PFISR Science: The First Three Years

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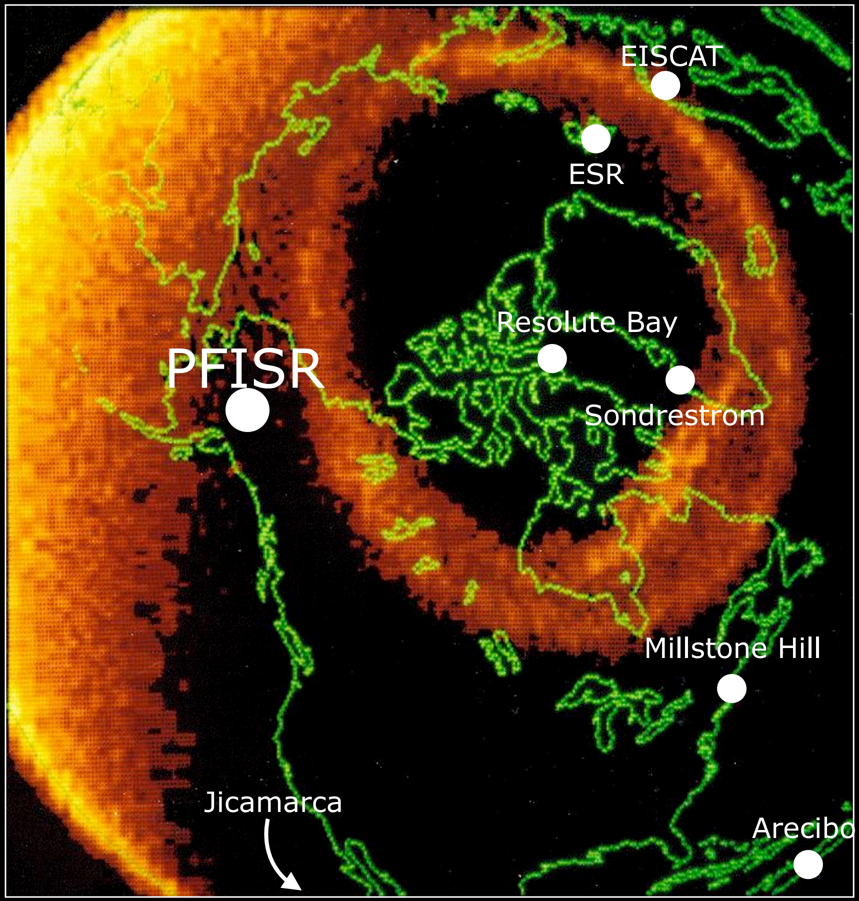
Poker Flat Incoherent Scatter Radar (PFISR)

Poker Flat, Alaska



How does a Doppler radar work?

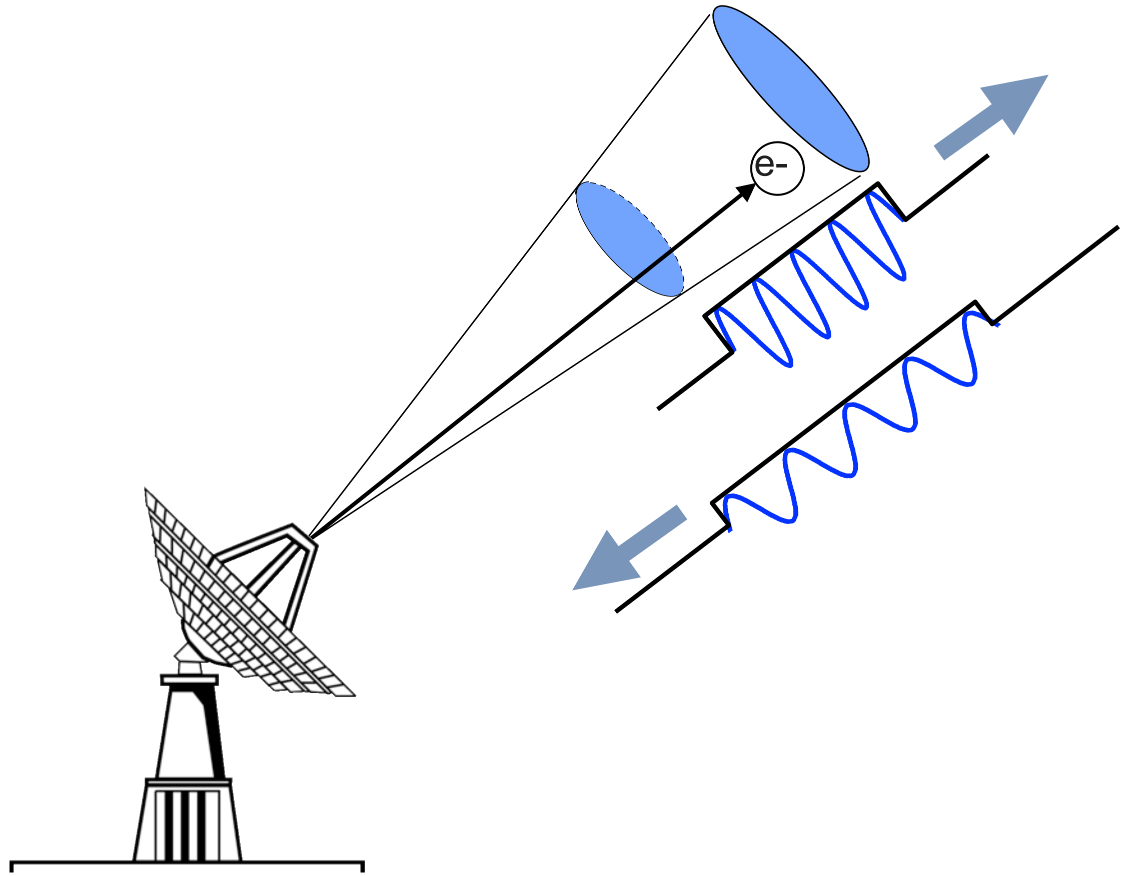
Two key concepts:

Distant ⇔ Time

$$R = c\Delta t/2$$

Velocity ⇔ Frequency

$$v = -f_D\lambda_0/2$$



A Doppler radar measures backscattered power as a function range and velocity. Velocity is manifested as a Doppler frequency shift in the received signal.

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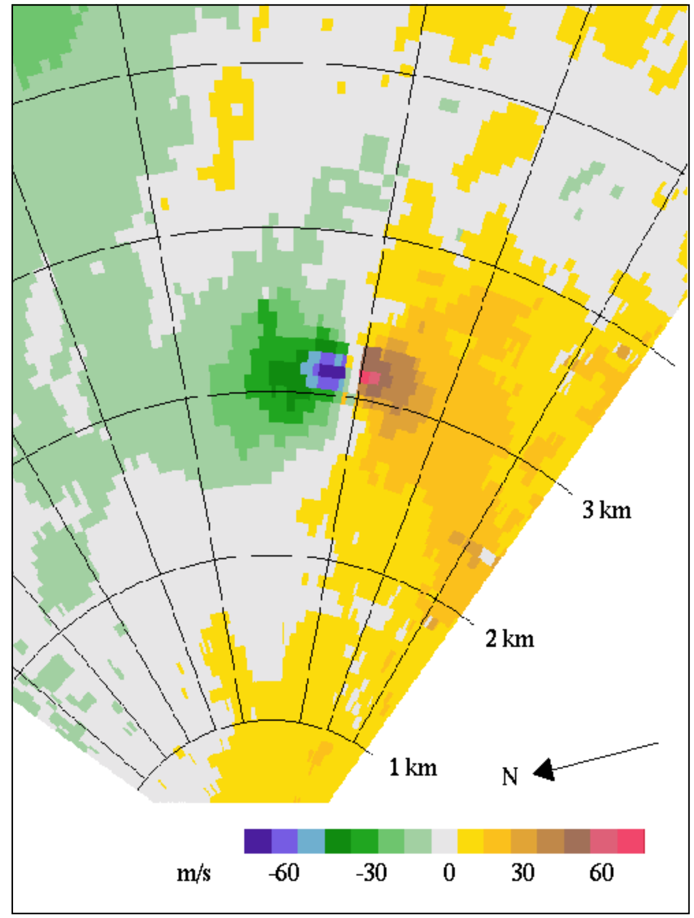

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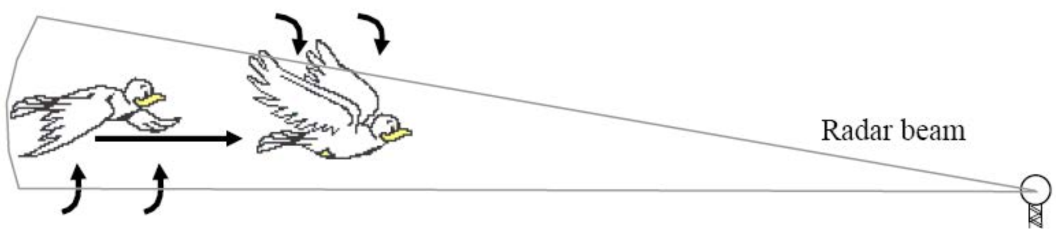
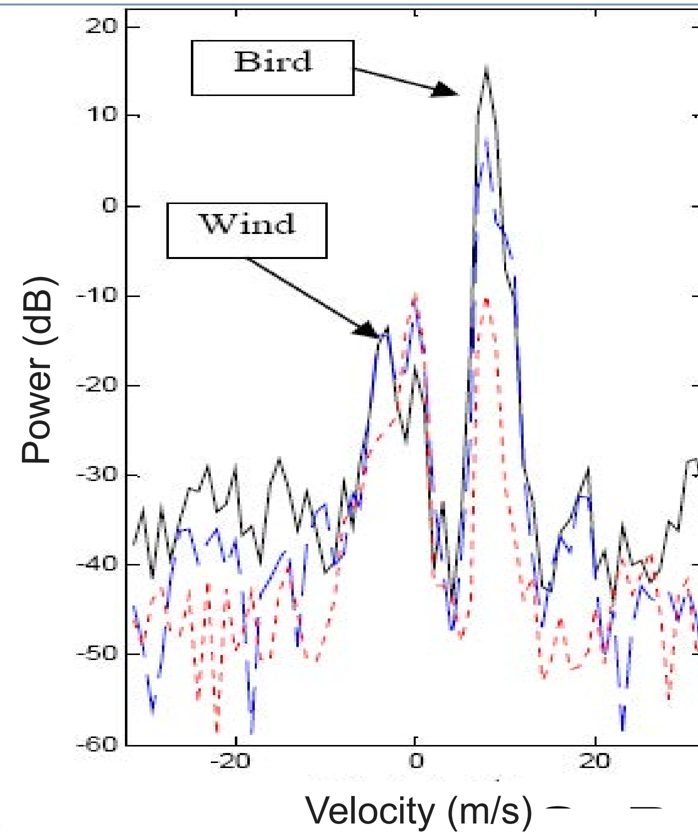




If there is a distribution of targets moving at different velocities (e.g., electrons in the ionosphere) then there is no single Doppler shift but, rather, a Doppler spectrum.

What is the Doppler spectrum of the ionosphere at UHF (λ of 10 to 30 cm)?

