Jean-Paul and coauthors: why a mix of very slow modes and much faster ones?

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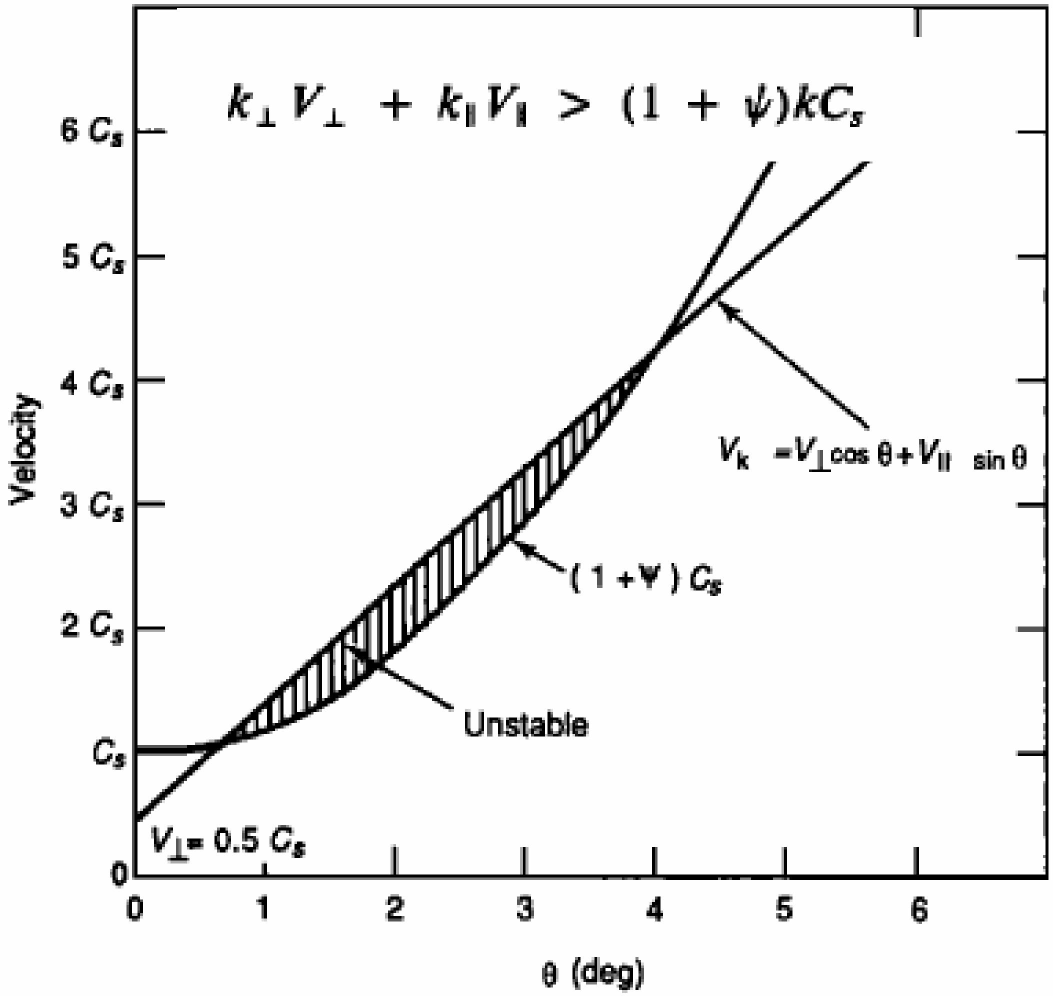

Fig. 7. Illustration of the destabilizing effect of parallel electron–ion drift on the ion acoustic or modified Farley–Buneman instability. The semi-parabolic curve represents the threshold condition for instability as a function of the off-perpendicular angle, θ. For the straight line a subcritical perpendicular electron–ion drift, $V_\perp = 0.5\ C_s$, is assumed and the parallel electron–ion drift is taken to be $V_\parallel = 40\ C_s$. As the off-perpendicular angle increases the threshold condition for instability is met and then exceeded (shaded region).

Answer proposed: a current convective instability.

Problems:

1- that's a lot of current over widespread areas (hundreds of micro amp/m^2)

