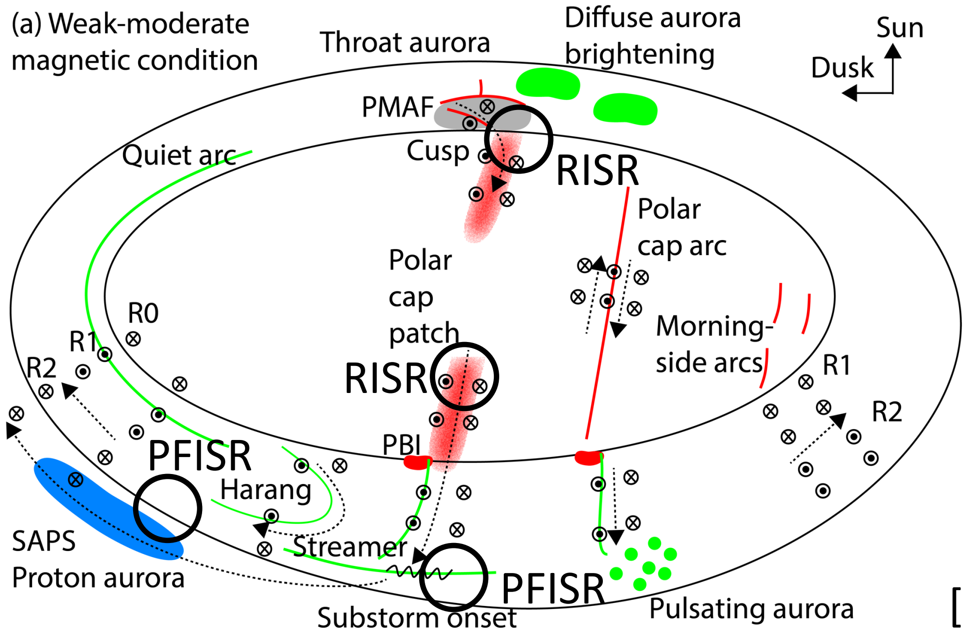
Exploring high-latitude electrodynamics using RISR and PFISR

Toshi Nishimura (Boston University)



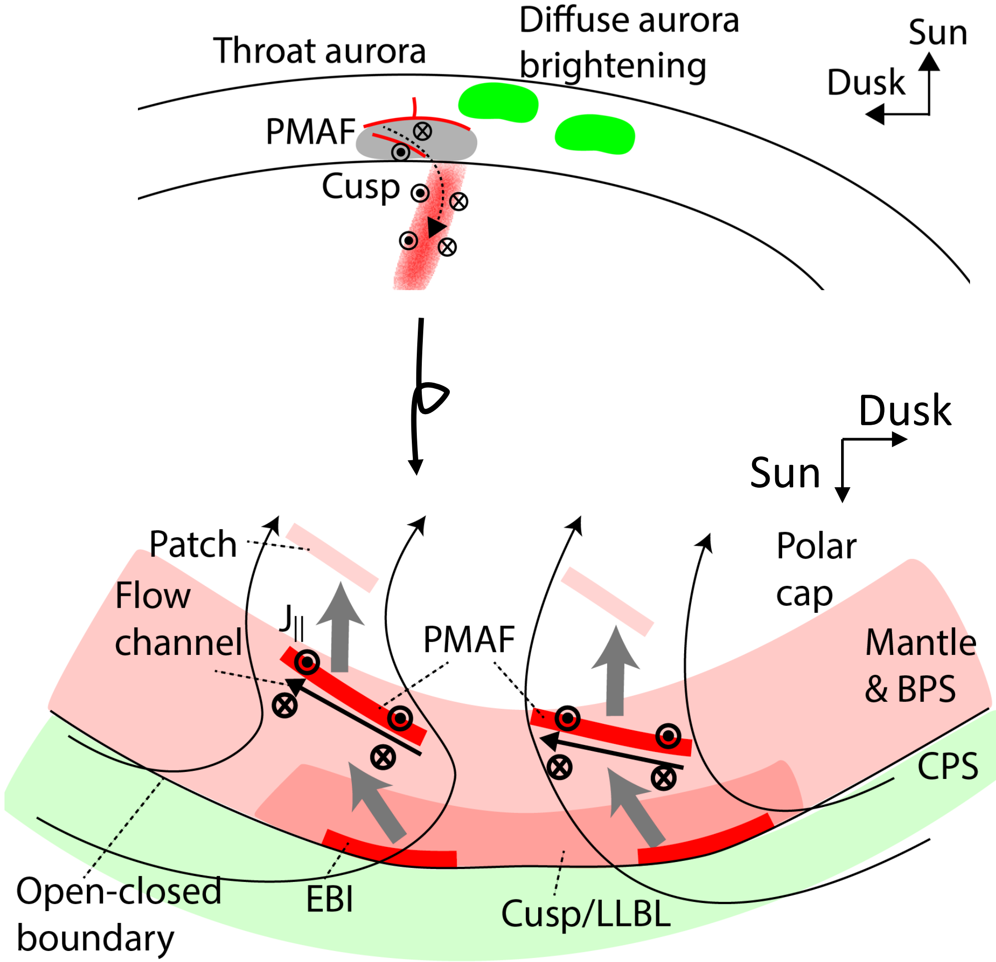
[Nishimura et al., 2021]

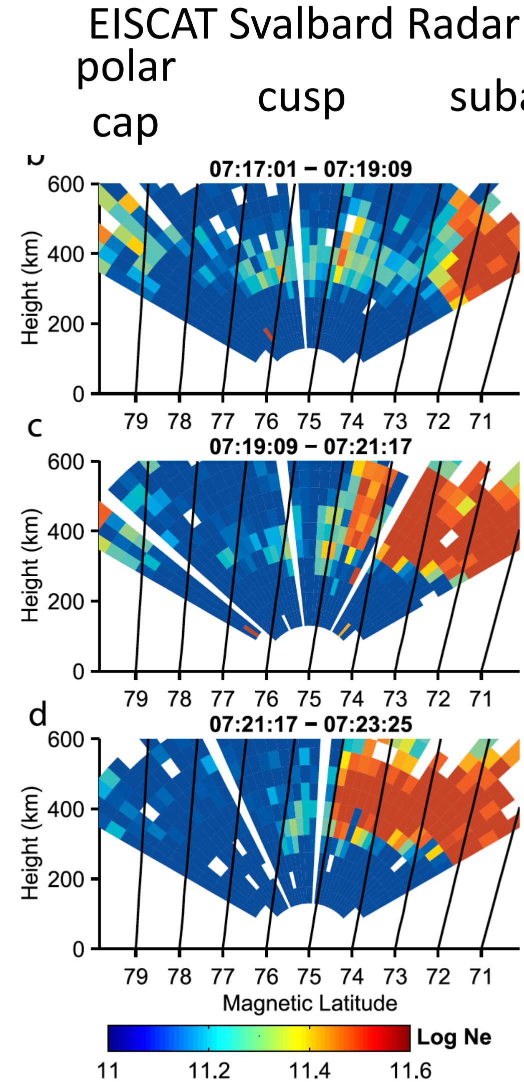
The ionosphere contains various localized phenomena embedded in the large-scale system. But it is often difficult to observe their spatial and temporal evolution.

ISRs are well situated to measure localized phenomena and their impacts in the M-I-T coupling system.

This talk will show several case studies about how RISR and PFISR can address key questions in high-latitude M-I-T coupling.

Cusp as a key region of energy input and deposition



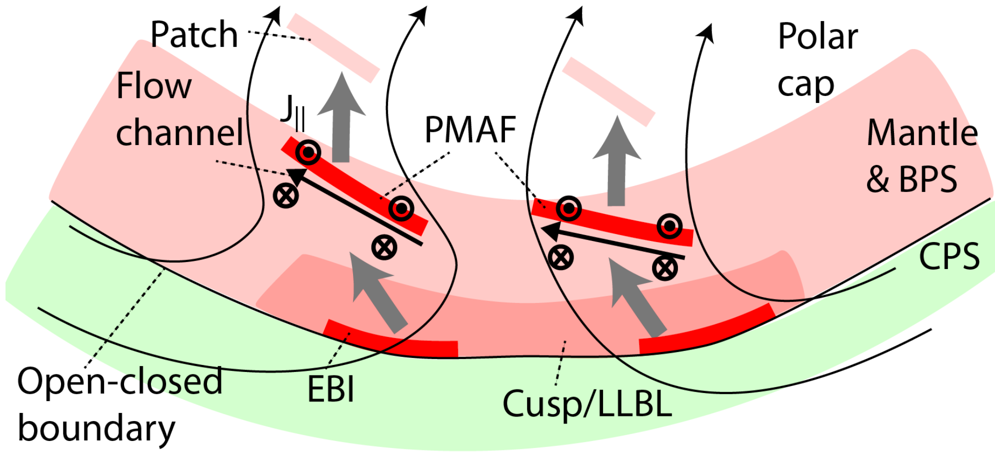


[Carlson et al., 2006]

The cusp is a region of large density, fast flows and enhanced temperature as the interface of the solar wind and magnetosphere.