Plasma simulation

Particle-in-cell (PIC):

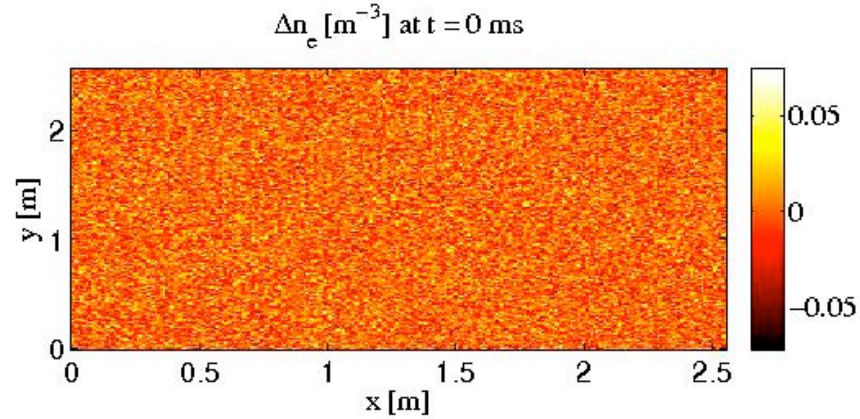
$$\frac{d\,\mathbf{v}_i}{d\,t} = \frac{q_i}{m_i}(\mathbf{E}(\mathbf{x}_i) + \mathbf{v}_i \times \mathbf{B}(\mathbf{x}_i))$$

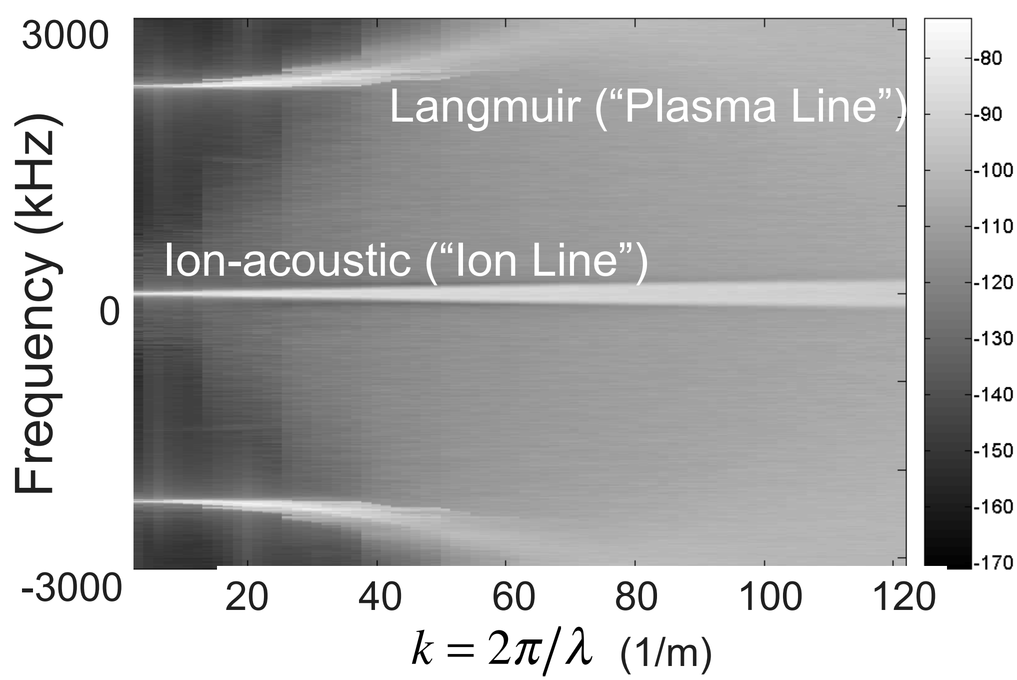
$$\nabla \times \mathbf{E} = \frac{-\partial \mathbf{B}}{\partial t}$$

$$\nabla \times \mathbf{B} = \mu_0 \mathbf{J} + \frac{1}{c^2}\frac{\partial \mathbf{E}}{\partial t}$$

$$\nabla \cdot \mathbf{E} = \frac{\rho}{\epsilon_0}$$

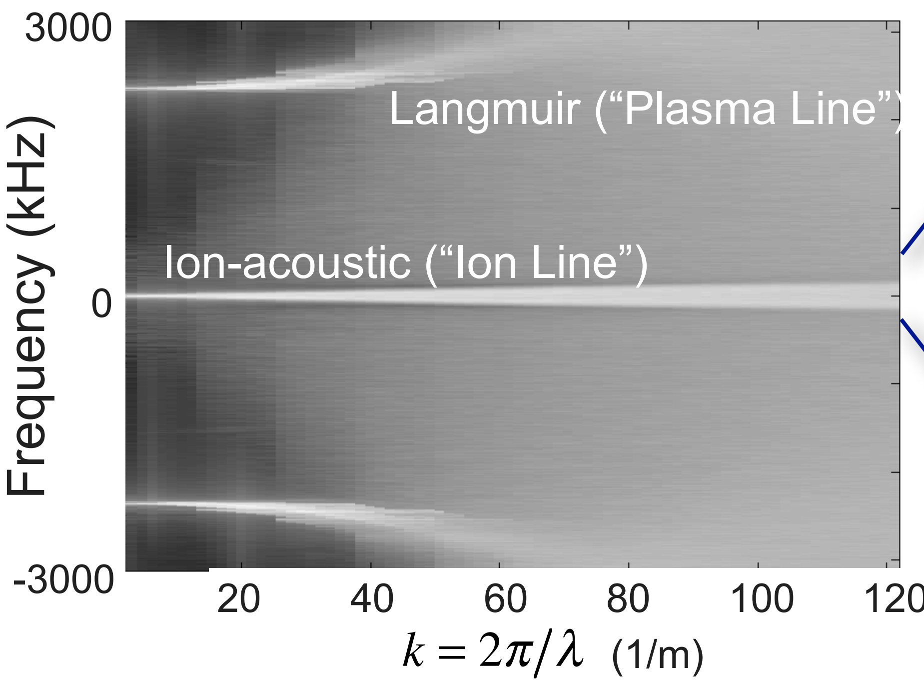
$$\nabla \cdot \mathbf{B} = 0$$

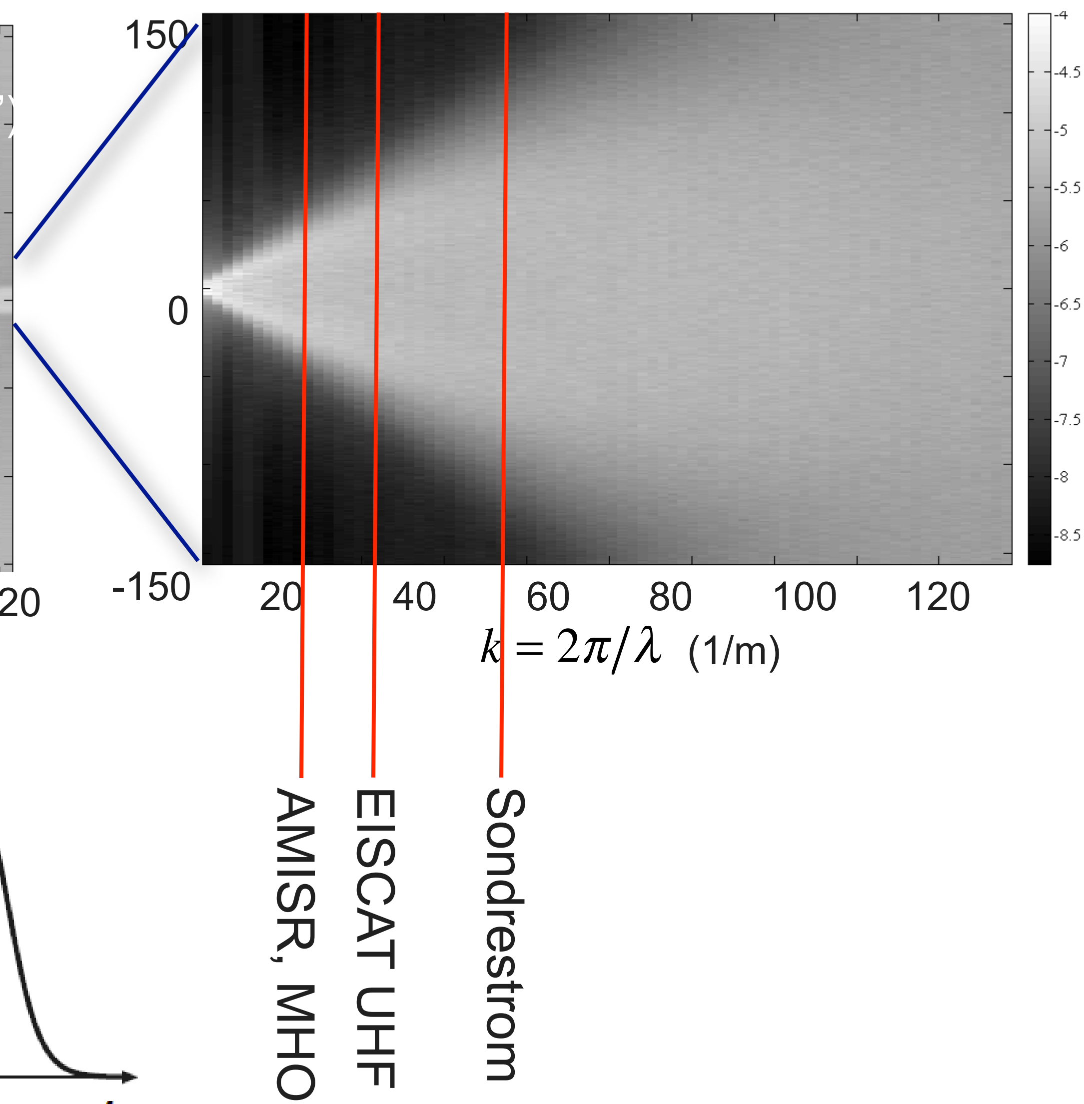




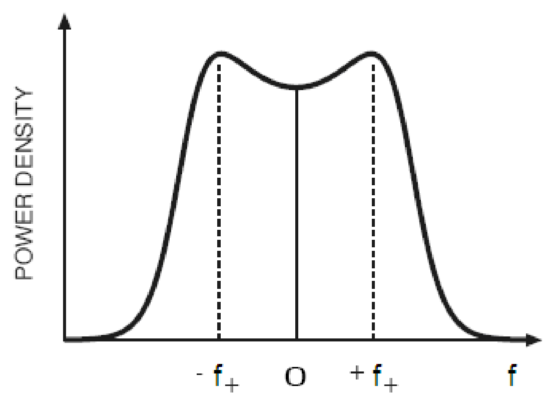
Simple rules yield complex behavior

ISR measures a cut through this surface at a particular wave number





Ion-acoustic "lines" are broadened by Landau damping



Exact expression for the radar cross section of the ionosphere at UHF

$$\sigma(\omega) = \frac{\left|1 + \left(\frac{\lambda}{4\pi}\right)^2 \sum_1 \left(\frac{1}{D_i}\right)^2 F_i(\omega)\right|^2 \overline{\left|N_e^0(\omega)\right|^2} + \left(\frac{\lambda}{4\pi D_e}\right)^4 \left|F_e(\omega)\right|^2 \sum_i \overline{\left|N_i^0(\omega)\right|^2}}{\left|1 + \left(\frac{\lambda}{4\pi}\right)^2 \left\{\left(\frac{1}{D_e}\right)^2 \cdot F_e(\omega) + \sum_i \left(\frac{1}{D_i}\right)^2 F_i(\omega)\right\}\right|^2}$$

where:

$$F_e(\omega) = 1 - \omega \int_o^\infty \exp\left(-\frac{16\pi^2 K T_e}{\lambda^2 m_e}\tau^2\right)\sin(\omega\tau)\,d\tau - j\omega\int_0^\infty \exp\left(-\frac{16\pi^2 K T_e}{\lambda^2 m_e}\tau^2\right)\cos(\omega\tau)\,d\tau$$