2- It seems to me that the Doppler shift should have been 2Cs to 3Cs, not 0.5 Cs

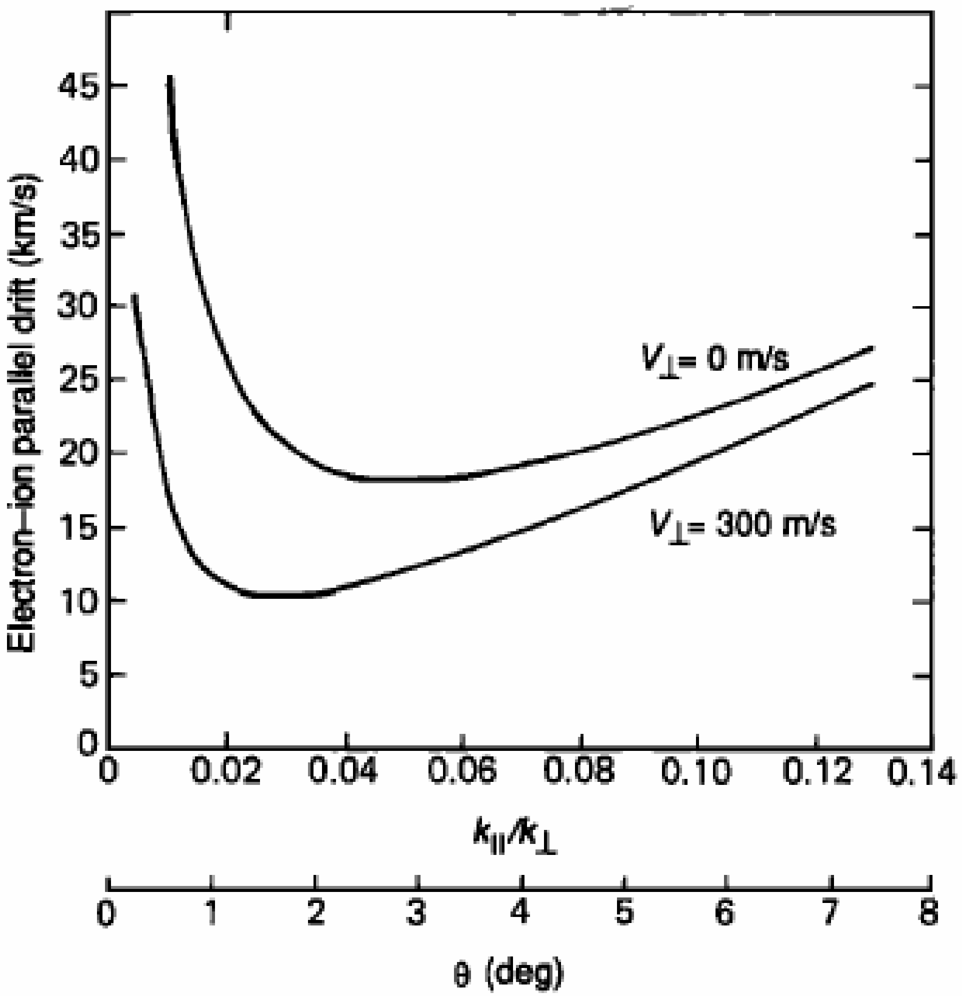

Fig. 8. Parallel electron–ion drift velocity required to destabilize the plasma through the ion acoustic instability as a function of $k_\parallel/k_\perp$. The x-axis is also scaled as a function of the off-perpendicular angle, θ. The curve for $V_\perp$ = 300 m/s illustrates the threshold condition for a direction in which the perpendicular electron-ion drift is 300 m/s. The curve for $V_\perp$ = 0 m/s gives the drift velocity required to produce irregularities in the absence of a perpendicular electron-ion drift or in the direction orthogonal to both **B** and $V_\perp$ for any value of $V_\perp$.

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Enter the HAIR echoes

- Jean-Paul showed me the work to see what I'd think: it was in his mind totally related to his 1990 paper occurrence of such echoes the "high-aspect angle irregularity region" or HAIR. It is suggested that backscatter is observed at aspect angles as high as 30°, with an aspect sensitivity as low as 1 dB deg^{-1}. These echoes are distinguished from normal electrojet backscatter by having low Doppler shifts with an azimuthal dependence that appears more consistent with the direction of the convection electric field $\boldsymbol{E}$ than with the expected electron $\boldsymbol{E} \times \boldsymbol{B}$ drift direction. This is discussed in terms of the linear theory dispersion relation for electrojet waves.

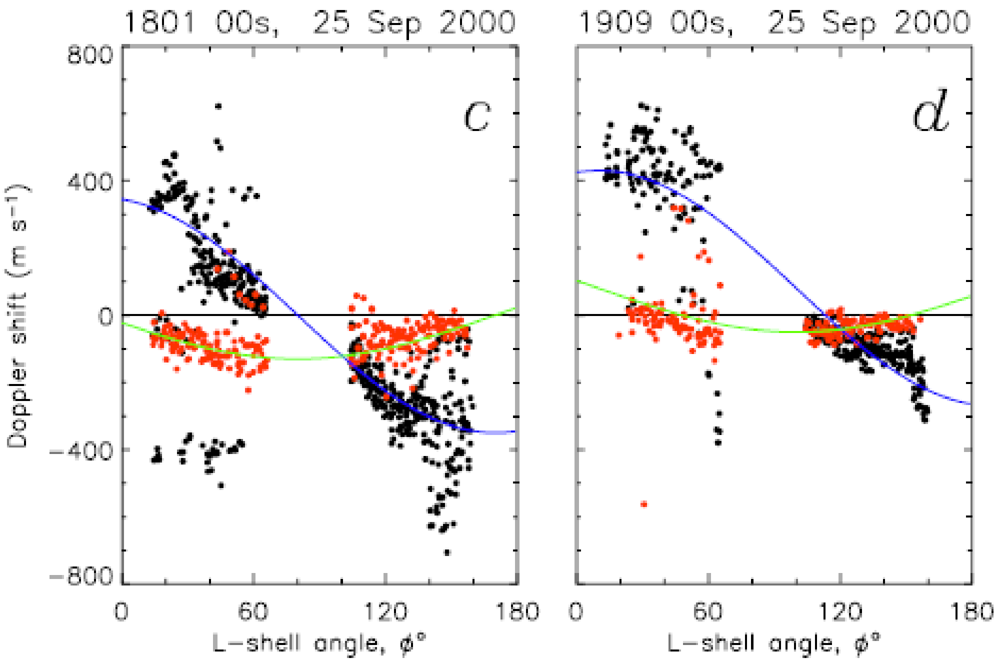

Fig. 12. Doppler shift as a function of L-shell angle for two examples from the westward electrojet **(a)** and **(b)** and two from the eastward electrojet **(c)** and **(d)**. Normal echoes are indicated in black, HAIR echoes in red. Superimposed blue curves show rough expectations for eastward or westward flow, whereas the green curves show poleward or equatorward flow.