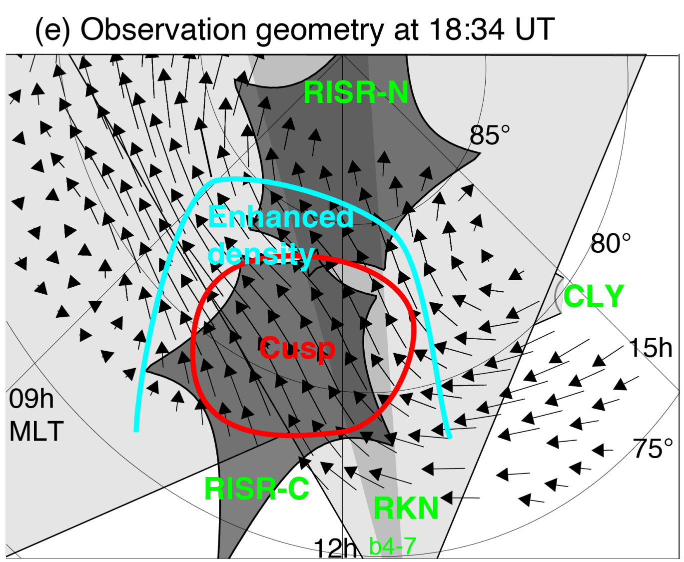
However, it is difficult to determine the 3-d structure of the cusp.

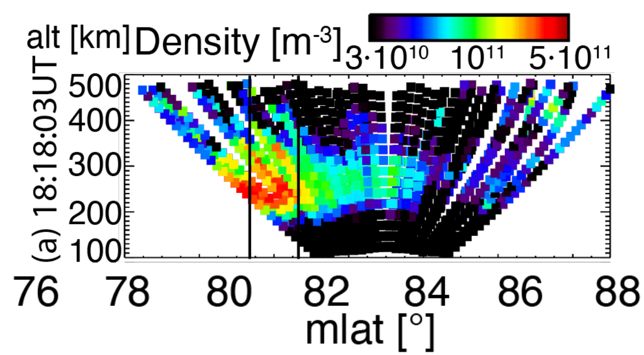
RISR observation of the 3-d cusp structure and evolution

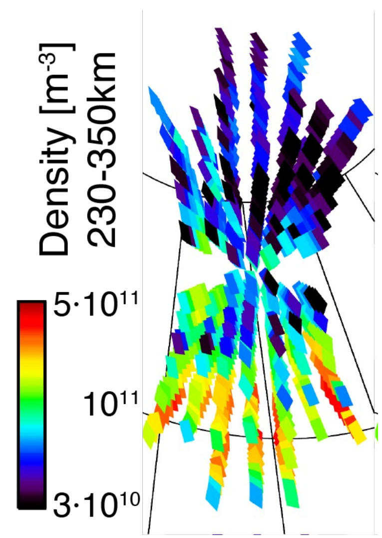


RISR provide 102 beams with 84 sec integration.

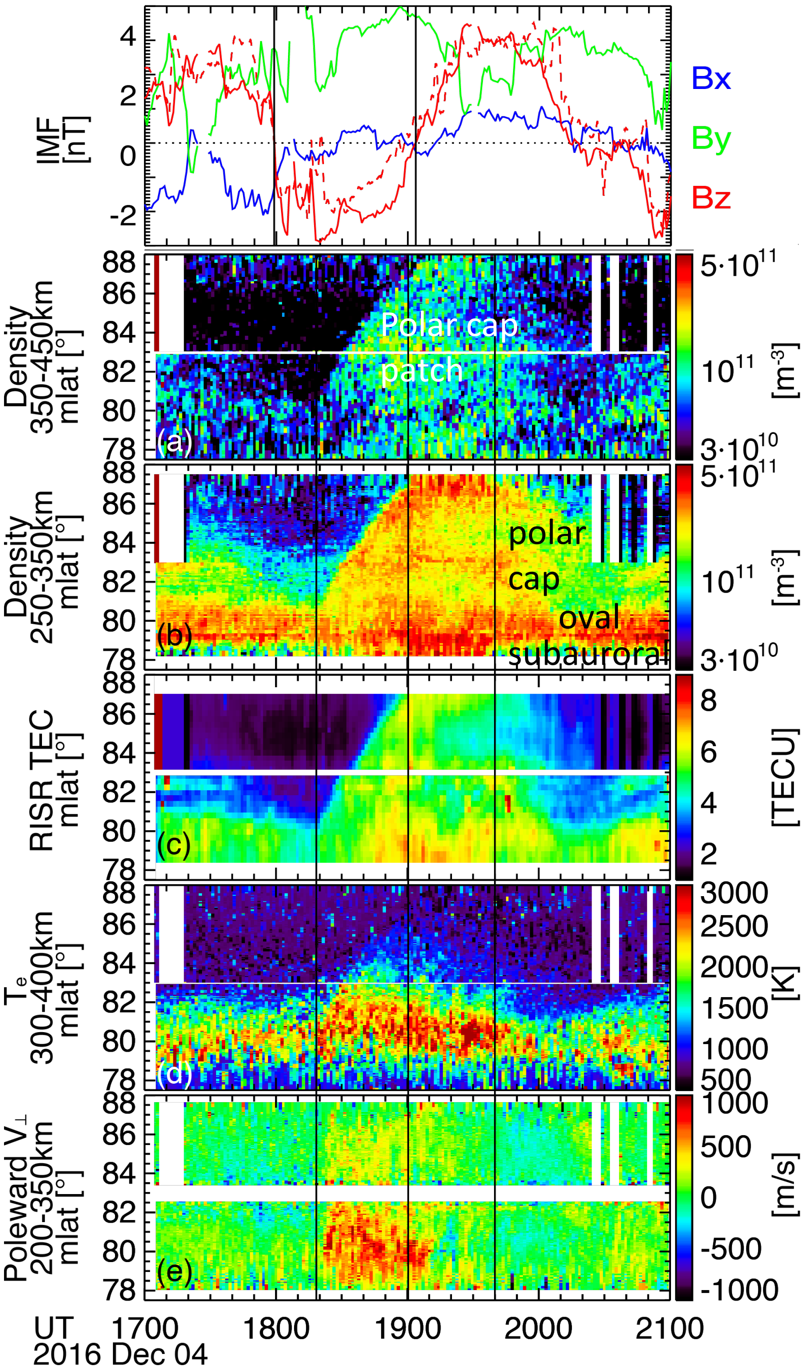
The 3-d structure of the cusp, as well as the subauroral ionosphere and polar cap, can be seen nearly simultaneously.