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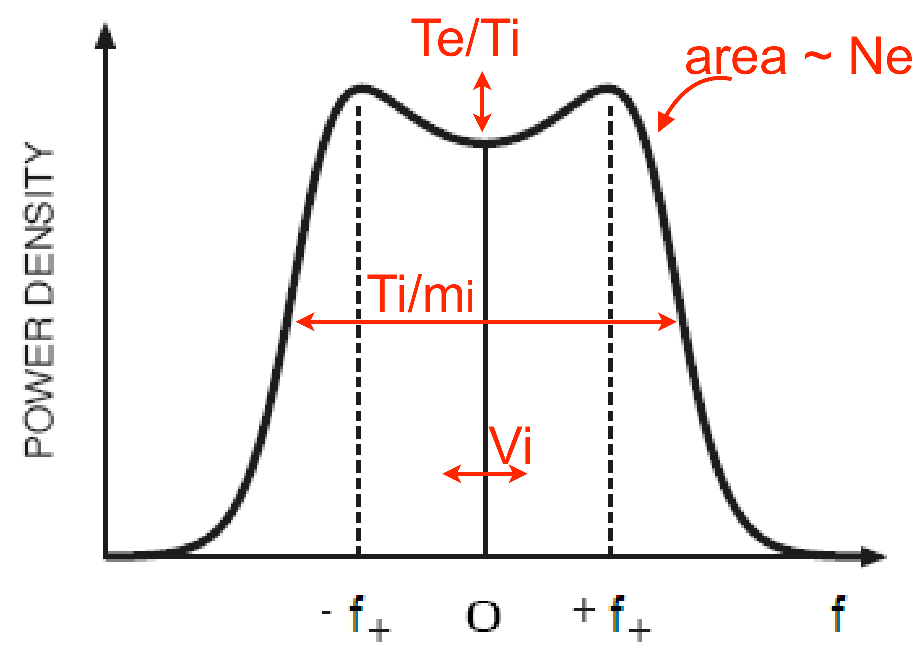
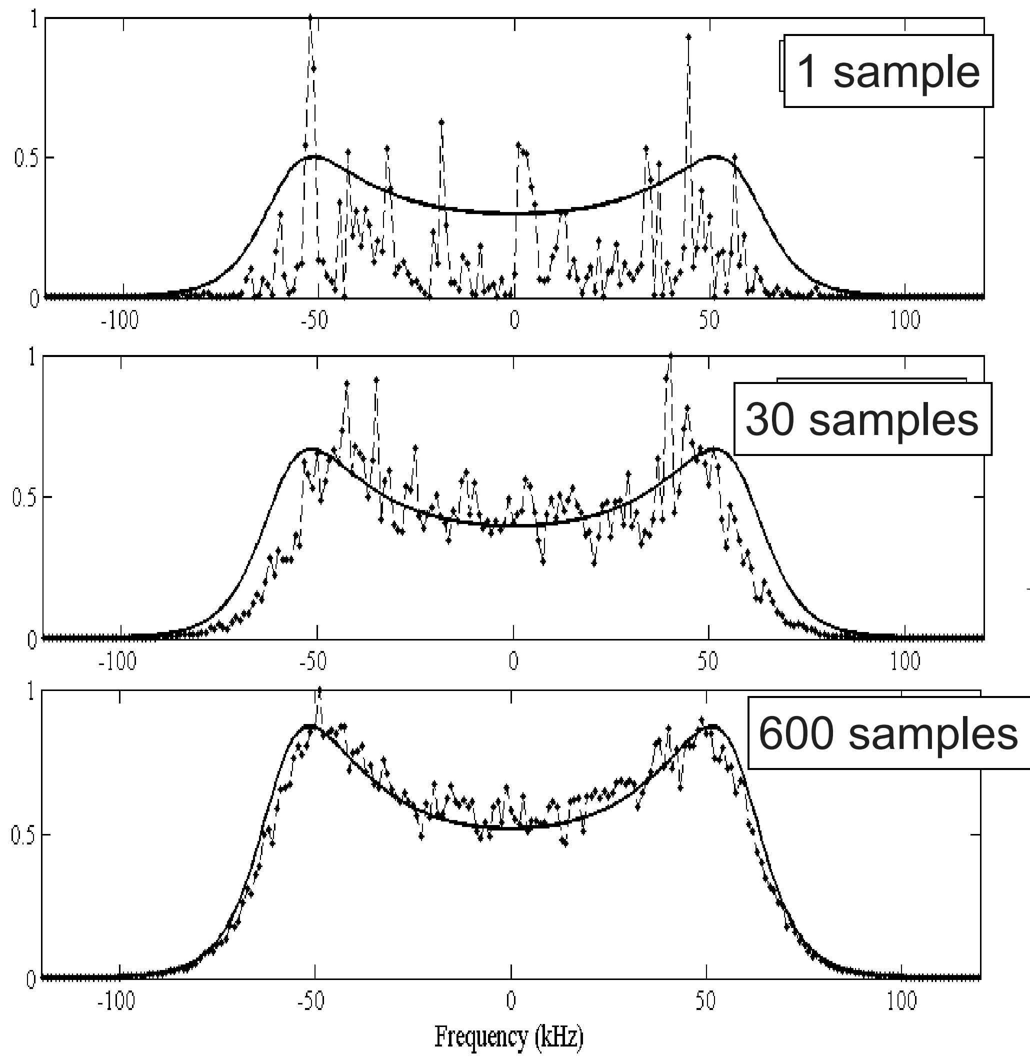


From Evans, IEEE Transactions, 1969

Incoherent averaging

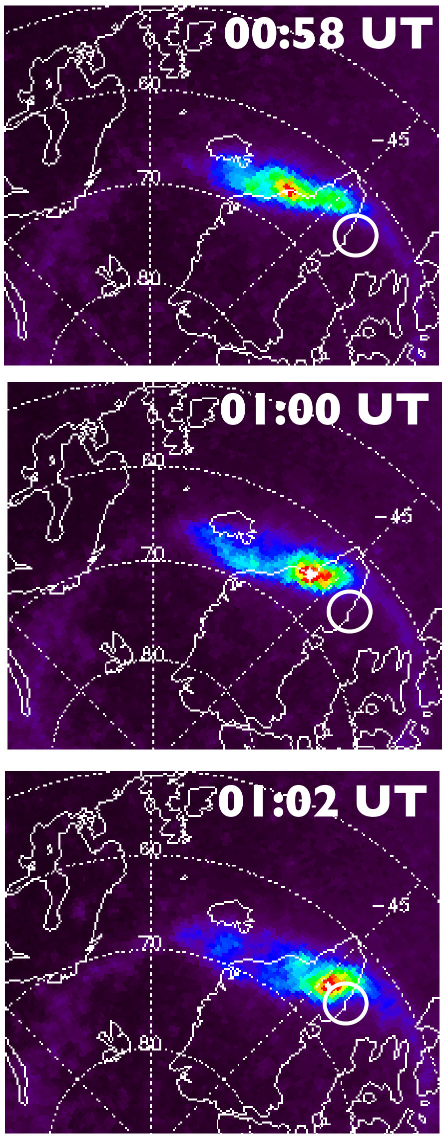
Normalized ISR spectrum for different integration times at 1290 MHz

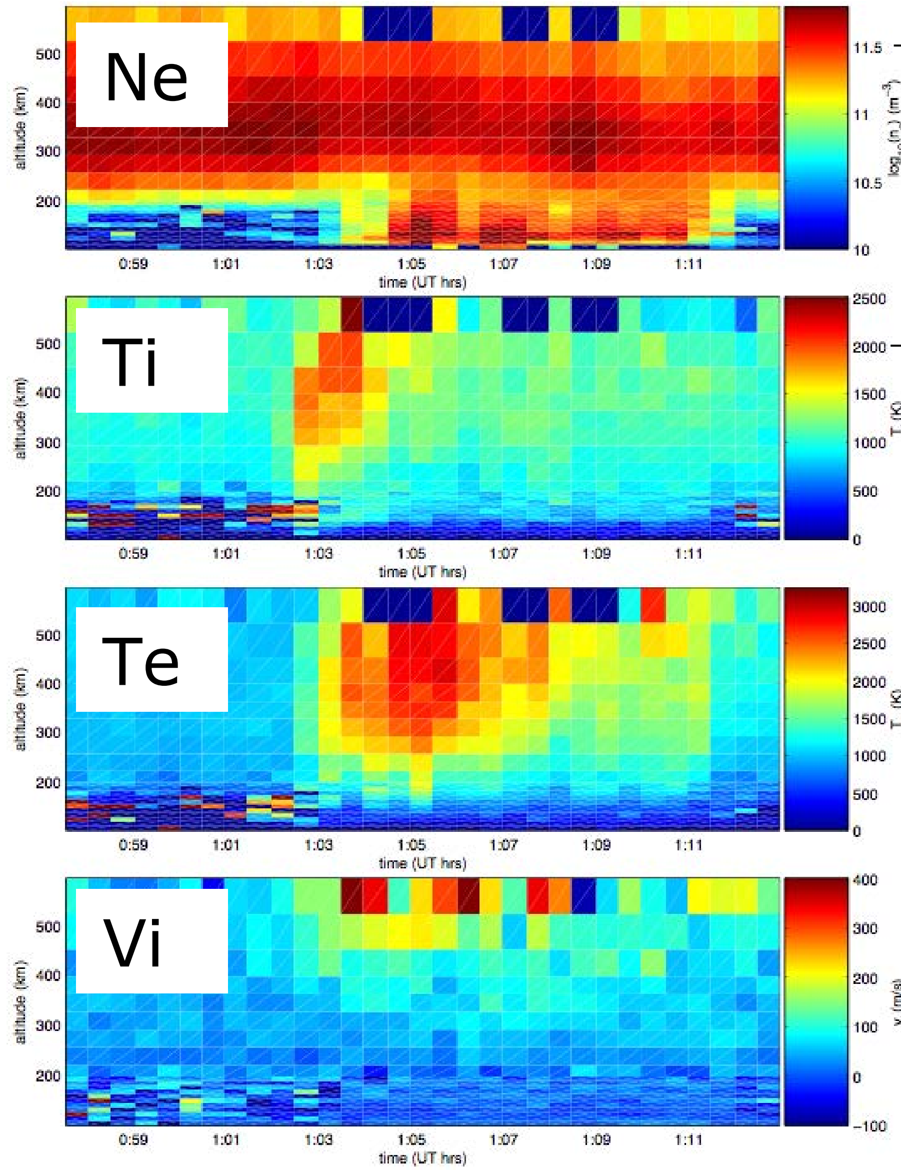


We are seeking to estimate the power spectrum of a Gaussian random process. This requires that we sample and average many independent "realizations" of the process.