Origin of Hair echoes

- Proposal by Milan et al:

$$\omega_r = \frac{1}{1+\Psi}\boldsymbol{k}\cdot\boldsymbol{V}_e + \frac{\Psi}{1+\Psi}\boldsymbol{k}\cdot\boldsymbol{V}_i, \tag{8}$$

where

$$\Psi = \frac{\nu_e\nu_i}{\Omega_e\Omega_i}\left(\cos^2\alpha + \frac{\Omega_e^2}{\nu_e^2}\sin^2\alpha\right), \tag{9}$$

$\boldsymbol{k}$ is the wave vector, $\boldsymbol{V}_e$ and $\boldsymbol{V}_i$ are the electron and ion drift velocities given by

$$\boldsymbol{V}_e = \frac{\Omega_e^2}{\nu_e^2+\Omega_e^2}\frac{\boldsymbol{E}\times\boldsymbol{B}}{B^2} - \frac{\nu_e\Omega_e}{\nu_e^2+\Omega_e^2}\frac{\boldsymbol{E}}{B} \tag{10}$$

$$\boldsymbol{V}_i = \frac{\Omega_i^2}{\nu_i^2+\Omega_i^2}\frac{\boldsymbol{E}\times\boldsymbol{B}}{B^2} + \frac{\nu_i\Omega_i}{\nu_i^2+\Omega_i^2}\frac{\boldsymbol{E}}{B}, \tag{11}$$

The need for a modified explanation

- Since the aspect angle is large, the expressions used for the frequencies were incorrect
- Still had to find a source for the large amplitude of the waves at the inferred large aspect angles

What we proposed

- The growth of 10 m waves is slow and the instability is convective
- The derivative of the aspect angle can become infinite in the convective description
- When the derivative becomes infinite the waves crash and feed damped zero frequency modes

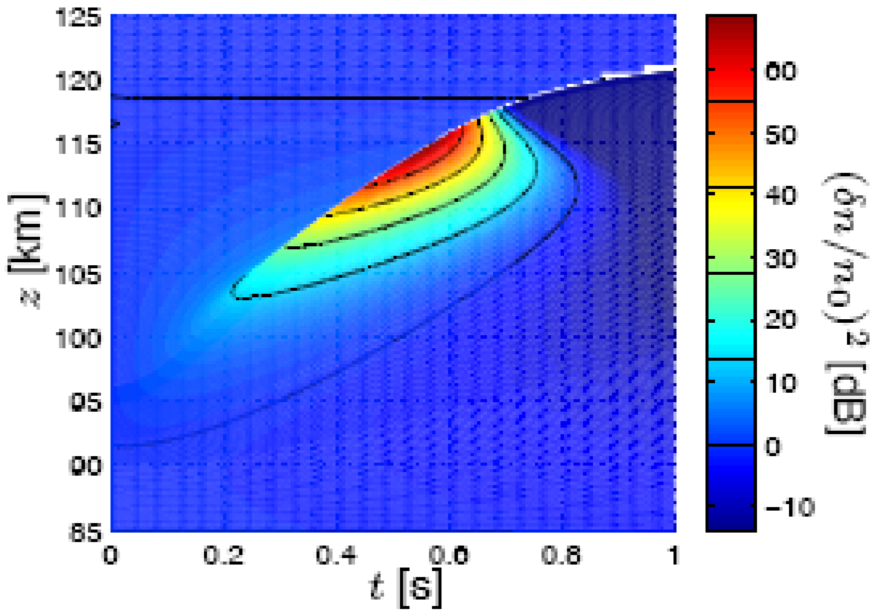

Fig. 3. Wave amplitude corresponding to the parameters of Fig. 2. The color scale represents the amount of growth in dB relative to the initial value at t=0 s.