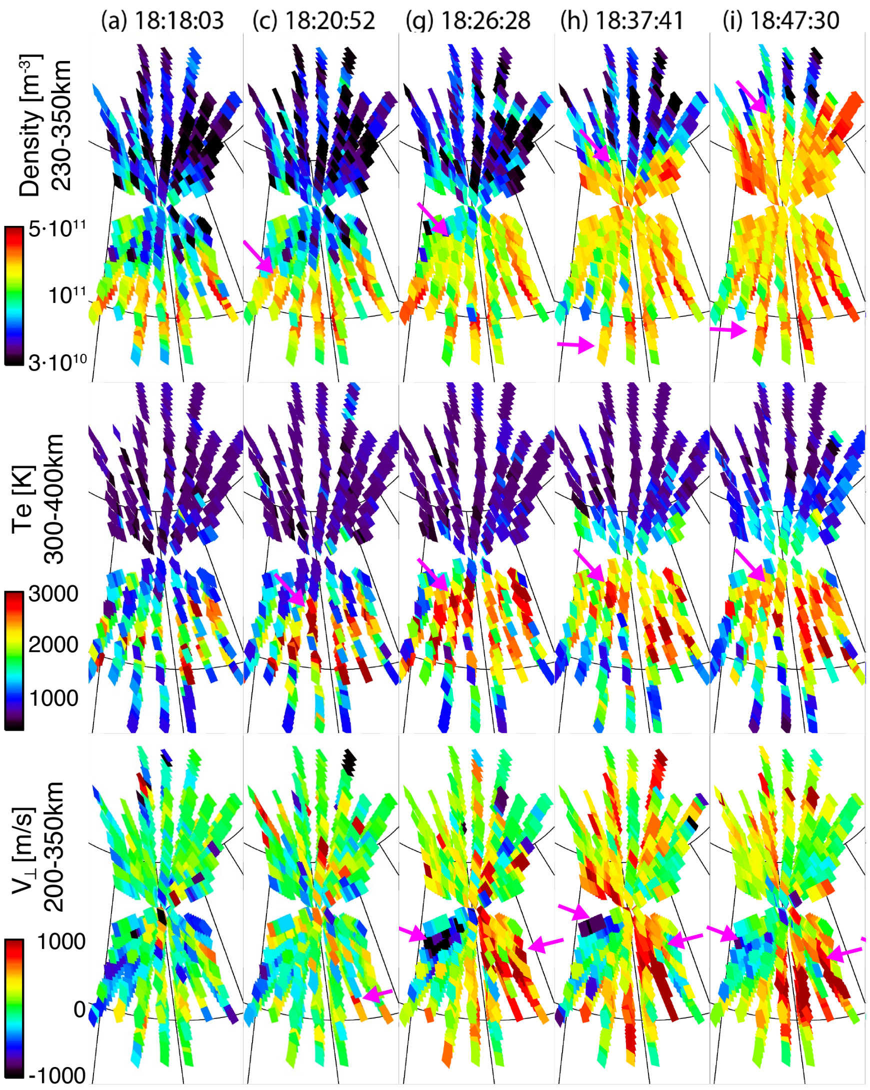
RISR observation: latitudinal structure



- Latitudinal distributions of the RISR density, electron temperature and poleward velocity in the F-region.
- The cusp density and temperature increase and expand poleward.
- Separating two sources of patch density:
  - The leading edge of the patch forms in the cusp.
  - Then the subauroral ionospheric density increases and moves into the cusp.

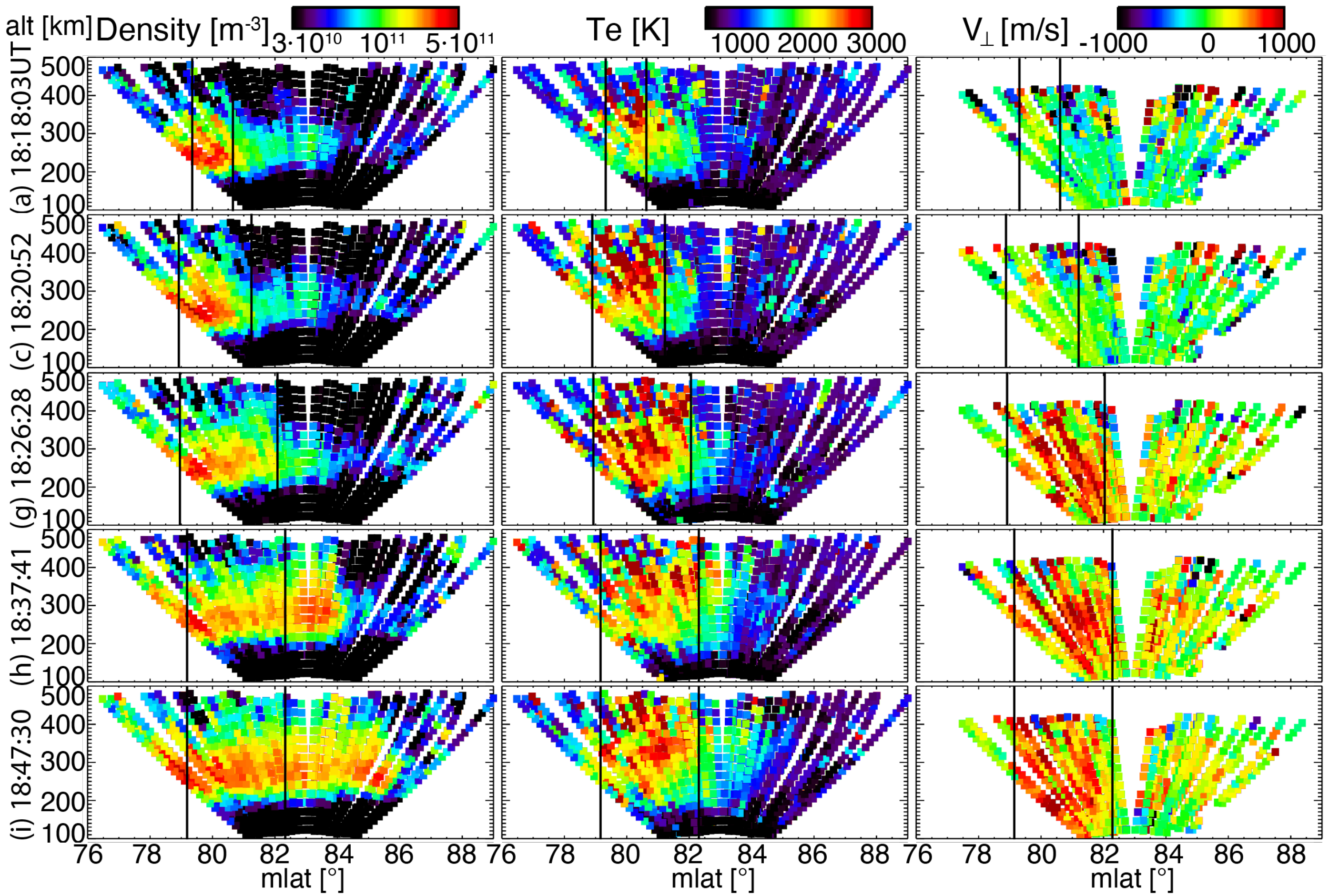
[Nishimura et al., 2020]

RISR observation: horizontal structure



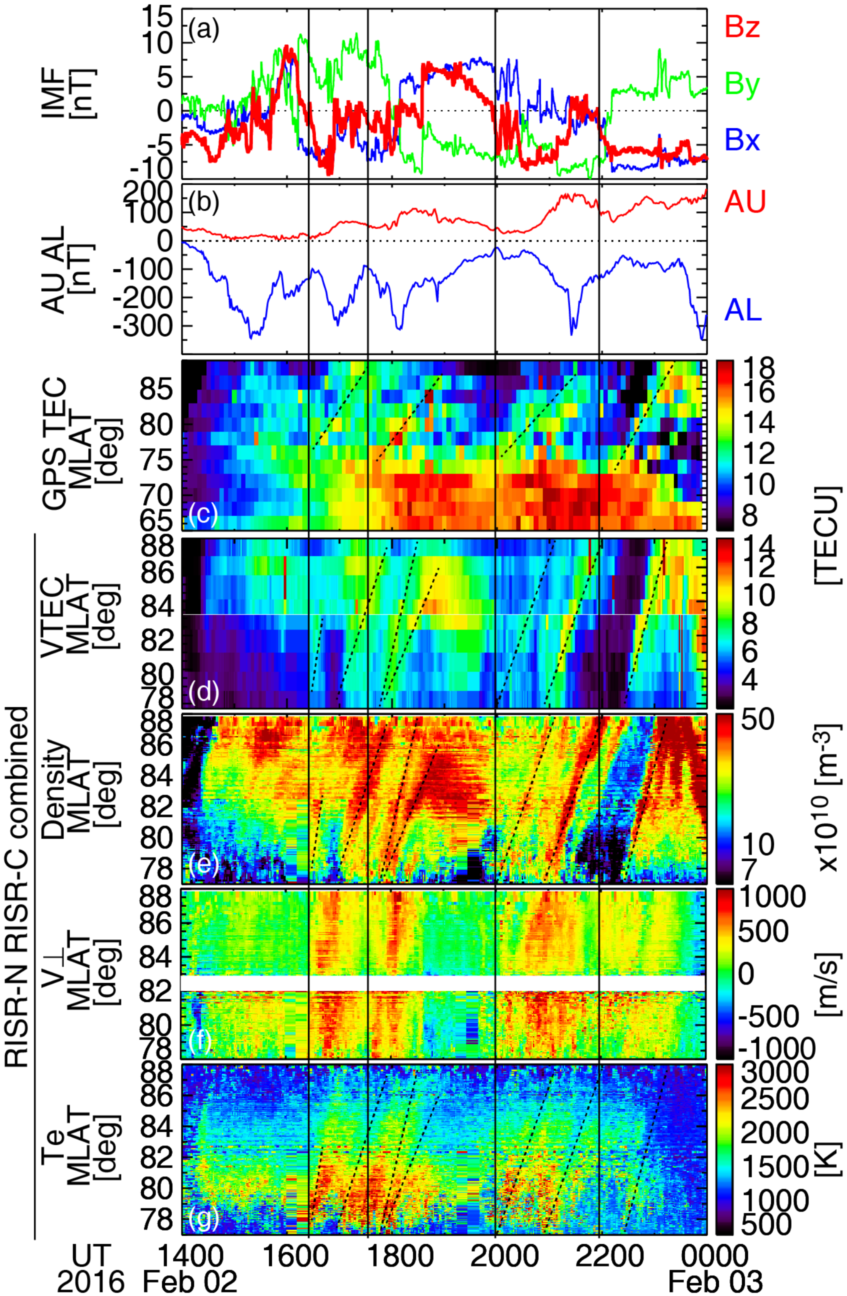
- The cusp can be seen as a region of enhanced density and temperature.
- Even smaller density, temperature and flow structures are present, known as poleward moving auroral forms (PMAFs).
- The patch forms in the cusp and propagates poleward. Then subauroral density increases.