$$\text{Uncertainties} \propto \frac{1}{\sqrt{\text{Number of Samples}}}$$

The auroral ionosphere

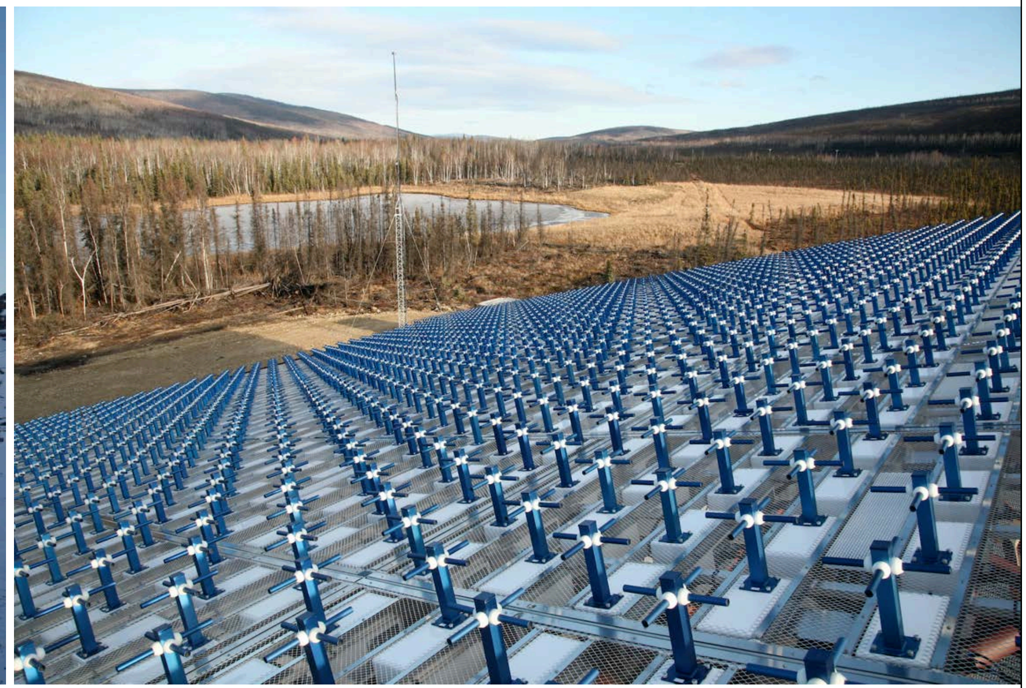




Sondrestrom
ISR

Semeter et al., jgra 2005

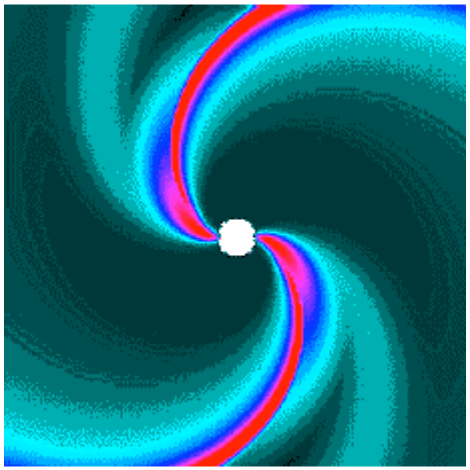
Dish Versus Phased-array



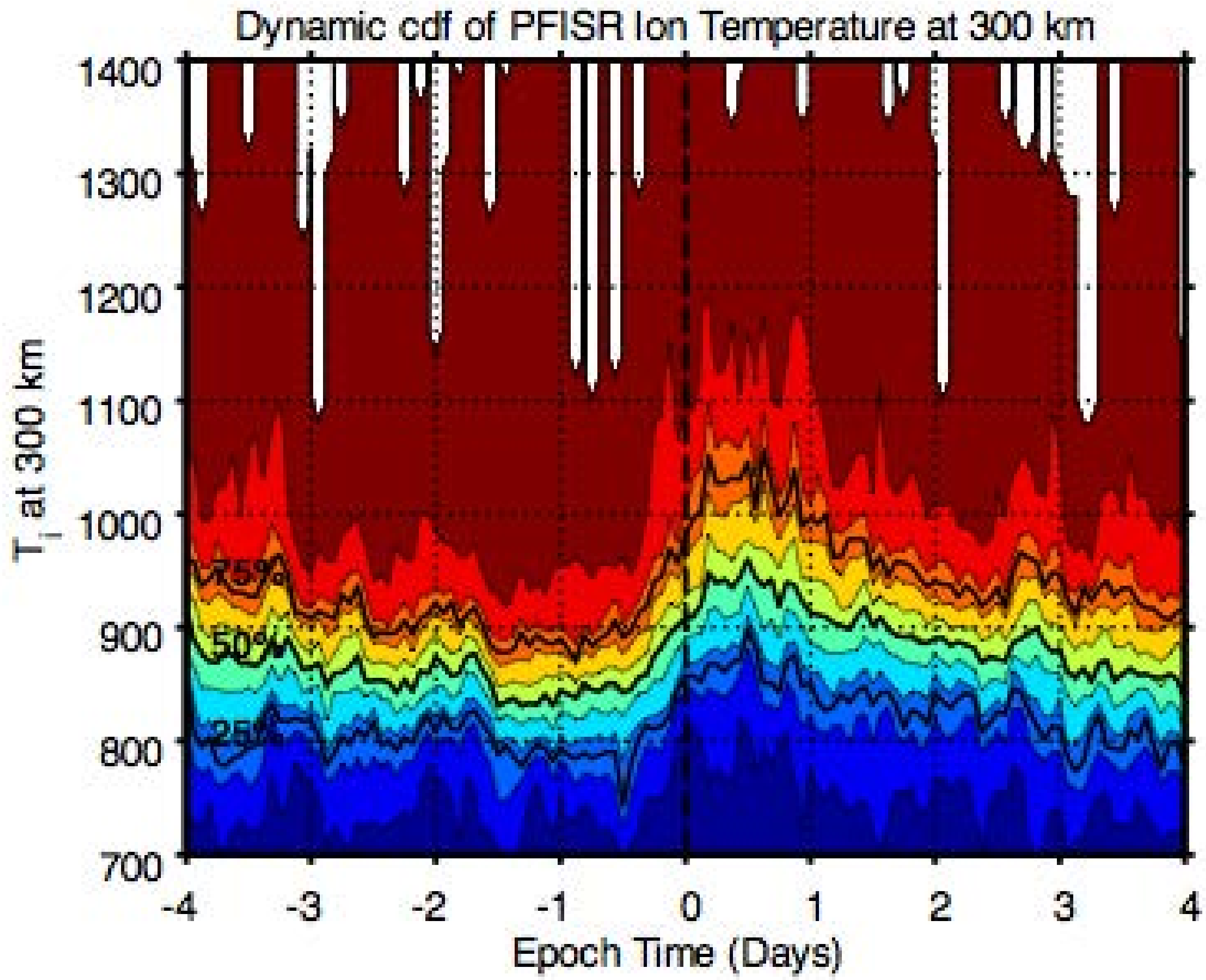
-FOV: Entire sky
-Integration at each position before moving
-Power concentrated at Klystron
-Significant mechanical complexity

-FOV: +/- 15 degrees from boresight
-Integration over all positions simultaneously
-Power distributed
-No moving parts

CIR heating of the auroral ionosphere

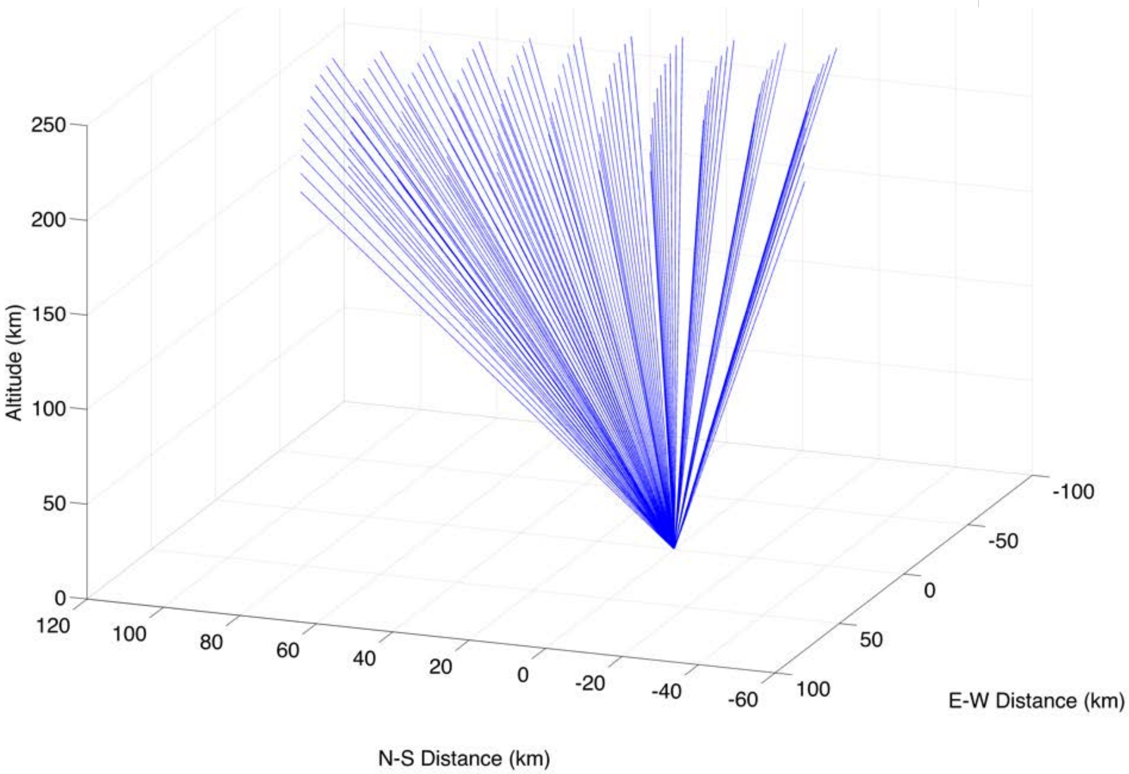


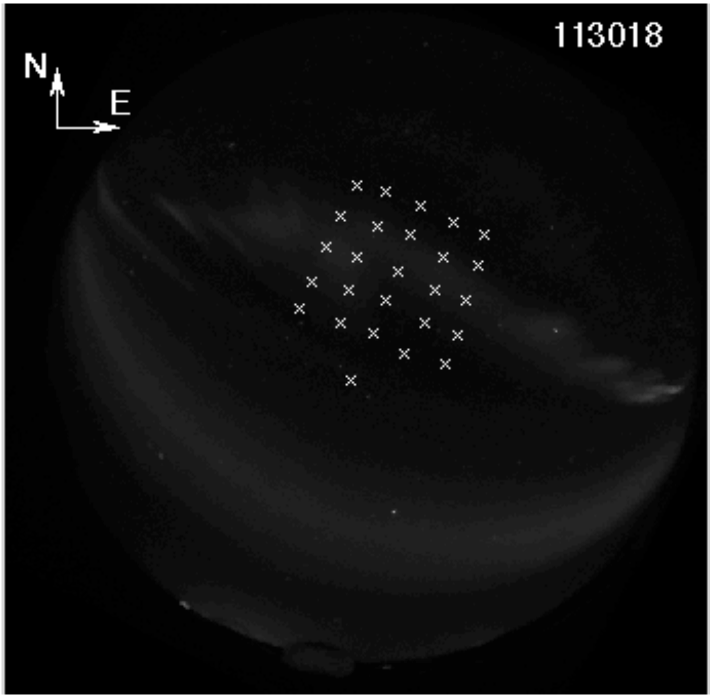
Corotating
Interaction
Region

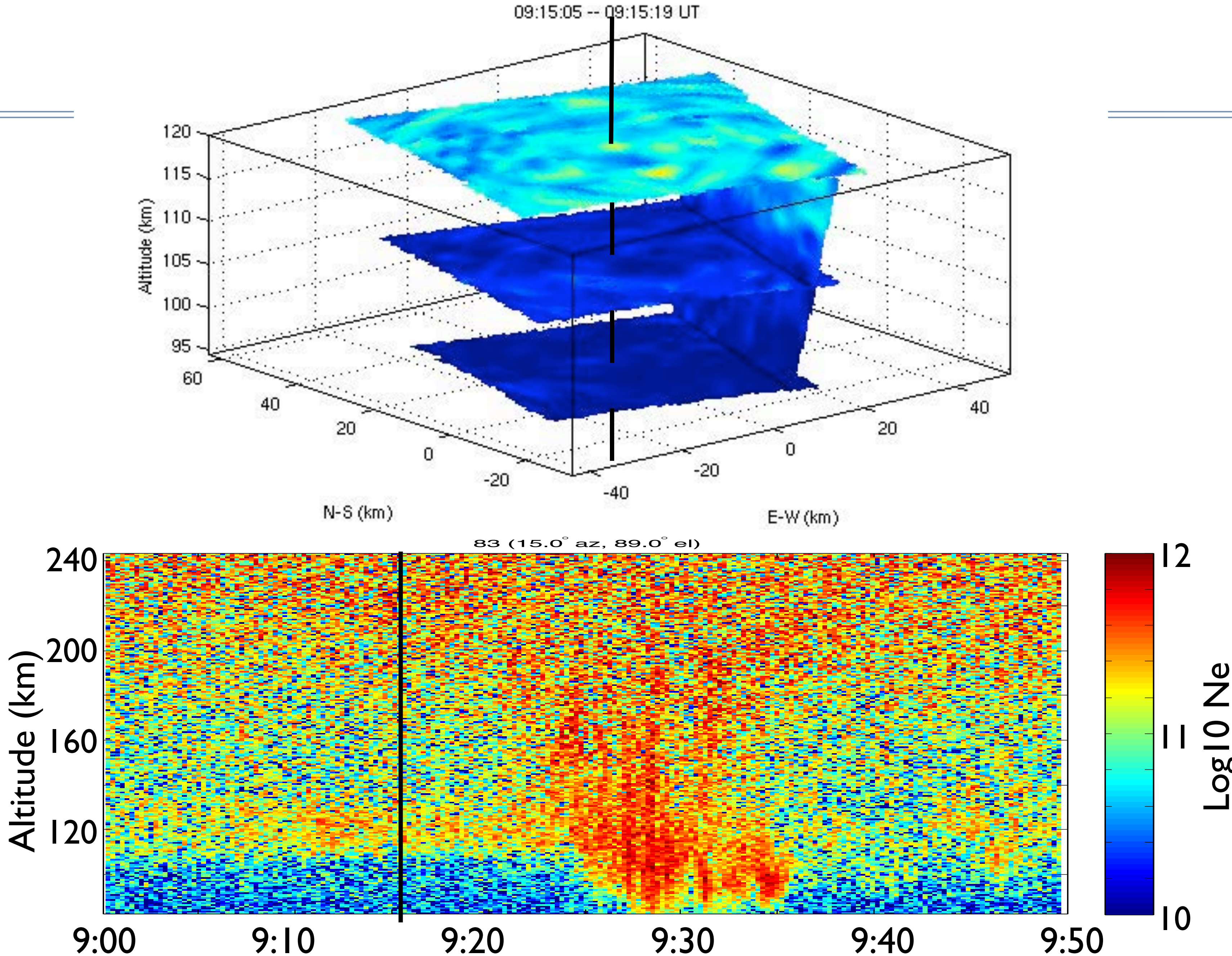


Sojka et al., GRL 2009.