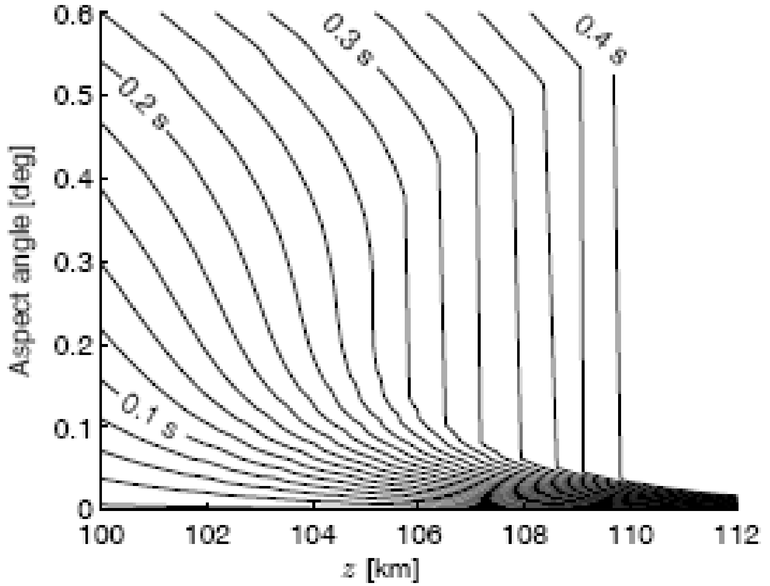

Fig. 4. Aspect angle profiles from t=0 s (left-most curve) to t=0.4 s (right-most curve) at 0.02 s intervals. After ~0.3 s a strong gradient and later a jump in the aspect angle develops.

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When modes with large aspect angle derivatives and large aspect angles are fed to the system the lower altitude solutions are purely damped modes moving with the ions

$$\omega_c'(\omega_c' + i\,\nu_i) - k_\perp^2 c_s^2 \approx 0 \tag{9}$$

We find the solution to be that of a damped harmonic oscillator, namely,

$$\omega_c' = \pm\sqrt{k_\perp^2 c_s^2 - \nu_i^2/4} - i\,\nu_i/2 \tag{10}$$

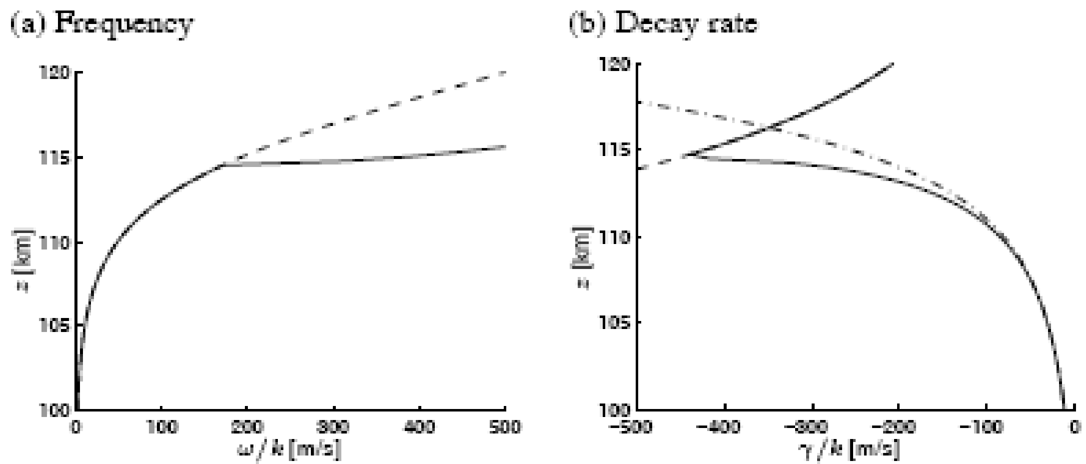

Fig. 1. Panel (a): Profile of the high-aspect angle phase speed ω/k seen by a ground-based observer (solid) and of the ion drift (dashed). Panel (b): Corresponding plots of the normalized decay rate γ/k (solid), as well as of $-\nu_i/2$ (dashed) and $-k_\perp^2 c_s^2/\nu_i$ (dash-dotted).

We also had fun with the F region

The great F region spectral shape debate (with Hanuise and Gresillon as co-conspirators)

- Lorentzian, Gaussian, in between?
- What’s the meaning of the width?
  - Lifetime of a structure? If so
    - Ordinary diffusion?
    - Weak turbulence? (Lorentzian)
    - Turbulent diffusion? Self similar or not?
  - Superposition of narrow features with different Doppler velocities?
  - Turbulence in the driver itself?

What if one approach could be to understand the origin of individual structures and use self-similarity to understand the spectra?

(Work by Moorcroft explaining why spectra are neither Lorentzian nor Gaussian)

