European interests in GDC science: synergy, science and lessons

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Scientific synergies with GDC

Global causes and consequences of solar wind-magnetosphere-ionosphere-thermosphere coupling

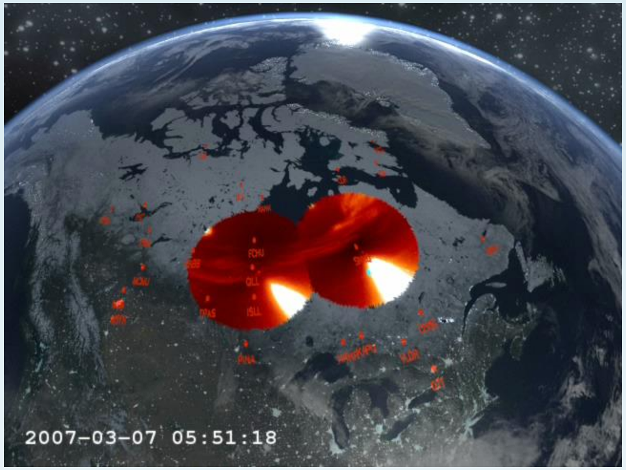
- Local reconnection creates global consequences
- Large-scale energy transfer via EM waves
- Field-aligned currents

Time dependence and localization

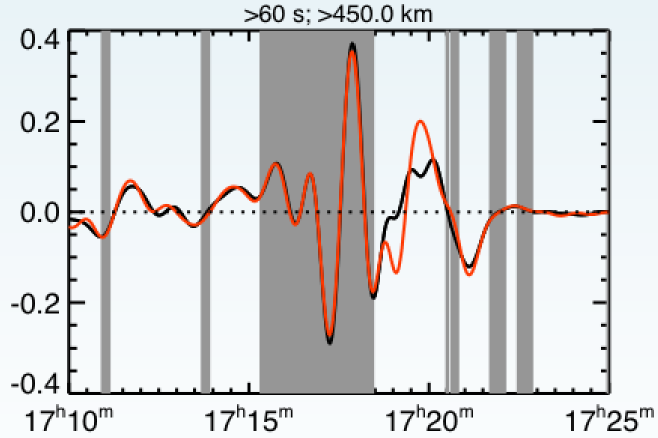
- Explosive energy release in substorms
- Auroral Acceleration

The interchange between the magnetosphere and thermosphere through the ionosphere

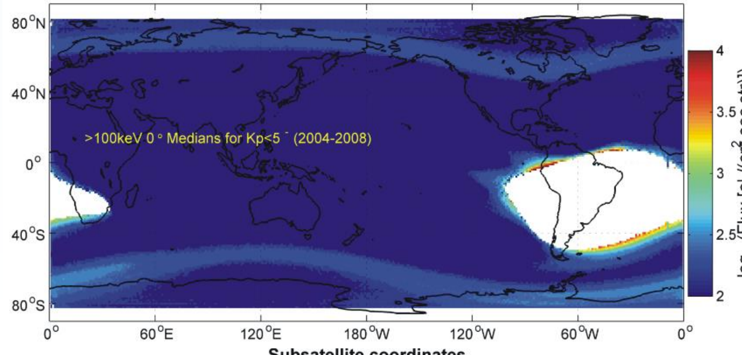
- Storm-time dynamics
- Energetic particle precipitation
- Thermospheric driving



Rae et al. [2009]

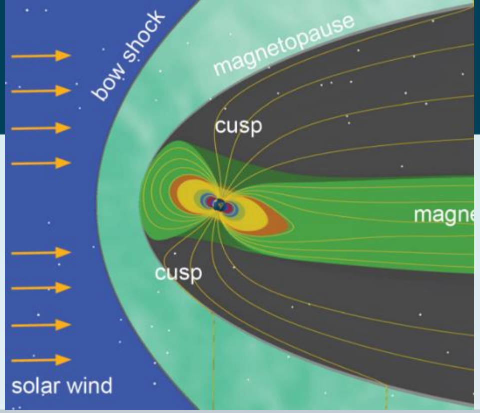


Forsyth et al. [2017]