3-D imaging of auroral ionization



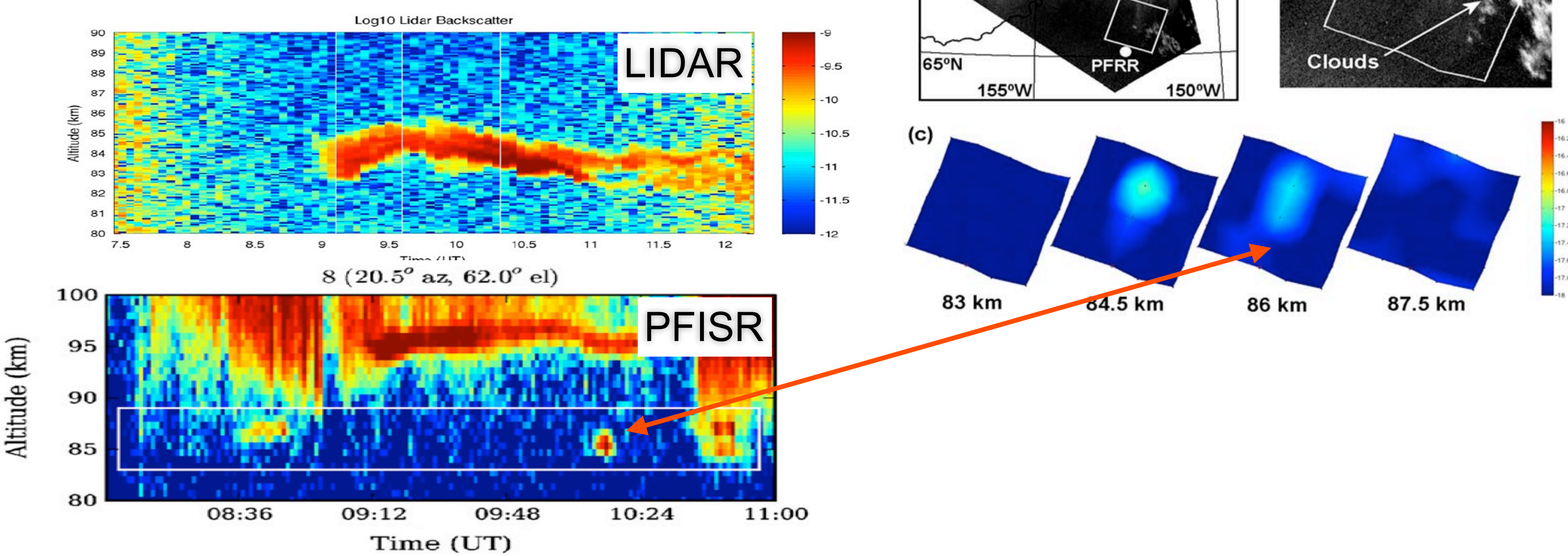




09:15:05 -- 09:15:19 UT
Altitude (km)
120
115
110
105
100
95
60
40
20
0
-20
N-S (km)
-40
-20
0
20
40
E-W (km)
83 (15.0° az, 89.0° el)
240
200
160
120
Altitude (km)
9:00
9:10
9:20
9:30
9:40
9:50
12
11
10
Log10 Ne

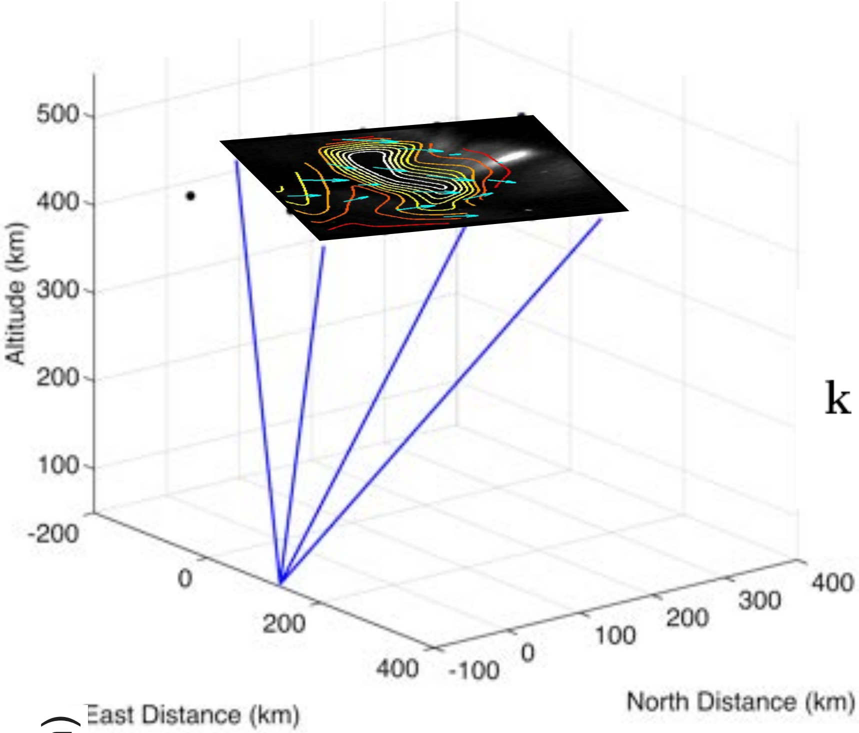
Multi-Instrument Measurements of Polar Mesospheric Clouds

Panoramic image of NLC display on 10-11, August, 2007.



Taylor et al., JASTP 2009

2D Imaging of Convective Flows

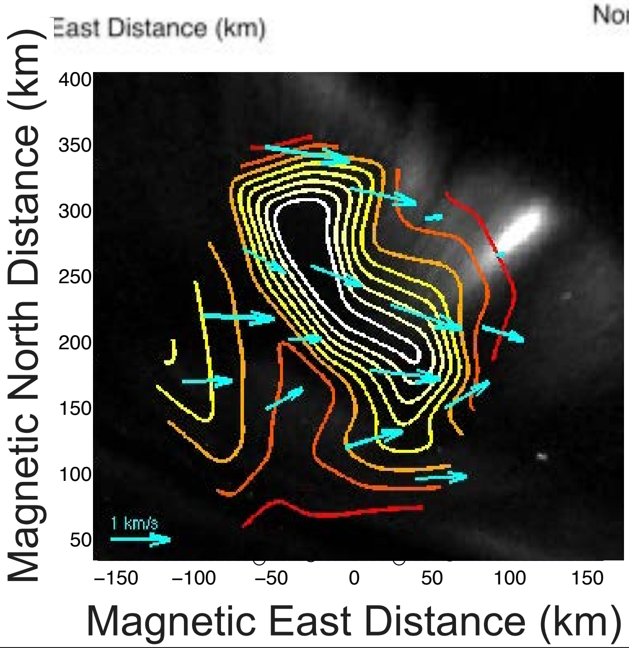


$$v_{los} = \mathbf{k} \cdot \begin{bmatrix} v_e & v_n & v_{\|} \end{bmatrix}^T$$

$$\mathbf{k} = \begin{bmatrix} \cos\theta \sin\phi \\ \cos\theta\cos\phi \\ \sin\theta \end{bmatrix}^T \begin{bmatrix} \cos\delta & \sin I \sin\delta & -\cos I \sin\delta \\ -\sin\delta & \cos\delta \sin I & -\cos I \cos\delta \\ 0 & \cos I & \sin I \end{bmatrix}$$

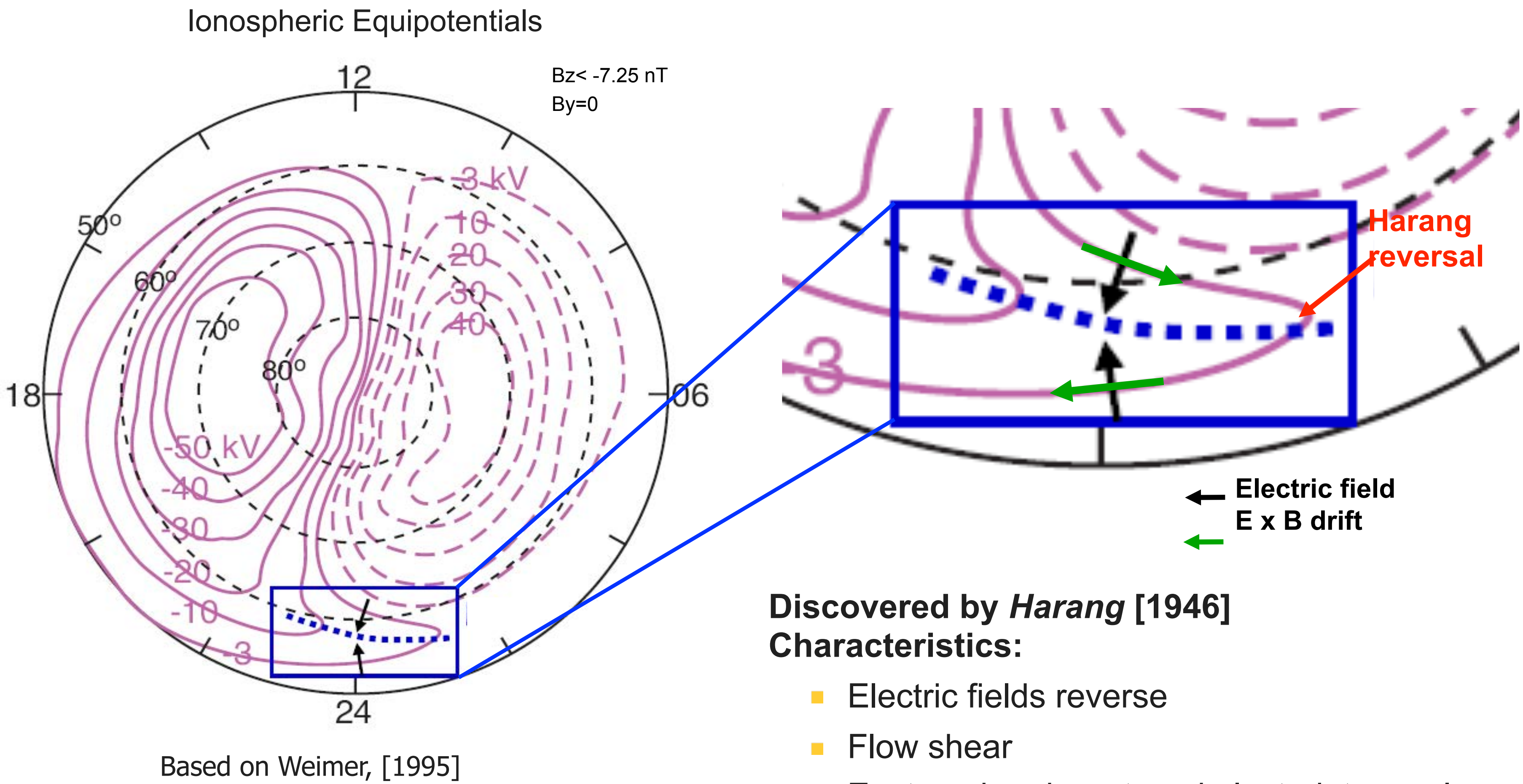
$$\begin{bmatrix} v_{los}^1 \\ v_{los}^2 \\ \vdots \\ v_{los}^i \\ \vdots \\ v_{los}^N \end{bmatrix} = \begin{bmatrix} \mathbf{k}^1 \\ \mathbf{k}^2 \\ \vdots \\ \mathbf{k}^i \\ \vdots \\ \mathbf{k}^N \end{bmatrix} \mathbf{v} + \begin{bmatrix} e_{los}^1 \\ e_{los}^2 \\ \vdots \\ e_{los}^i \\ \vdots \\ e_{los}^N, \end{bmatrix}$$