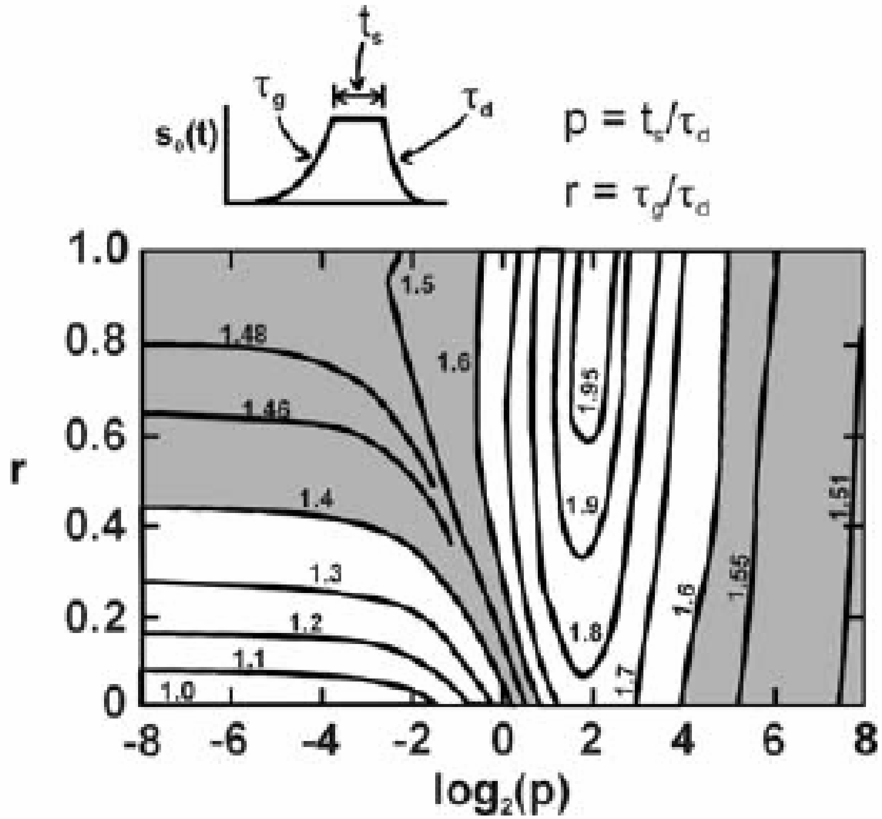

Figure 2. Values of n_T obtained by fitting with an exponential power law (equation (2)) the ACF magnitude (equations (13) and (14)) of the scatterer model (equation (12)) shown at the top of the figure. The curves are contours of constant n_T.

The great divergent F region echoes puzzle (Raphael Andre as co-conspirator)

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Super Dual Auroral Radar Network observations of velocity-divergent structures in the *F* region ionosphere

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Abstract. This paper describes Super Dual Auroral Radar Network observations of an unusual mesoscale (scale size $L \approx 300$ km) structure in the auroral convection pattern. This structure is characterized by an expansion motion of the plasma in a plane perpendicular to the magnetic field and then by an anomalously high velocity divergence. This study describes those observations and eliminates possible artifacts in the data analysis. Because the radar data strongly suggest that the structure is located in the *F* region, the observations are thus in opposition with the well-known divergence-free motion hypothesis. They are interpreted in terms of an ion demagnetization process, in which the collisionless ions become locally collisional in the *F* region.

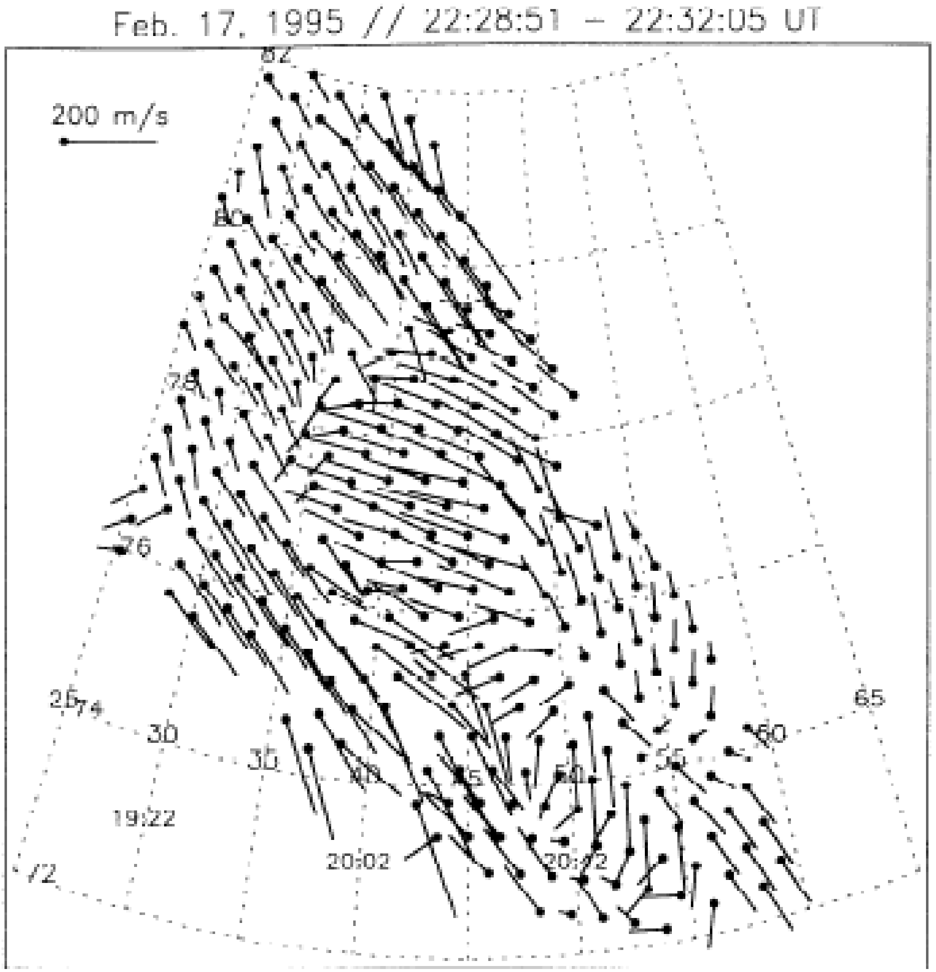

Figure 4. Velocity-divergent structure defined by the Goose Bay/Stokkseyri pair.