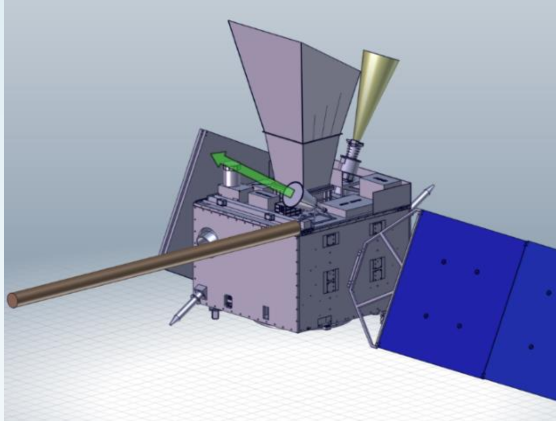
Rodger et al. [2013]

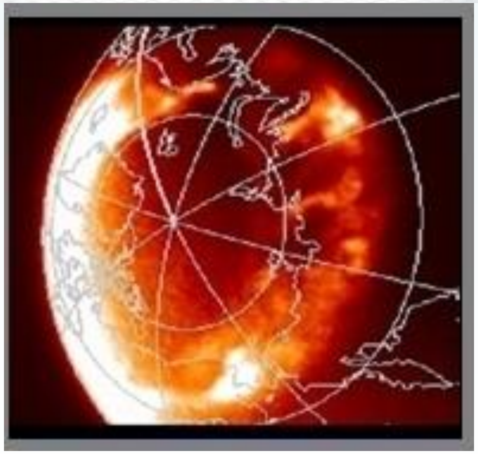
Solar wind Magnetosphere Ionosphere Link Explorer (SMILE)

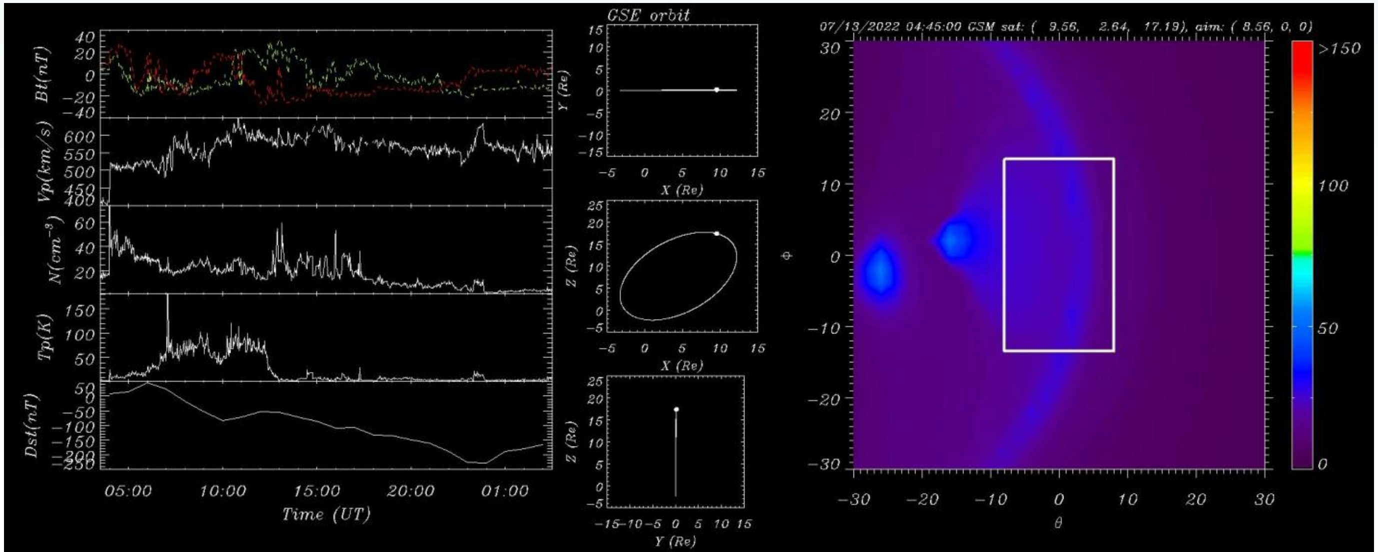


Co-PI: Graziella Branduardi-Raymont (MSSL)

- ESA/CAS with 2023 launch to study the global scale dynamic response of the magnetosphere to solar wind variability
- **Soft X-ray Imager** to *image* the solar wind driving
- **In situ package for solar wind and IMF**
- **UV global auroral imager for** magnetospheric dynamics