$$\mathbf{v}_{los} = A\mathbf{v} + \mathbf{e}_{los}$$



Semeter et al, JGRA 2010

The Harang Reversal Region and Substorm Onset

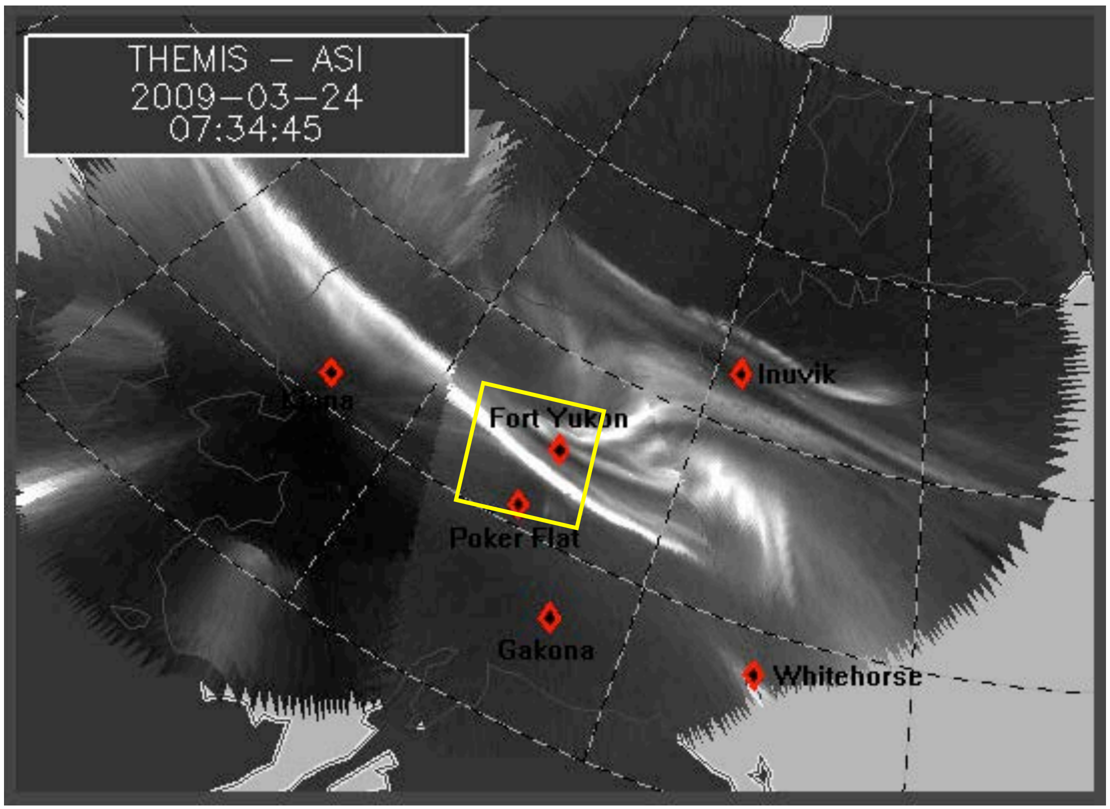


Discovered by *Harang* [1946]
Characteristics:

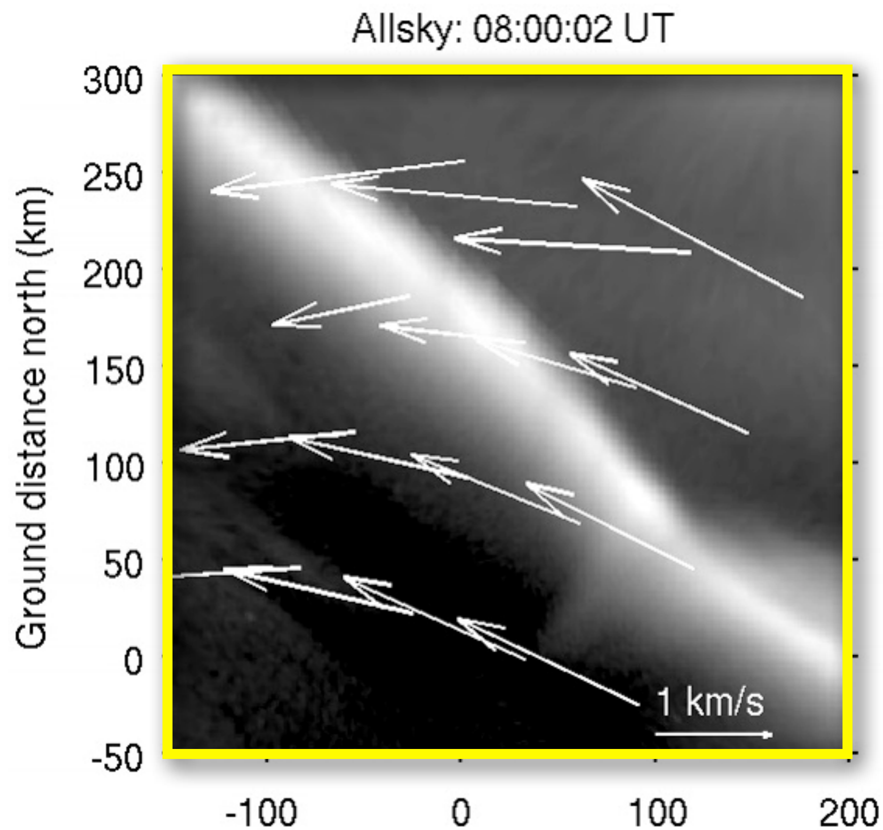
- Electric fields reverse
- Flow shear
- Eastward and westward electrojets overlap

Zou et al., JGRA 2009; Lyons et al., JASTP 2009

Dynamic 2D flow fields and auroral forms



Courtesy Emma Spanswick and Eric Donovan

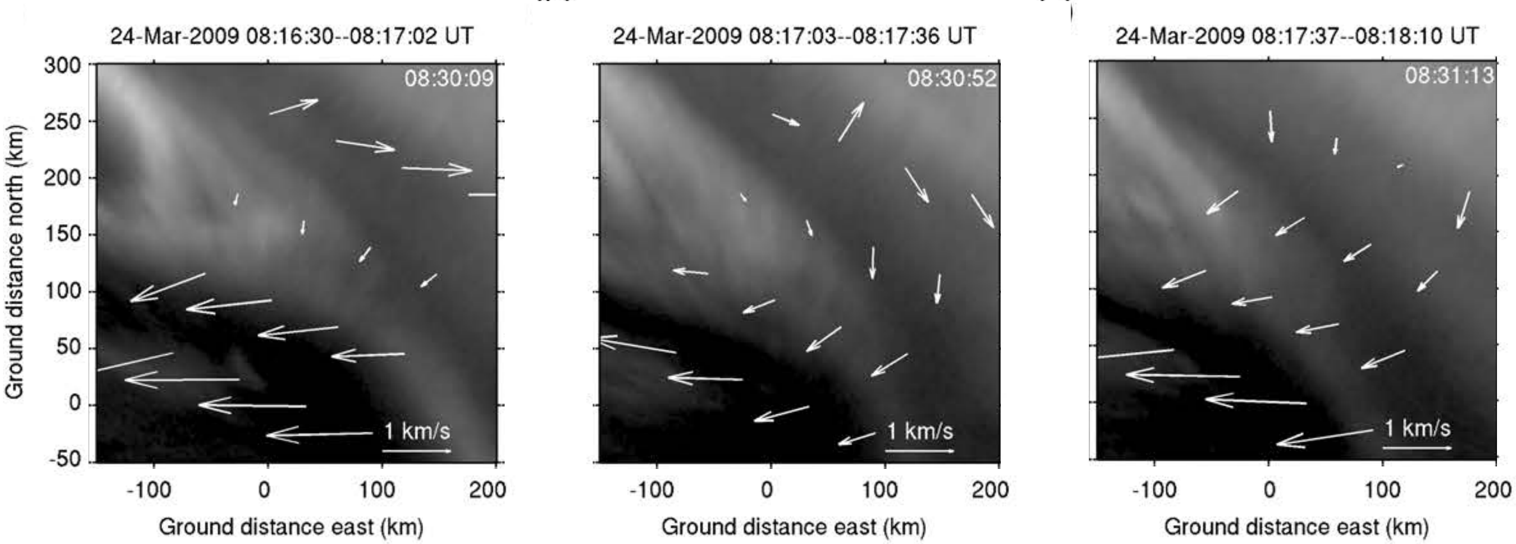


Zou et al., JGRA 2009; Lyons et al., JASTP 2009

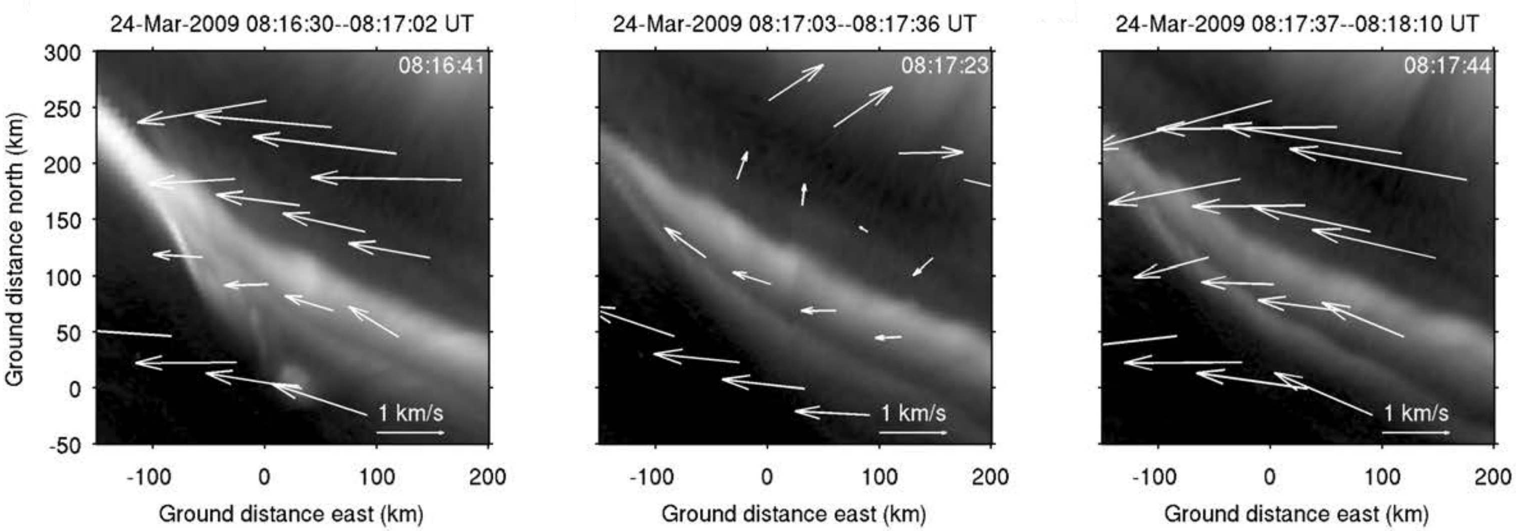
Butler et al., RS 2010

Dynamic 2D flow fields and auroral forms

Semeter et al. (JGRA 2010), Butler et al. (RS 2010, in press)