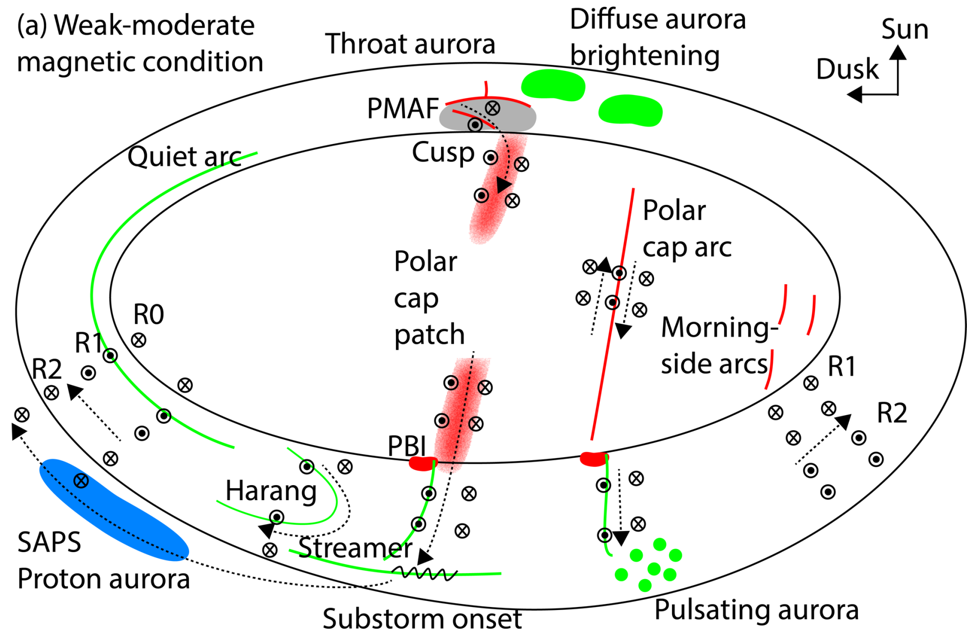
RISR observation: meridional structure



- The topside F-region density increases associated with the F-region heating.
- The density moves into the polar cap with the poleward velocity.
- Then the subauroral density increases.

RISR observation: polar cap

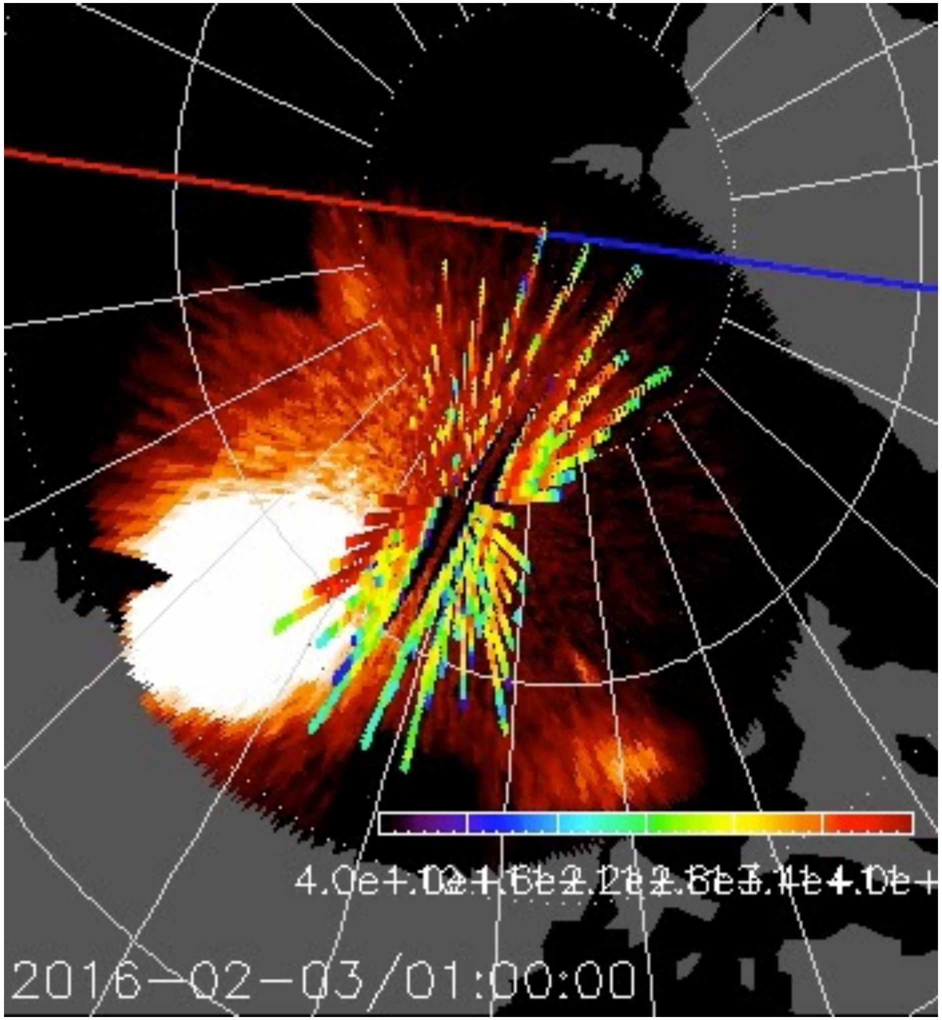




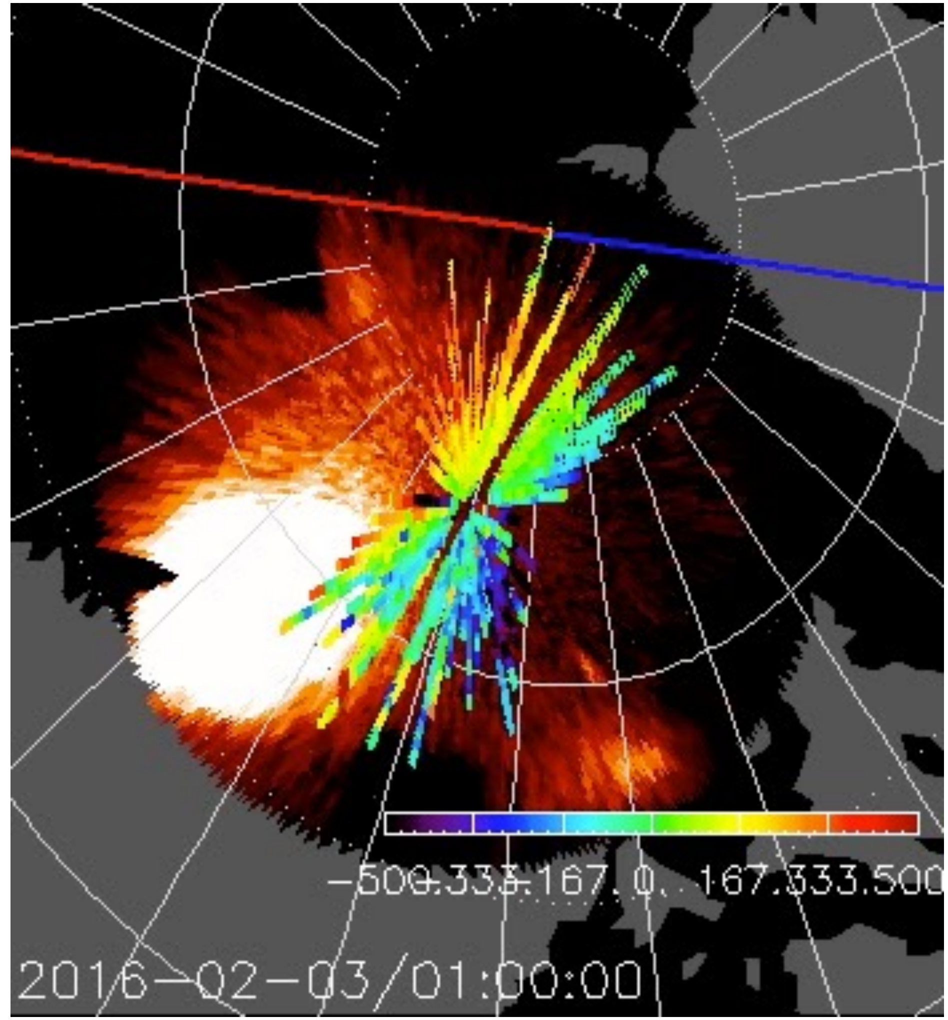
- Event with larger IMF Bz
- Flows and electron temperature are enhanced in association with multiple IMF orientation changes.
- Enhanced flows transport polar cap patches.
- The electron temperature in the patches are lower, suggesting subauroral sources.