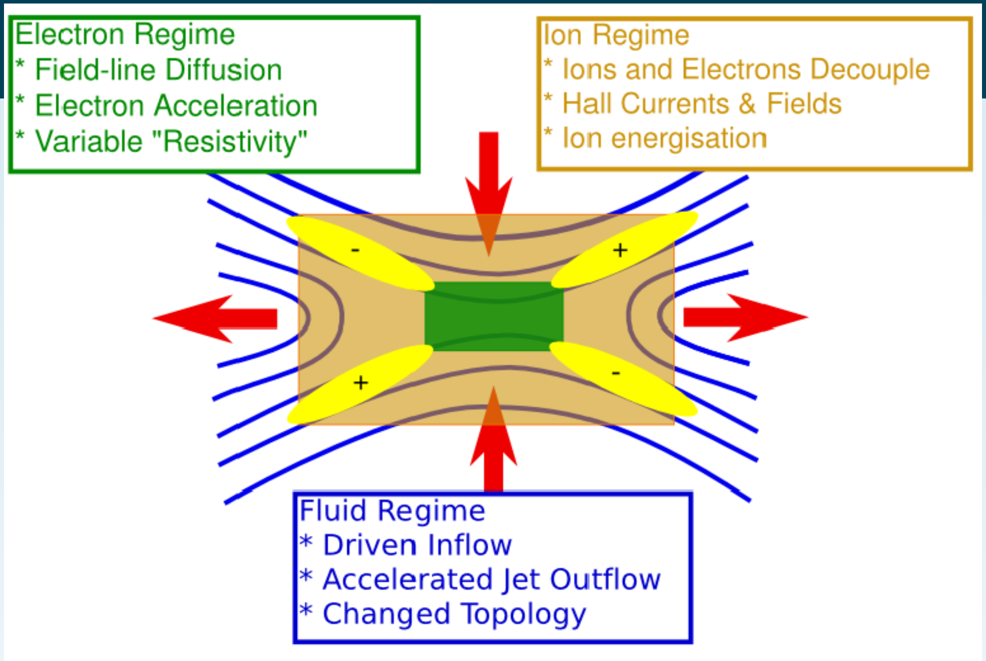


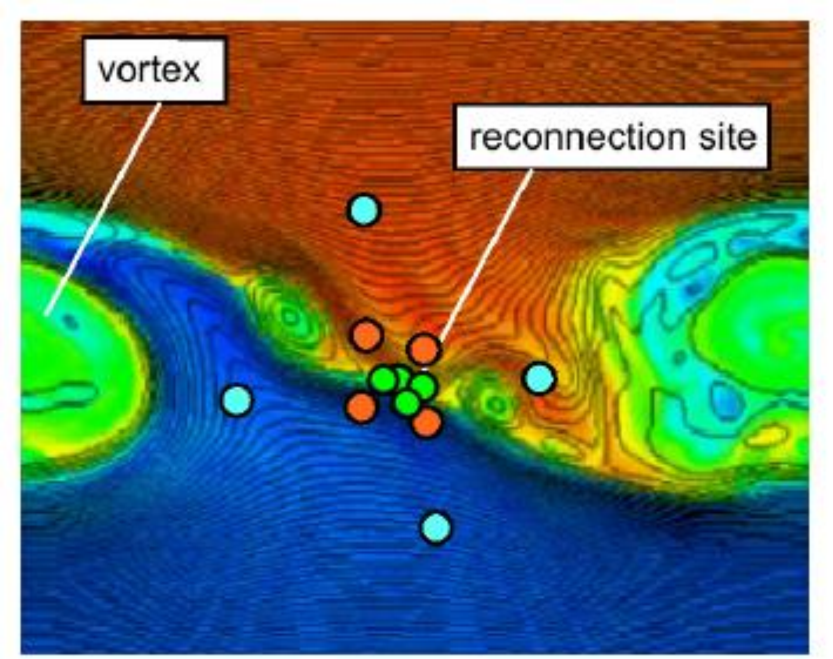


Local process with global consequences: Direct and Indirect energy transfer

- THEMIS fluid scales
- Cluster ion scales
- MMS electron scales

- We need to understand energy transfer with global context

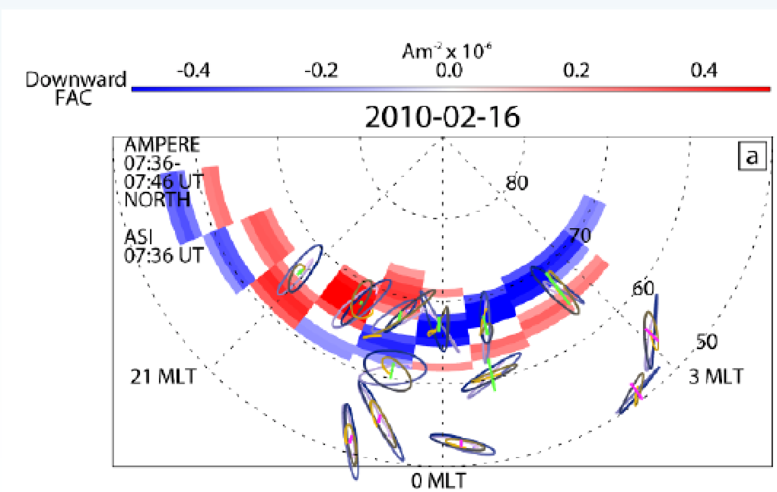