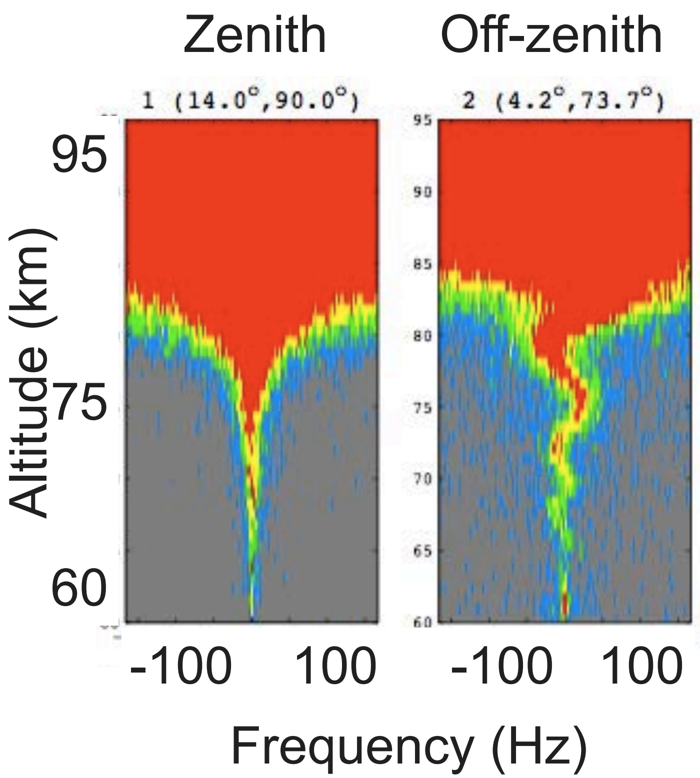
Plasma flow field confirms optical signature of Harang reversal

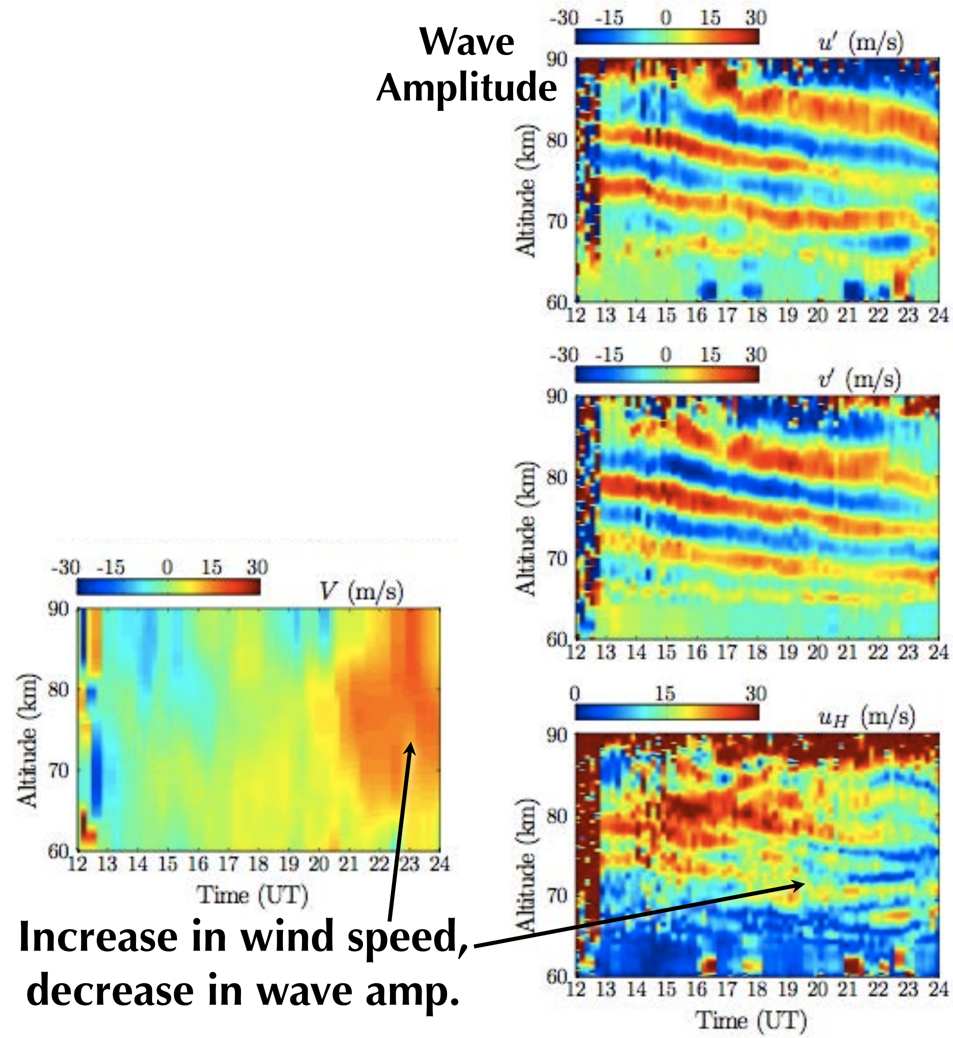


Rapid (~30-sec) coherent variations in flow also observed along “quiet” arc

Similar dynamic observed by Bristow et al. (JGRA 2008) with SuperDARN

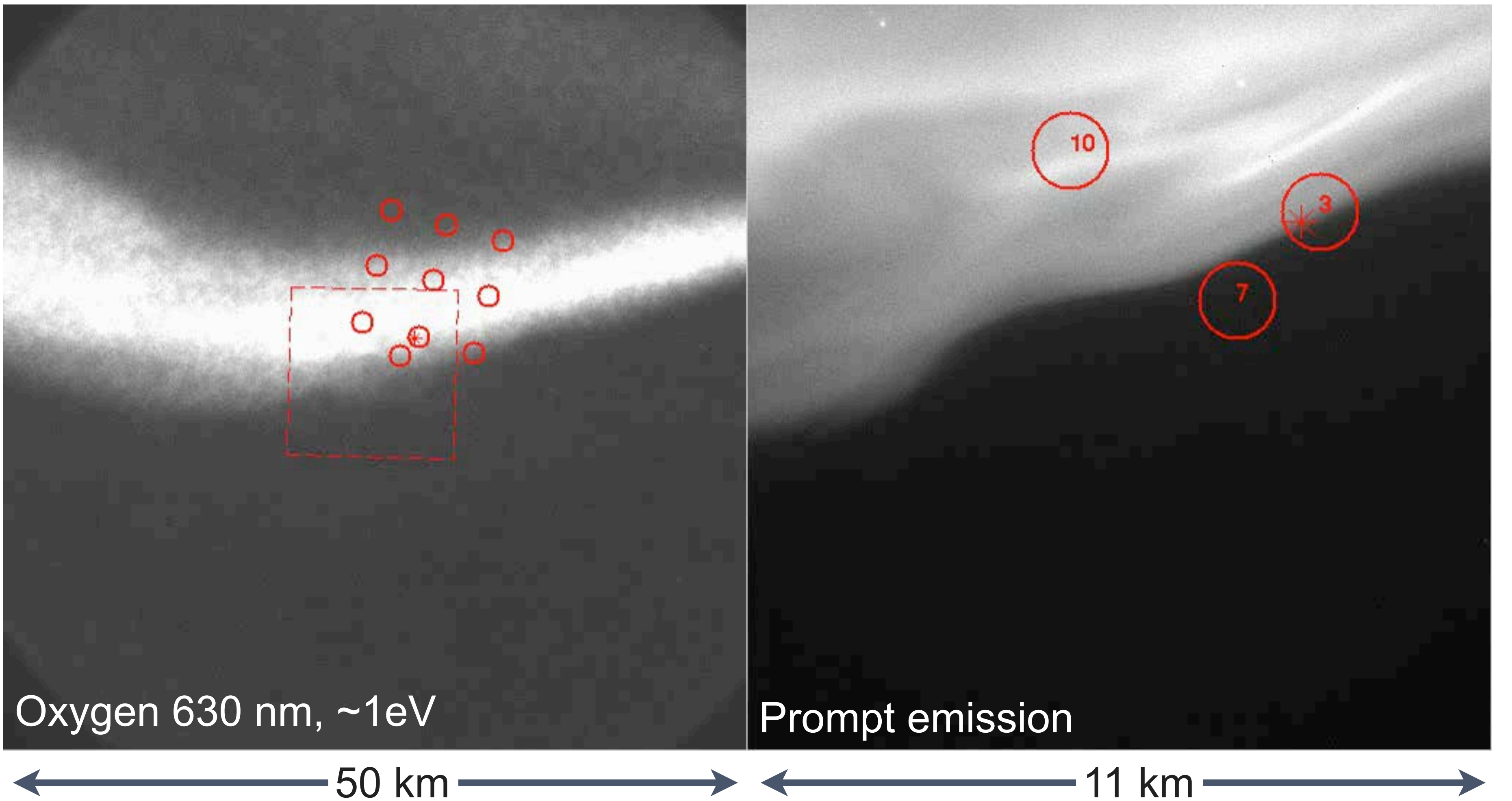
PFISR Measurements of Winds and Waves in the D region