RISR observation: polar cap

RISR density

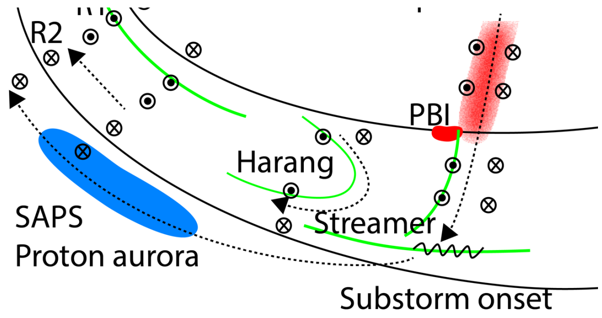


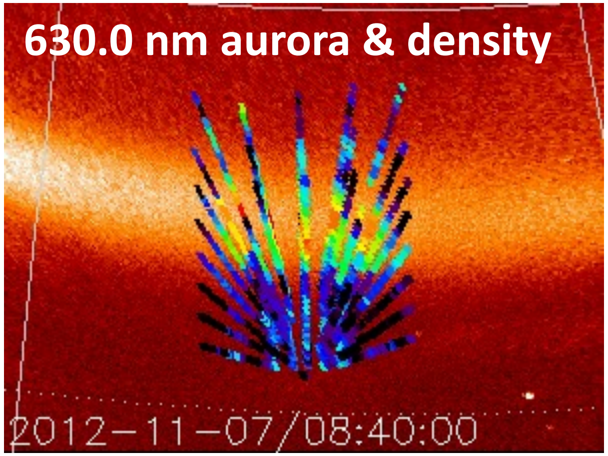
RISR velocity

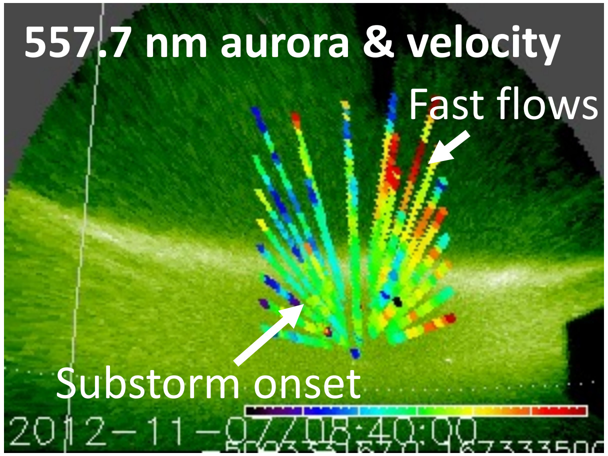


Polar cap patch density is associated with airglow emissions.
Some of them also come with flow variations, indicating that magnetic flux tubes with fast flows drift across the polar cap.

Isolated substorm event during a PFISR radar campaign







[Nishimura et al., 2014]

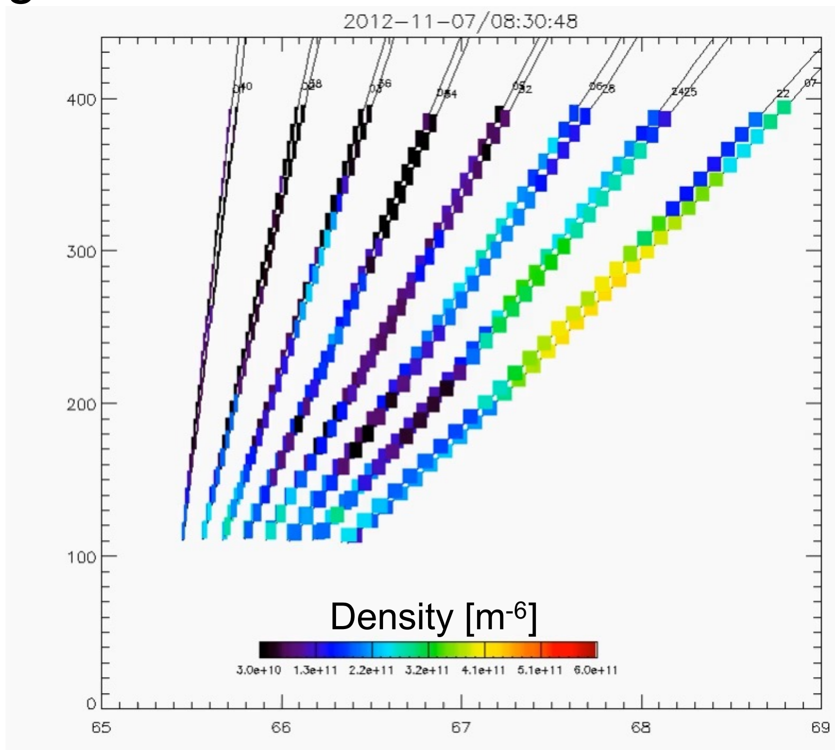
- Auroral onset initiating within PFISR radar field of view
- PFISR covers the whole latitudinal extent of the oval.
- Colored imager available

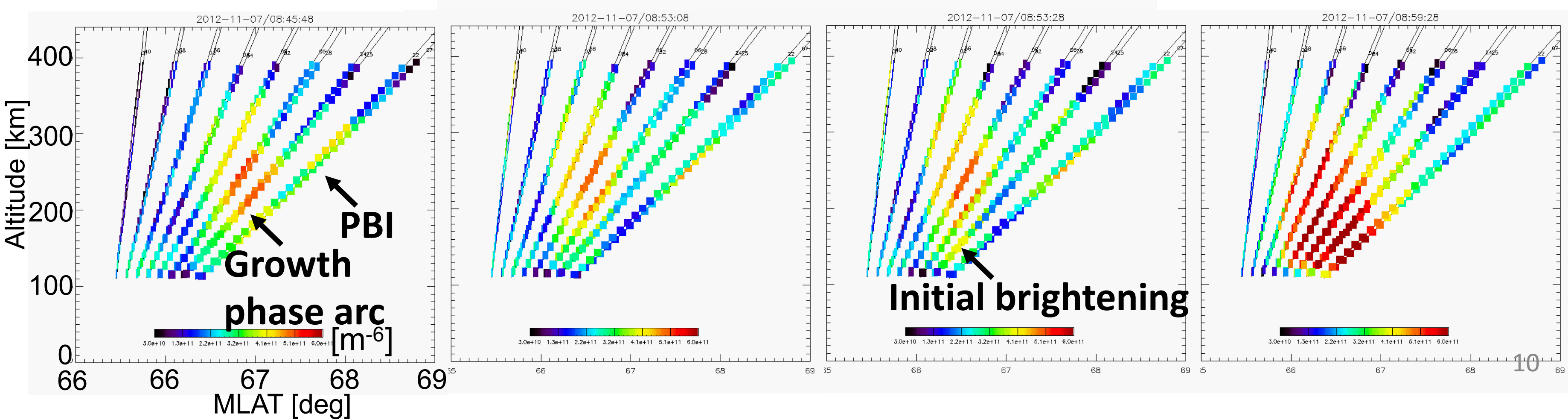
<u>Substorm precursor signature</u>

- Substorm auroral onset preceded by a poleward boundary intensification.
- Waves along the growth phase arc—growing soon after PBI.