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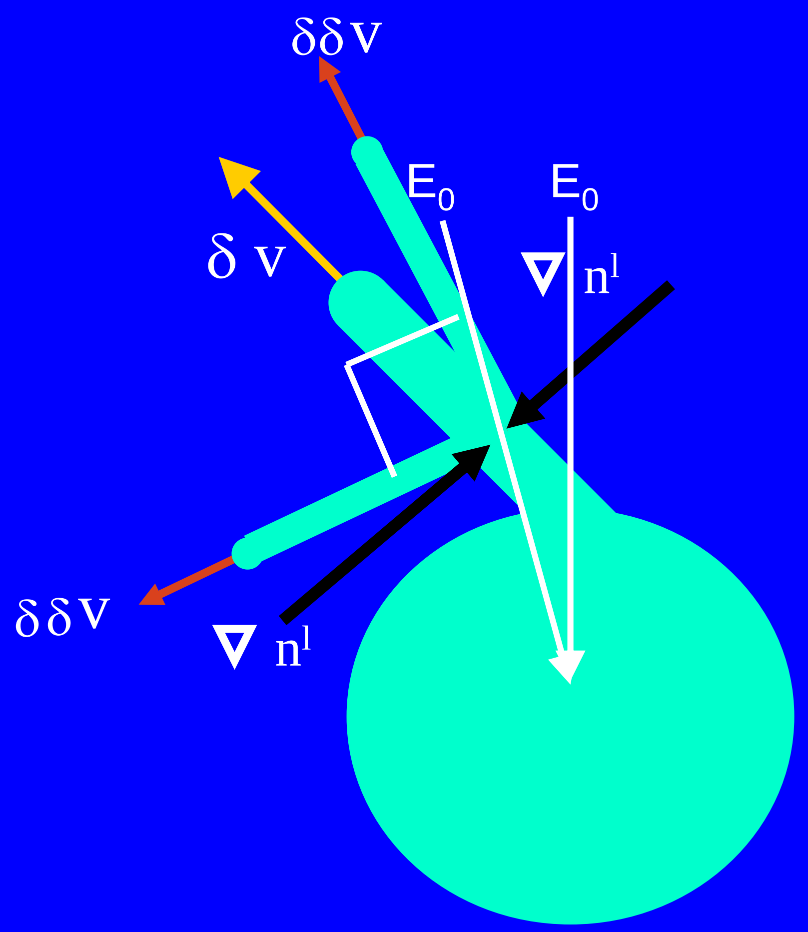
What they said:

If the effective collision frequency becomes larger than the ion gyrofrequency, the anomalous transport demagnetizes the trapped ions. The electric field fluctuations modify the trapped particle behavior, but their macroscopic motions are still defined by the macroscopic electric field projected from the magnetosphere. Such a process can demagnetize the *F* region ions and induce a highly divergent flow in a plane perpendicular to the magnetic field.

- Trouble with the explanation: F region would look like E region. However, instabilities do not diverge in the E region!
- *Alternate explanation* (which took years): fingers grow from the center of a vortex. Divergence is seen when strong fingers grow on the original fingers.

The secondary fingers propagate at right angles from each other with a slightly skewed symmetry with respect to the primary fingers



The orientation of the secondary fingers nicely enable SuperDARN to detect vortices

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Interesting F region features we worked on while I was visiting on sabbatical