Courtesy: S. Schwartz, cross-scale team

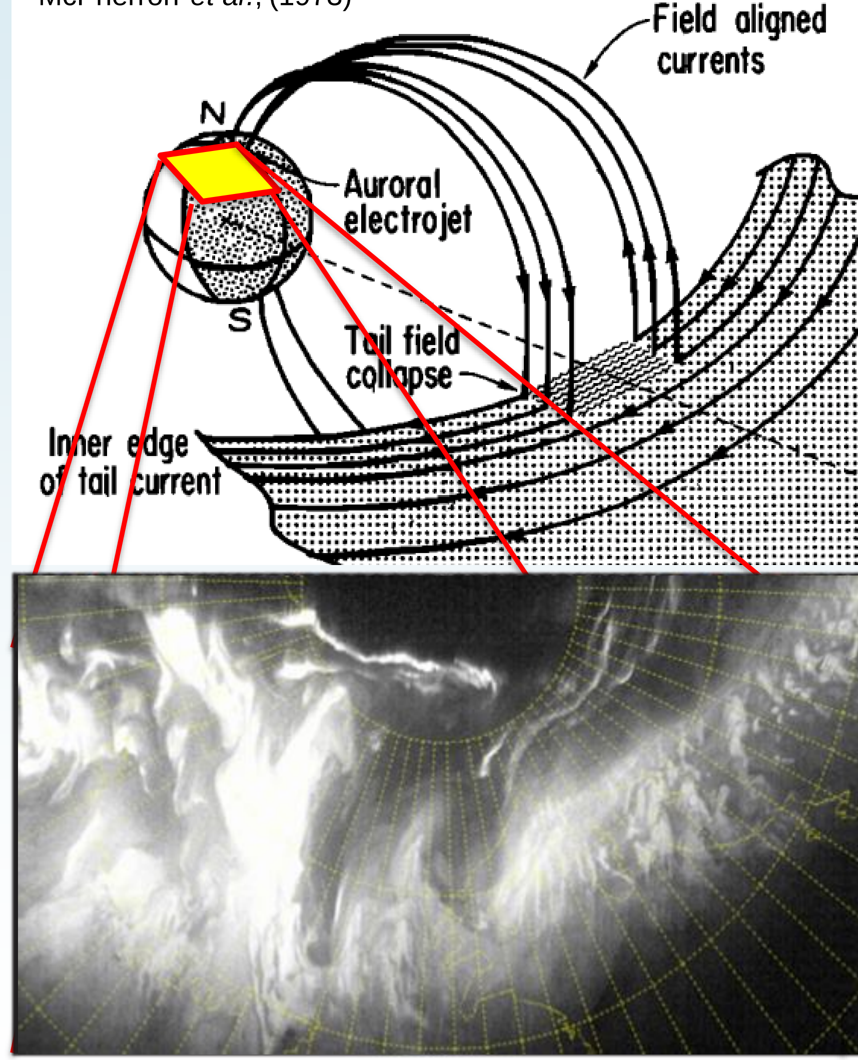
Large-scale field-aligned currents: the substorm example

- Understanding the coupling of the magnetosphere to the ionosphere remains an outstanding issue
- And one we are only beginning to understand



Murphy et al. [2013]

McPherron *et al.*, (1973)