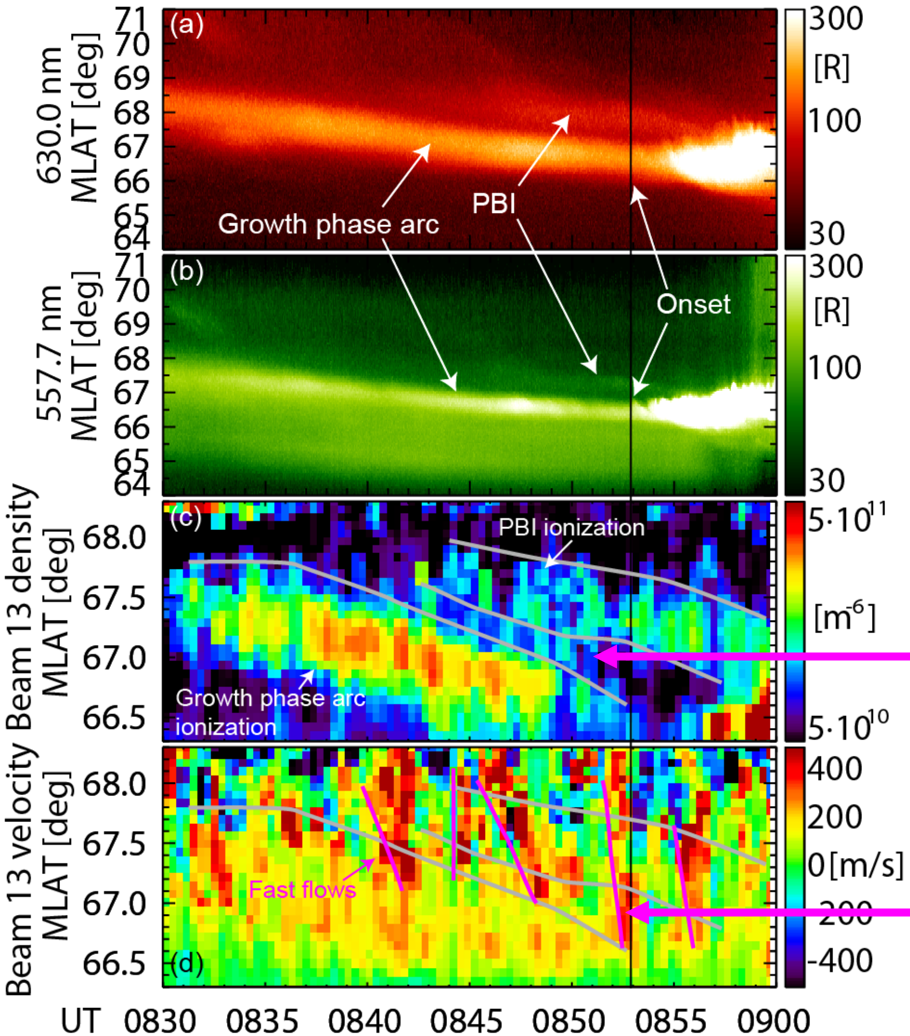
Isolated substorm event during a PFISR radar campaign

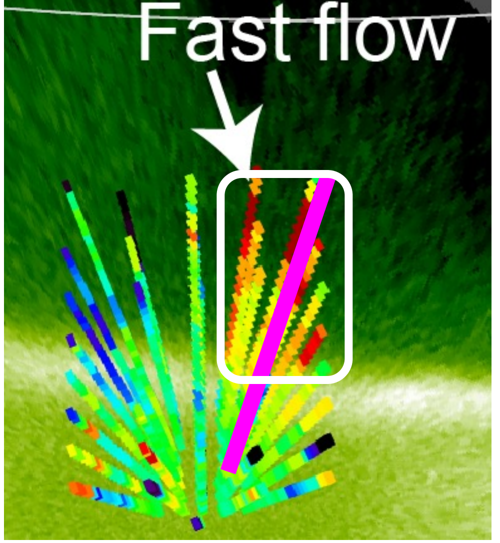
PFISR also reveals meridional structure of ionospheric density during the substorm.





Fast flows precursor to the substorm



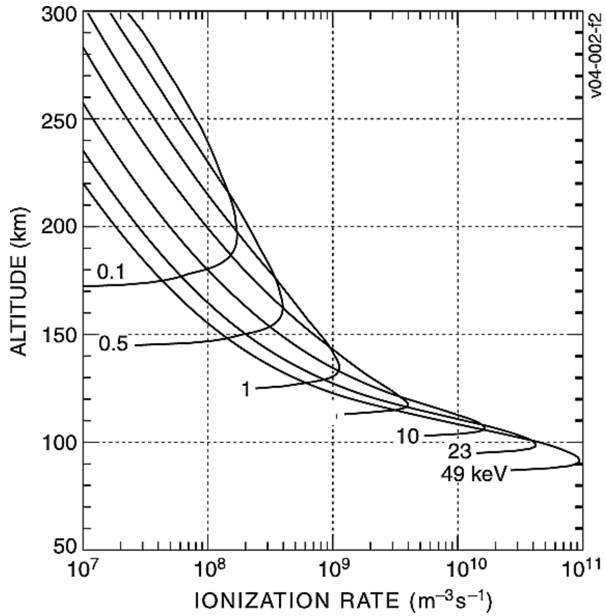


Poleward arc ionization approached very close to the equatorward arc

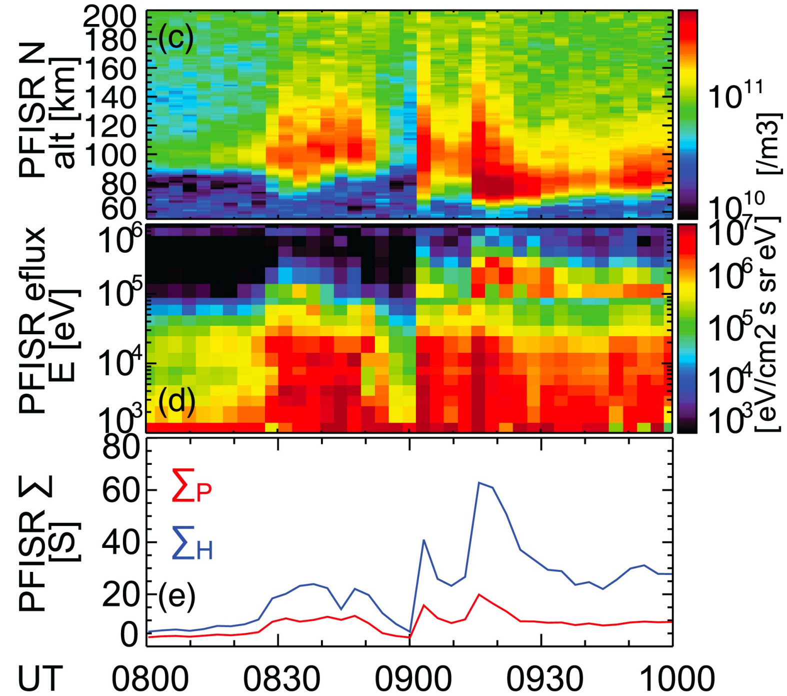
Equatorward/westward flows penetrating across the PBI arc and reach the growth phase arc

Radar data give continuous coverage of density and fast flows from the polar cap, reaching the near-Earth plasma sheet prior to substorm onset.
Other means of measurements do not provide such a resolution.

Deriving M-I-T coupling quantities: Precipitating flux and conductance



[Semeter and Kamalabadi, 2005]



[Nishimura et al., 2020]

Particle precipitation increases the ionospheric density.

$$\sigma_P = \frac{n_e \cdot e}{B}\left(\frac{k_e}{1+k_e^2} + \frac{k_i}{1+k_i^2}\right)$$

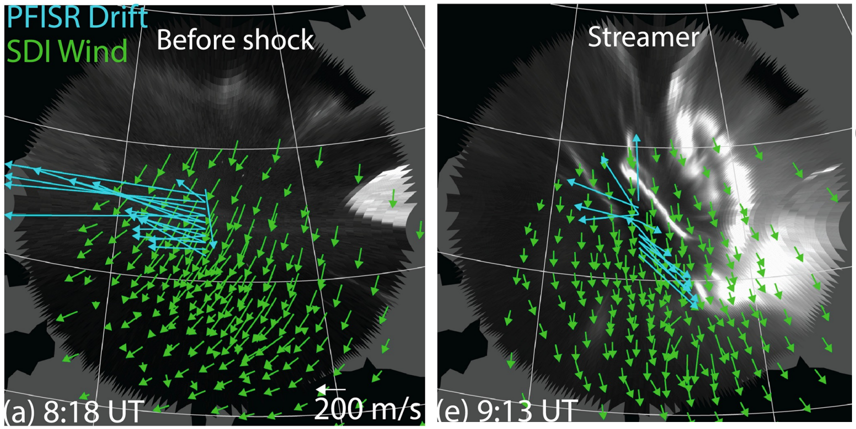
$$\sigma_H = \frac{n_e \cdot e}{B}\left(\frac{k_e^2}{1+k_e^2} - \frac{k_i^2}{1+k_i^2}\right)$$