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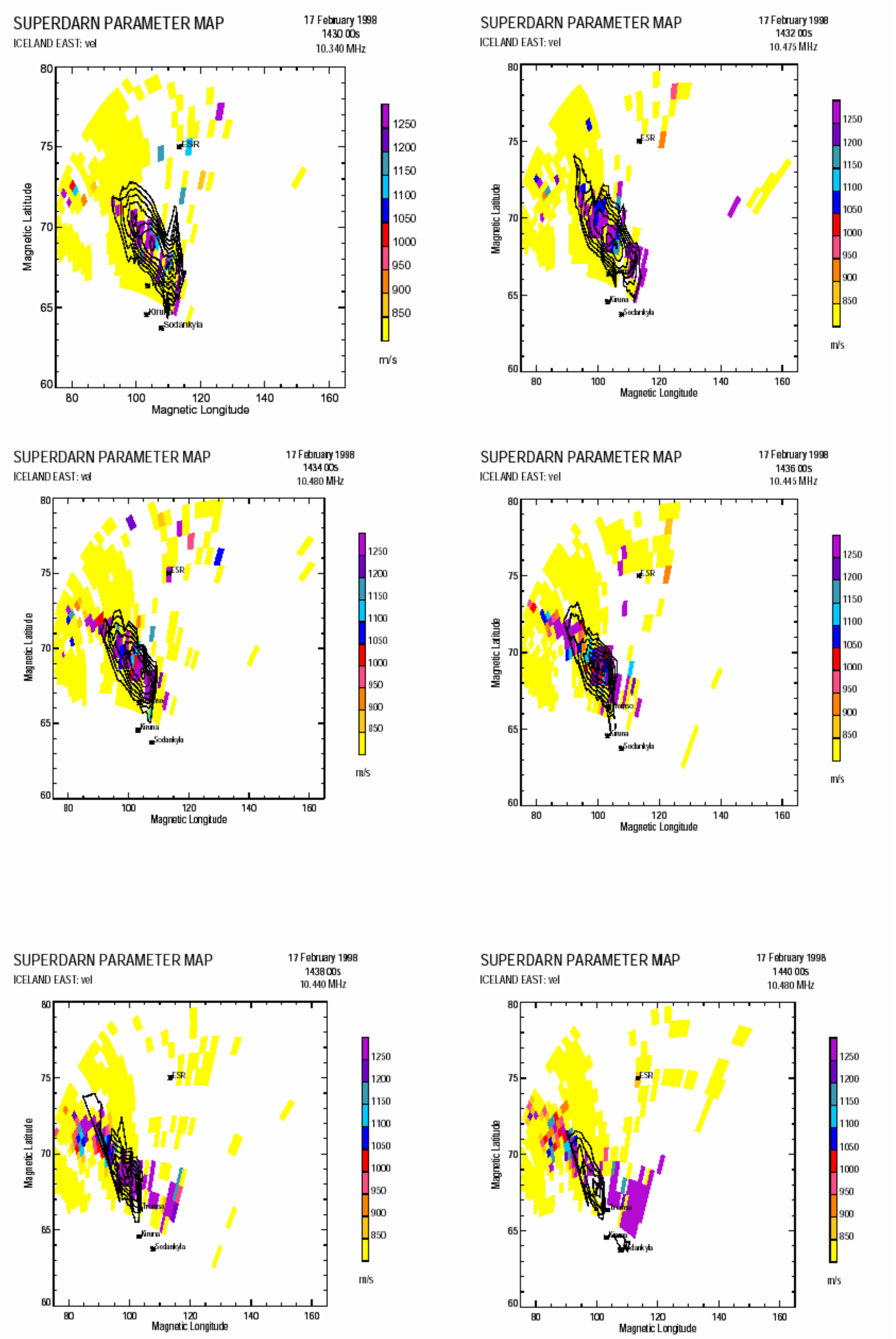
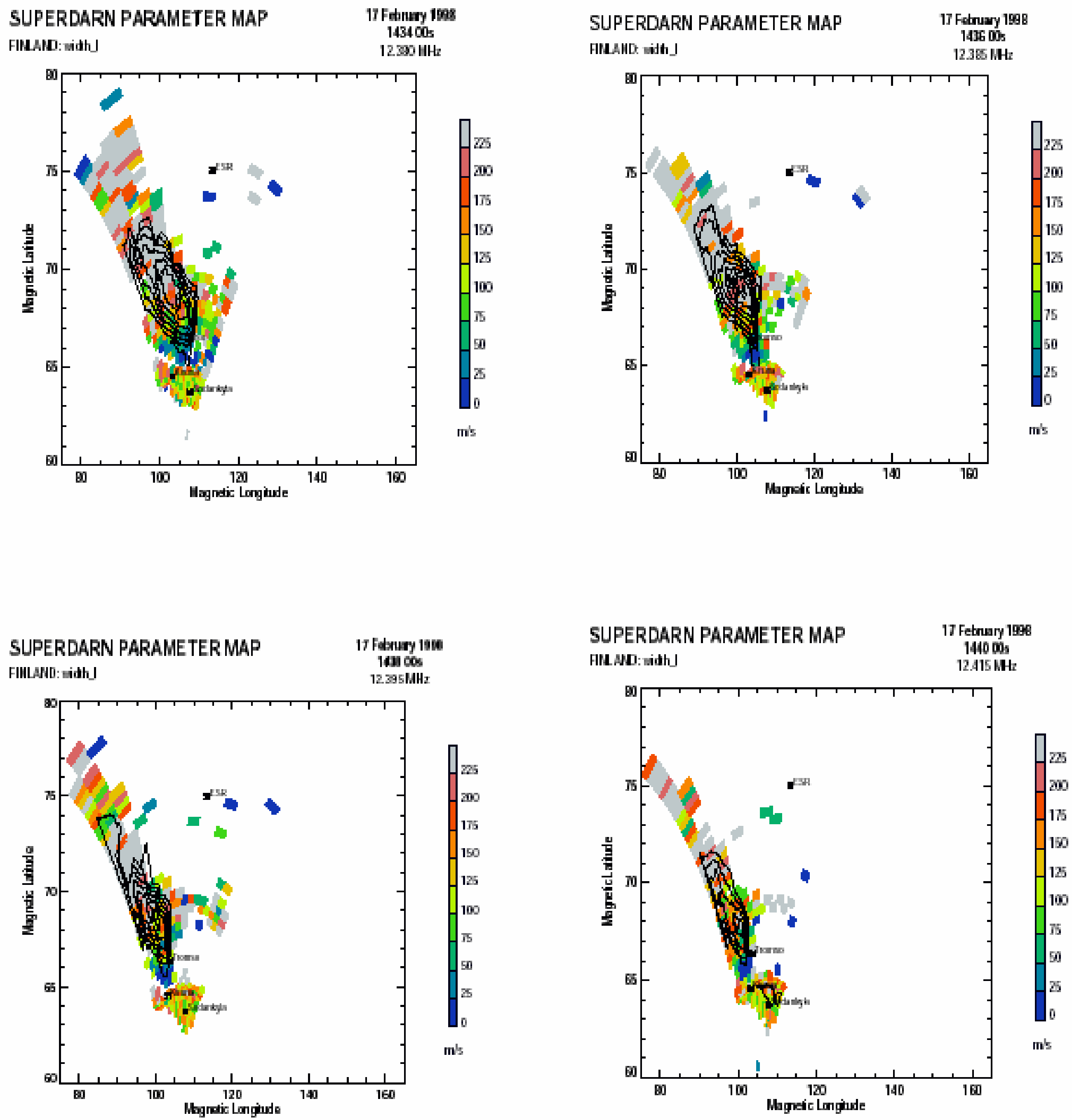
Finland power closely matches strong convection seen by Iceland East, but does not match its own Doppler speeds!