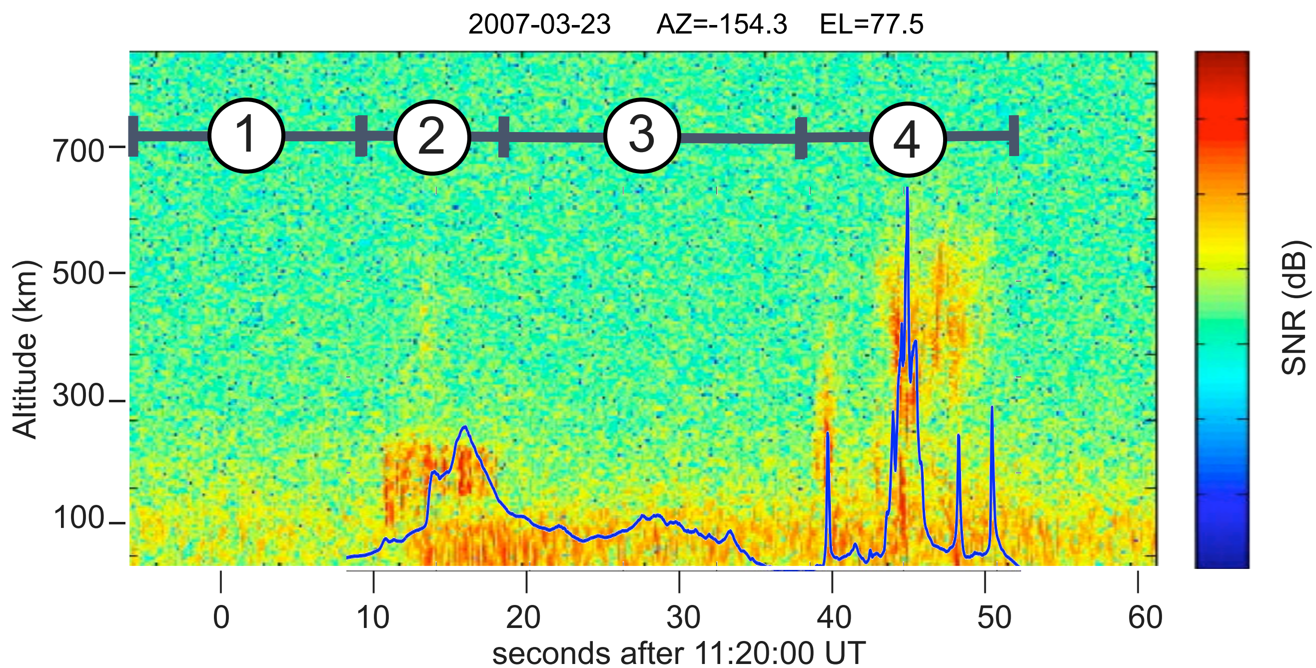
Nicolls et al., JGRA, 2010

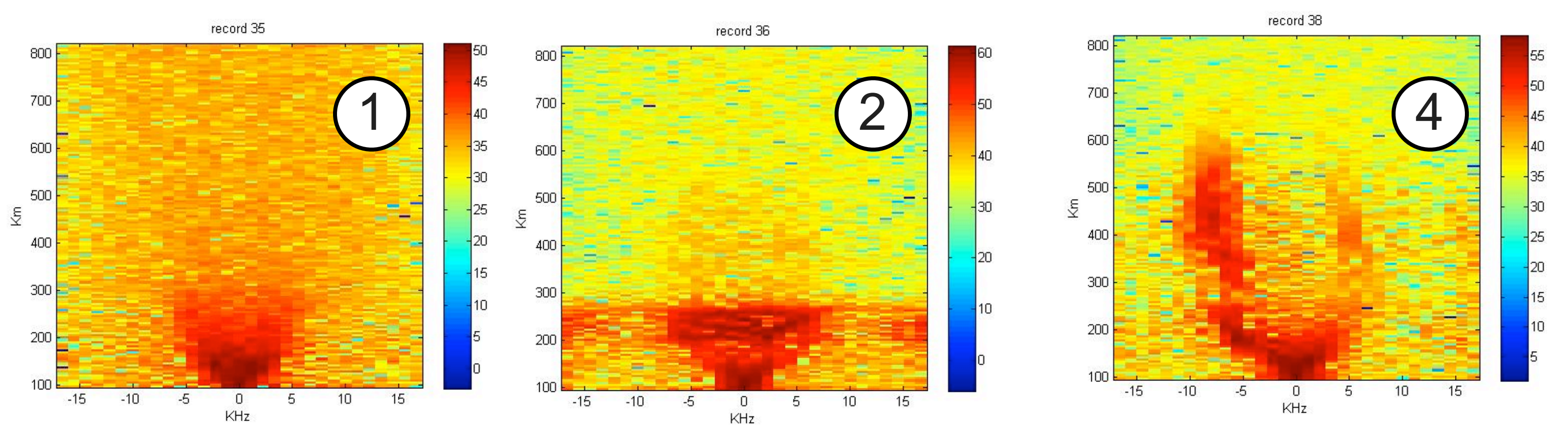
Low altitude ionospheric turbulence



Semeter et al., GRL 2006, JGRA 2009

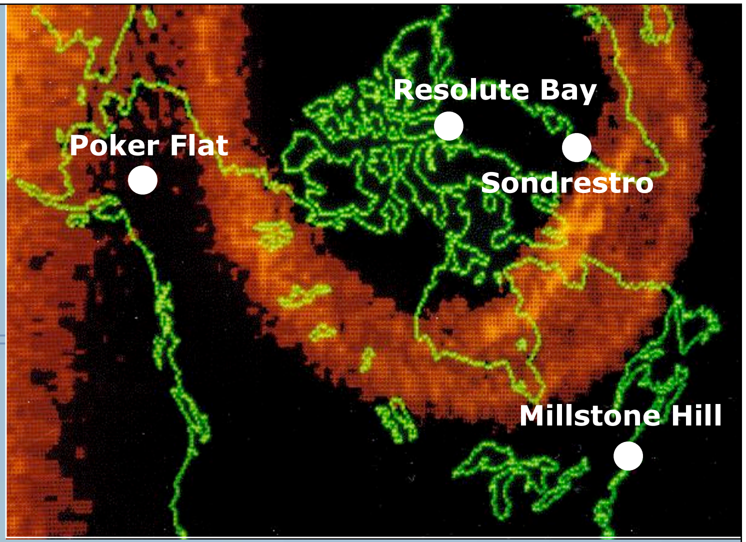
Non-thermal plasma



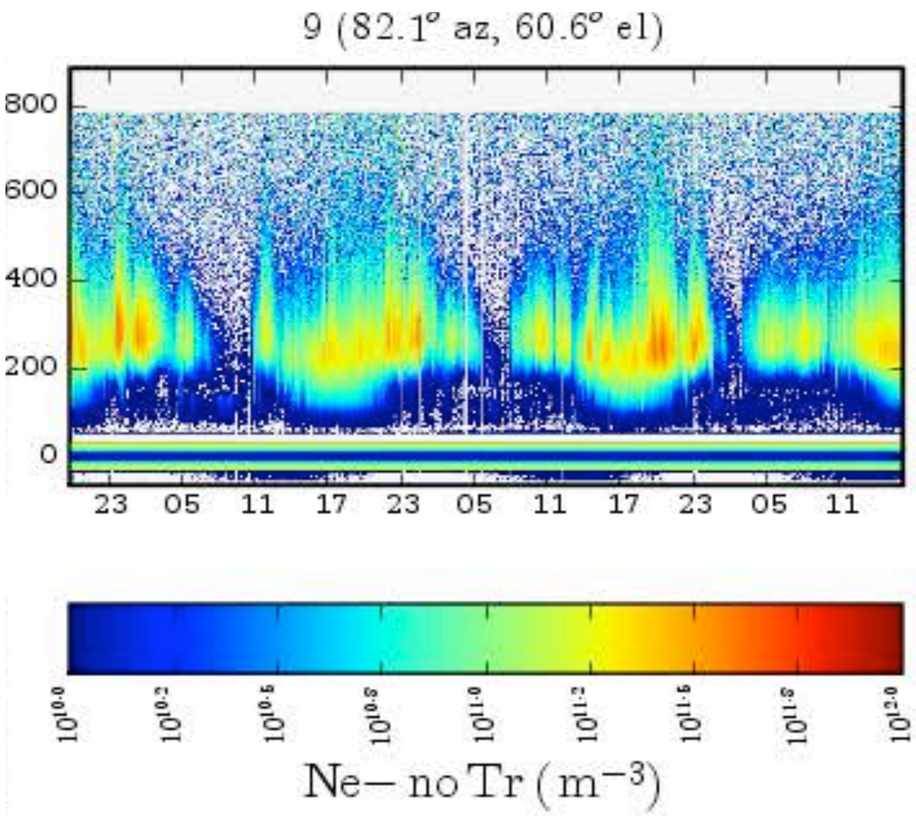


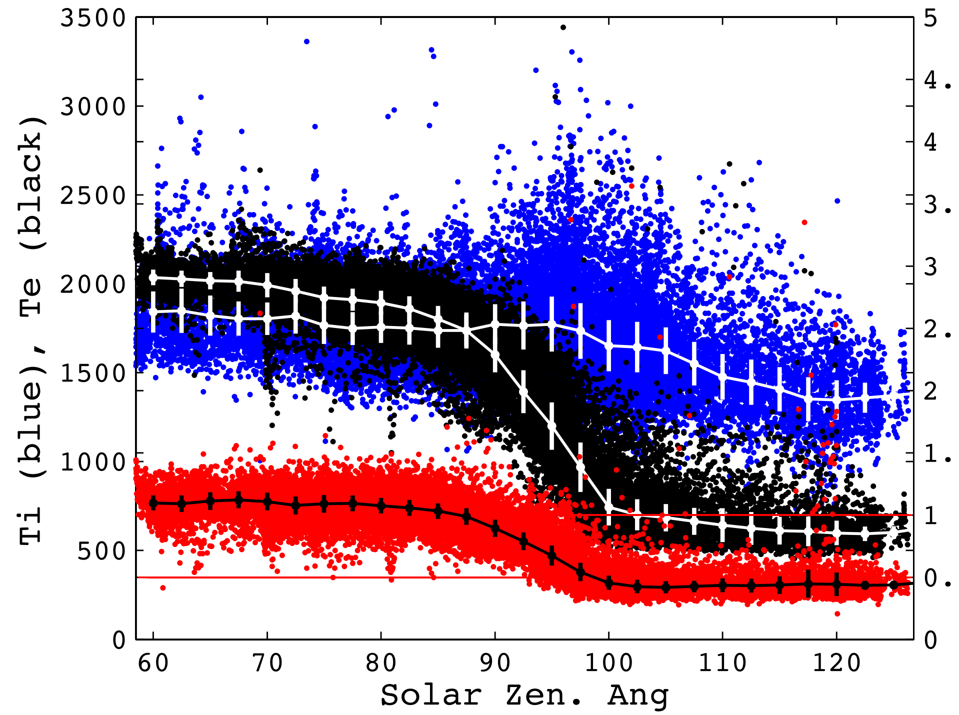
Stromme et al., AGU Fall Meeting, 2007

RISR: Resolute Bay ISR



RISR: An initial look at the polar cap ionosphere

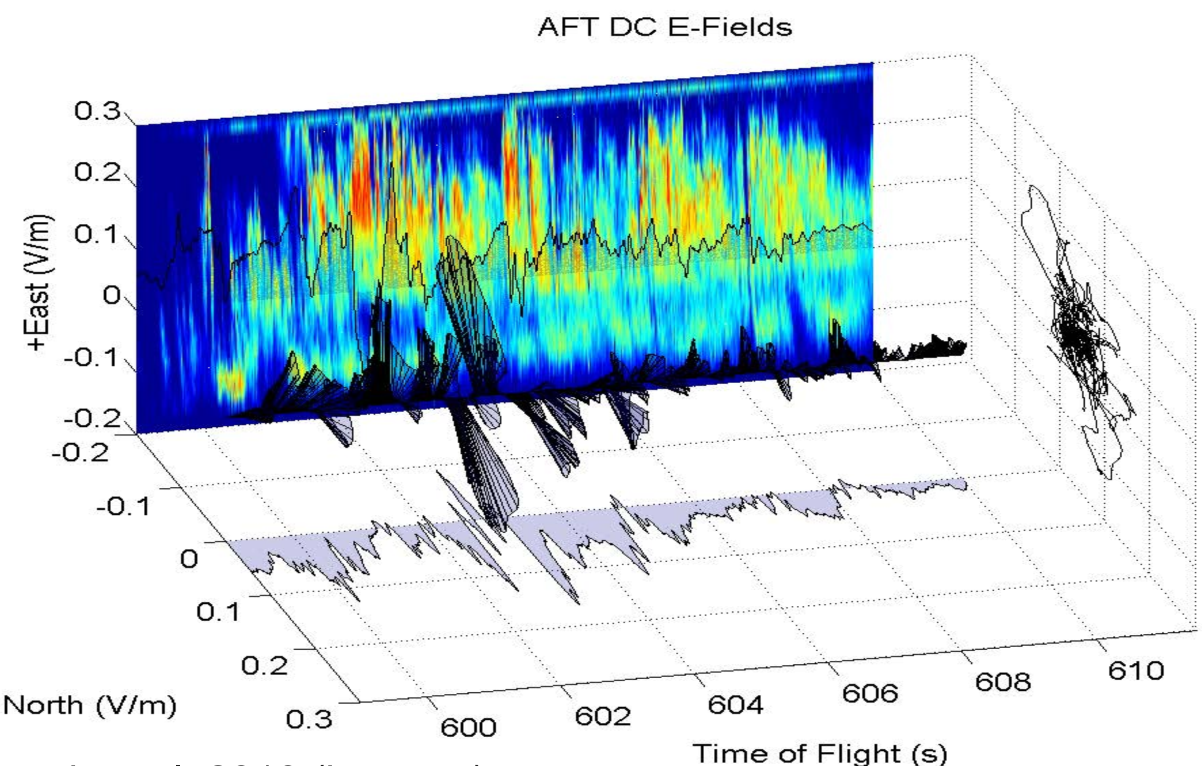




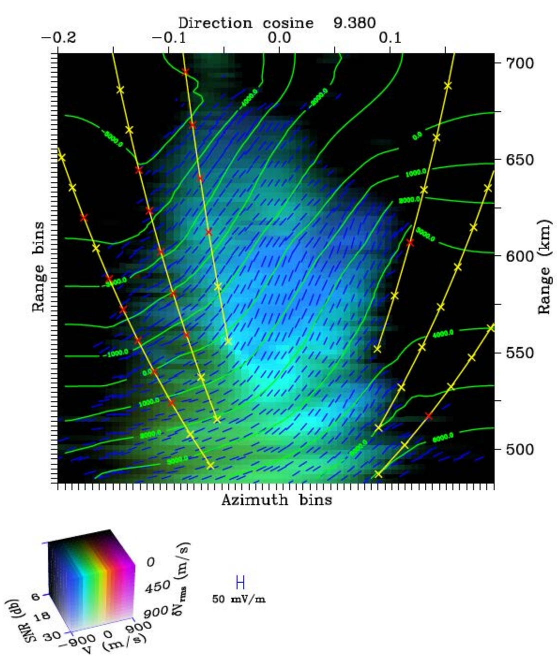
Nicolls , Heinselman, Kelly, et al., Unpublished

What has yet to be done

- Radar mode development
- Assimilation with ancillary diagnostics
- Conjugate studies with satellites and rockets



Lynch et al. 2010 (in press)



Hysell et al, Ann. Geophys. 2008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