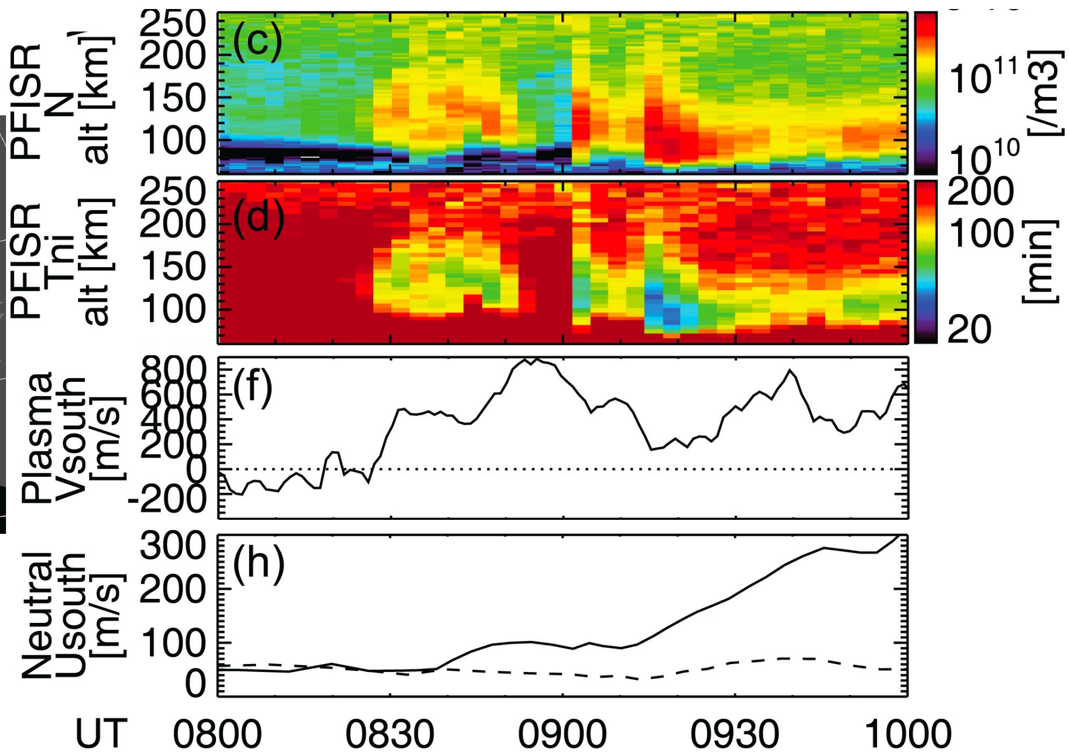
$$k_i = \Omega_i / \nu_{in} \quad k_e = \Omega_e / \nu_{en}$$

PFISR can specify the precipitating electron flux and conductance.

Relativistic (MeV) electron precipitation and large conductance increase were seen during a large substorm.

Deriving M-I-T coupling quantities: Ion drag time scale





$$\frac{\partial \boldsymbol{u}}{\partial t} = \nu_{ni}(\boldsymbol{v} - \boldsymbol{u}) + \cdots$$

$\boldsymbol{v}$: Plasma velocity

$\boldsymbol{u}$: Neutral velocity

ν_{ni}: neutral-ion collision frequency

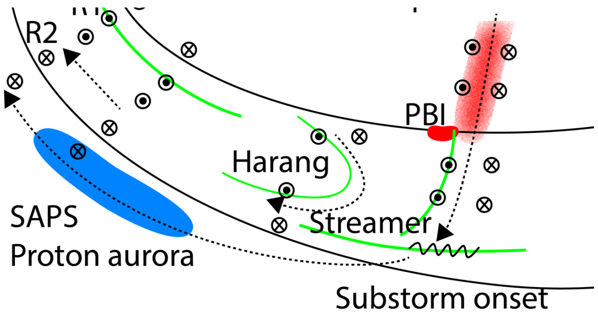
$1/\nu_{ni}$ gives ion-neutral coupling time scale by the ion drag force.

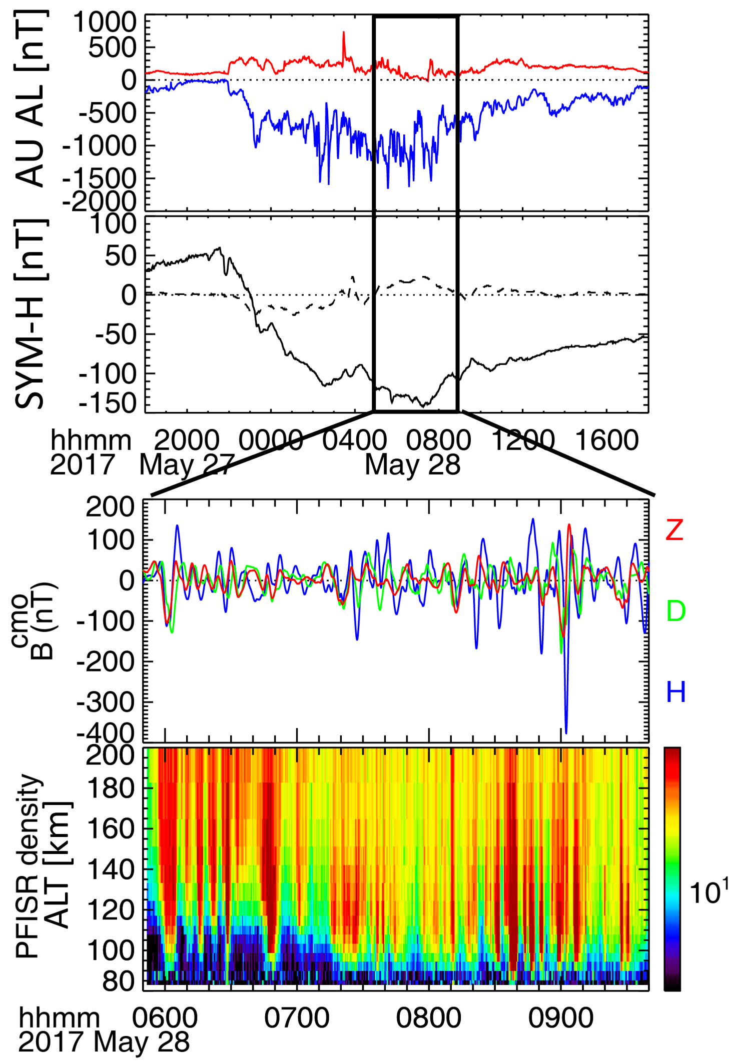
Enhanced plasma density decreases the coupling time scale.

The neutral wind is rapidly accelerated due to the tighter ion-neutral coupling.

Periodic modulation of the ionosphere during a storm: ULF waves

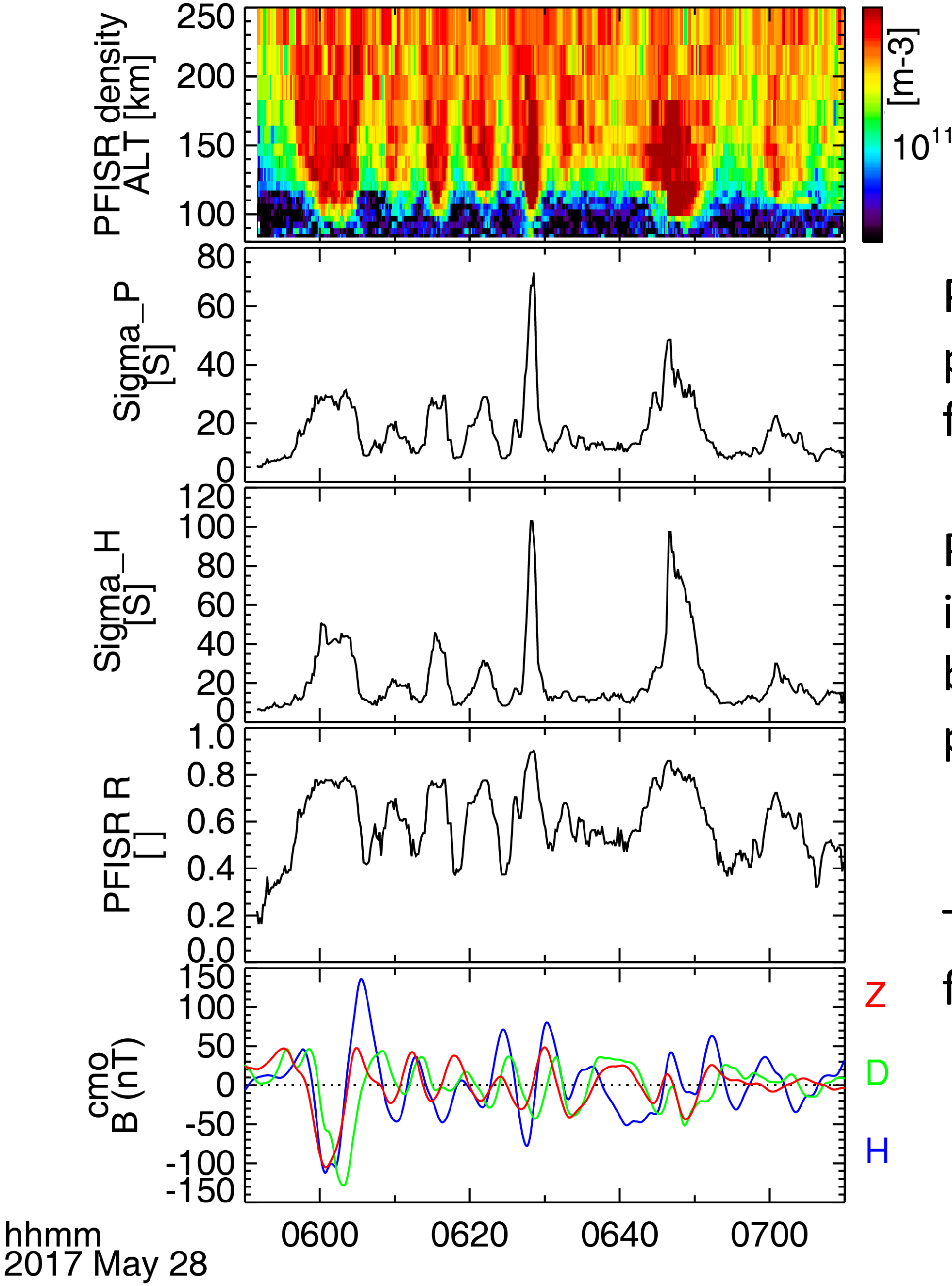
ULF: Ultra low frequency waves (1-10 min period)