Conclusion: Iceland sees a strong pinch in the flow more than a rotation while Finland is a good indicator of the magnitude of the sunward flow for this feature.





The event also had a strange region of very narrow fast moving echoes

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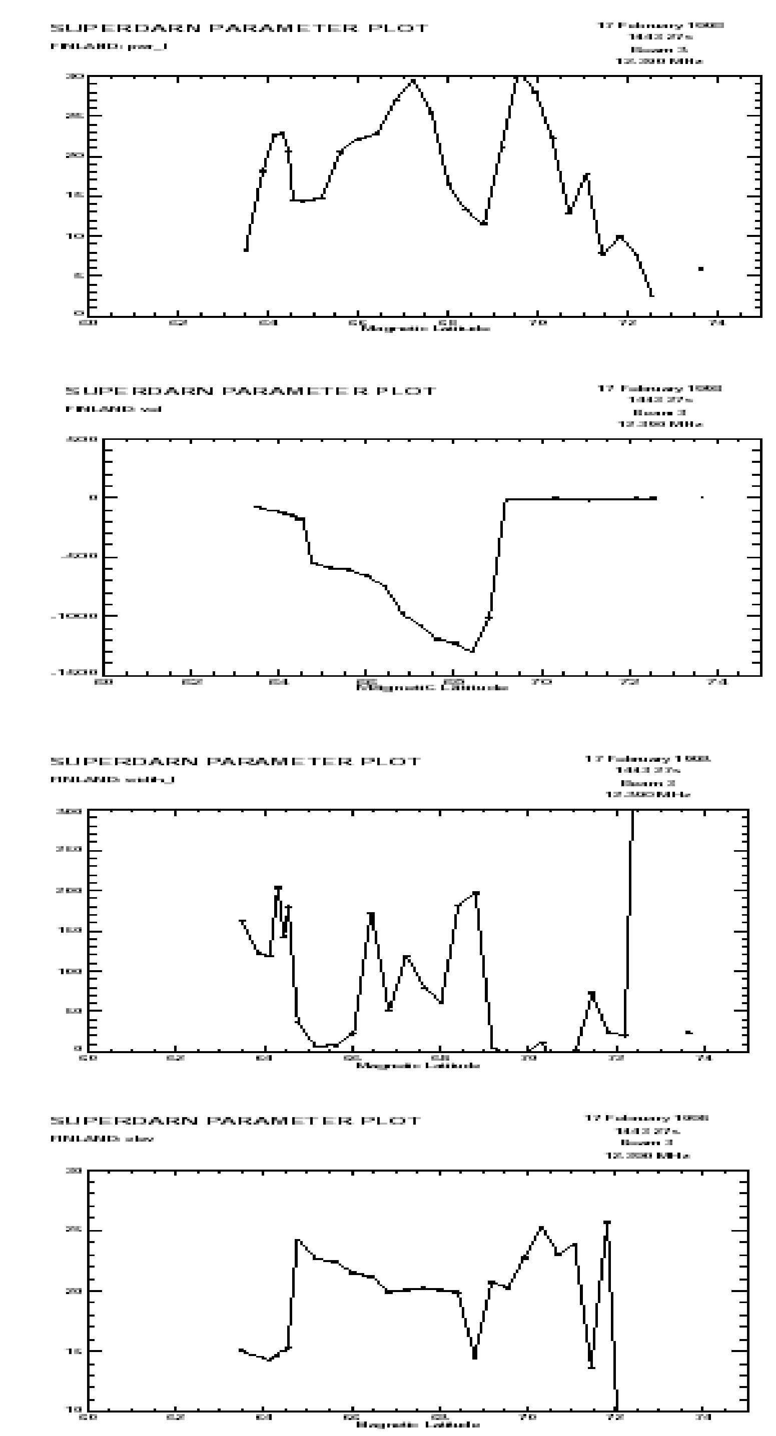
The narrow echoes:

1. Are the first F region echoes
2. Are at higher elevation angles than other F region echoes
3. Are inside of very near a region of strong shears
4. Are on the edge of more powerful F region echoes
5. Are very clean highly coherent features



The point of all this

- Jean-Paul had a knack to zoom in on key problems and to present them clearly
- He was impressive with instrument building, with data analysis and with theoretical understanding
- He threw good challenges for us all to deal with. Collaboration was always in his mind.
- He was a lot of fun to interact with and he was a caring very good friend

How I remember the man:

Playful yet driven. But above all, a good friend.