[Wang et al., 2020]

Periodic modulation of the ionosphere during a storm: ULF waves

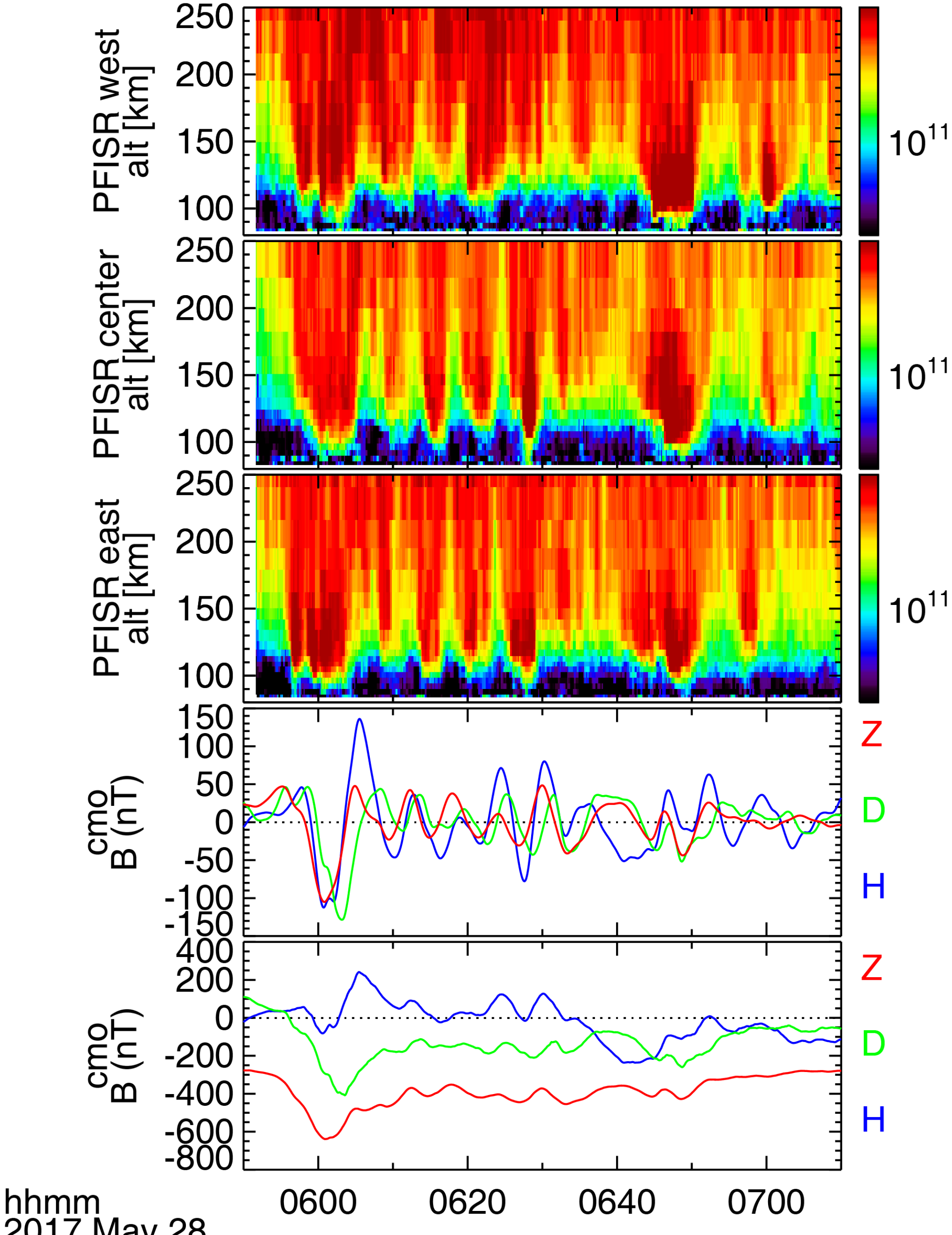


Precipitation correlates to –H perturbation of local ground magnetic field

Pedersen and Hall conductances increasing >3 times higher than the background due to ULF-modulation of precipitation

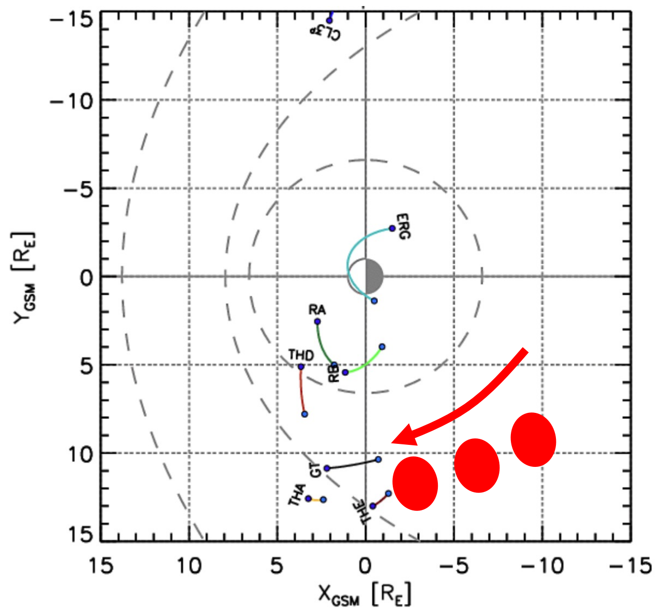
The reflection coefficient increasing from 0.4 to 0.8 during precipitation

Periodic modulation of the ionosphere during a storm: ULF waves

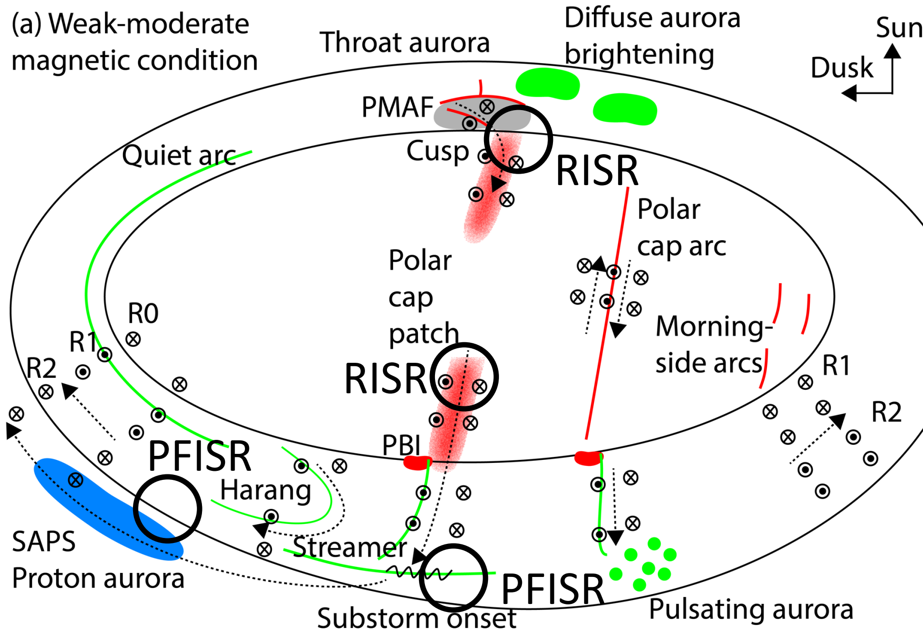


Ionosphere
2.6 km/s westward propagation
770 km azimuthal wavelength
m number = 52

Magnetosphere
56 km/s westward propagation
2.5 RE azimuthal wavelength



Summary



ISRs are powerful facilities for identifying properties of meso-scale plasma structures in the ionosphere.

ISR observations are critical for determining 3-d density structures. They can also provide additional quantities such as precipitating electron flux, conductivities, and ion-neutral coupling time. Velocity and temperature observations are important for identifying localized flow structures and plasma boundaries.