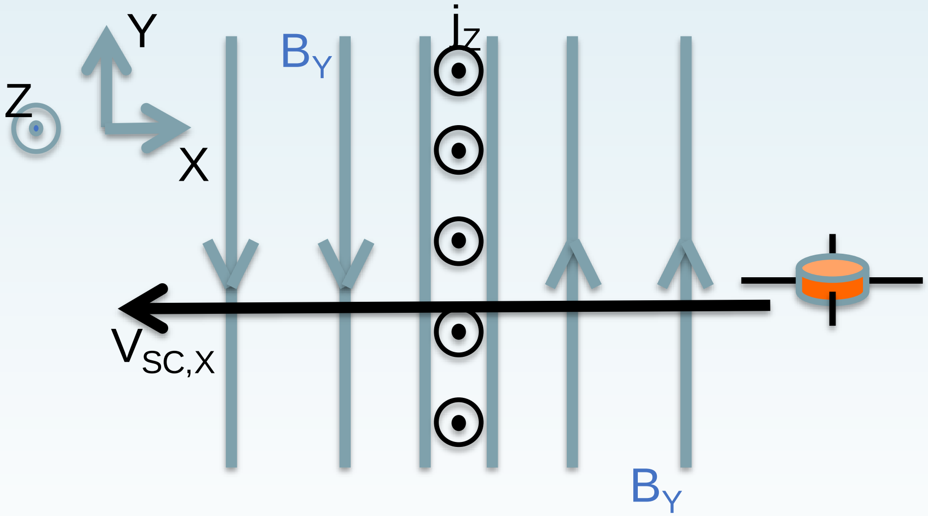


Gjerloev & Hoffman (2002)

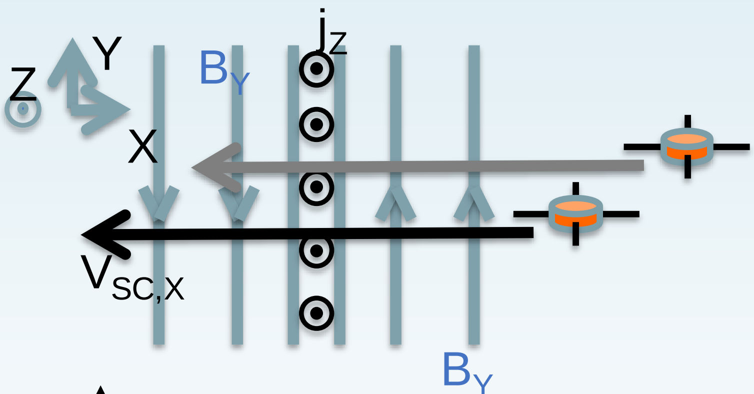
Courtesy: DMSP/NOAA. Note that this data is not coincident with the statistical Gjerloev & Hoffman (2002) map

Single spacecraft FAC assumptions

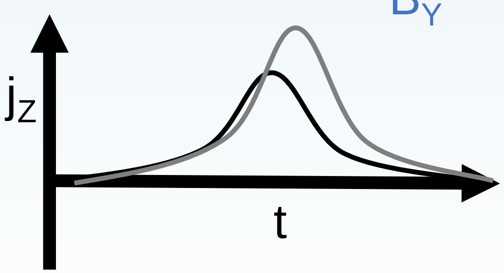
- For a sufficiently large current sheet, Ampère's law can be simplified to
$$-\frac{\partial B_Y}{\partial x} = \mu_0 j_z$$
- Perturbation field is from FAC only
- Current is sheet-like and field perturbation is in one component
- Spacecraft passes normally through current sheet
- Current does not move, rotate or change amplitude during crossing

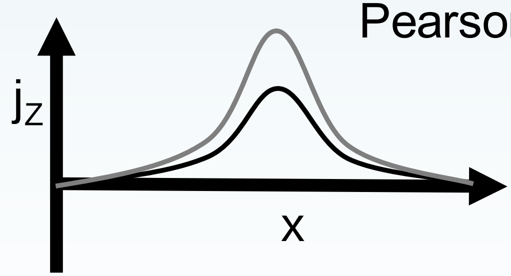


Lessons learned from Swarm: when are our assumptions violated?

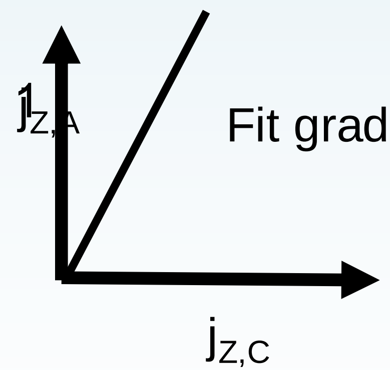


Cross-scale coupling provides driving and feedback

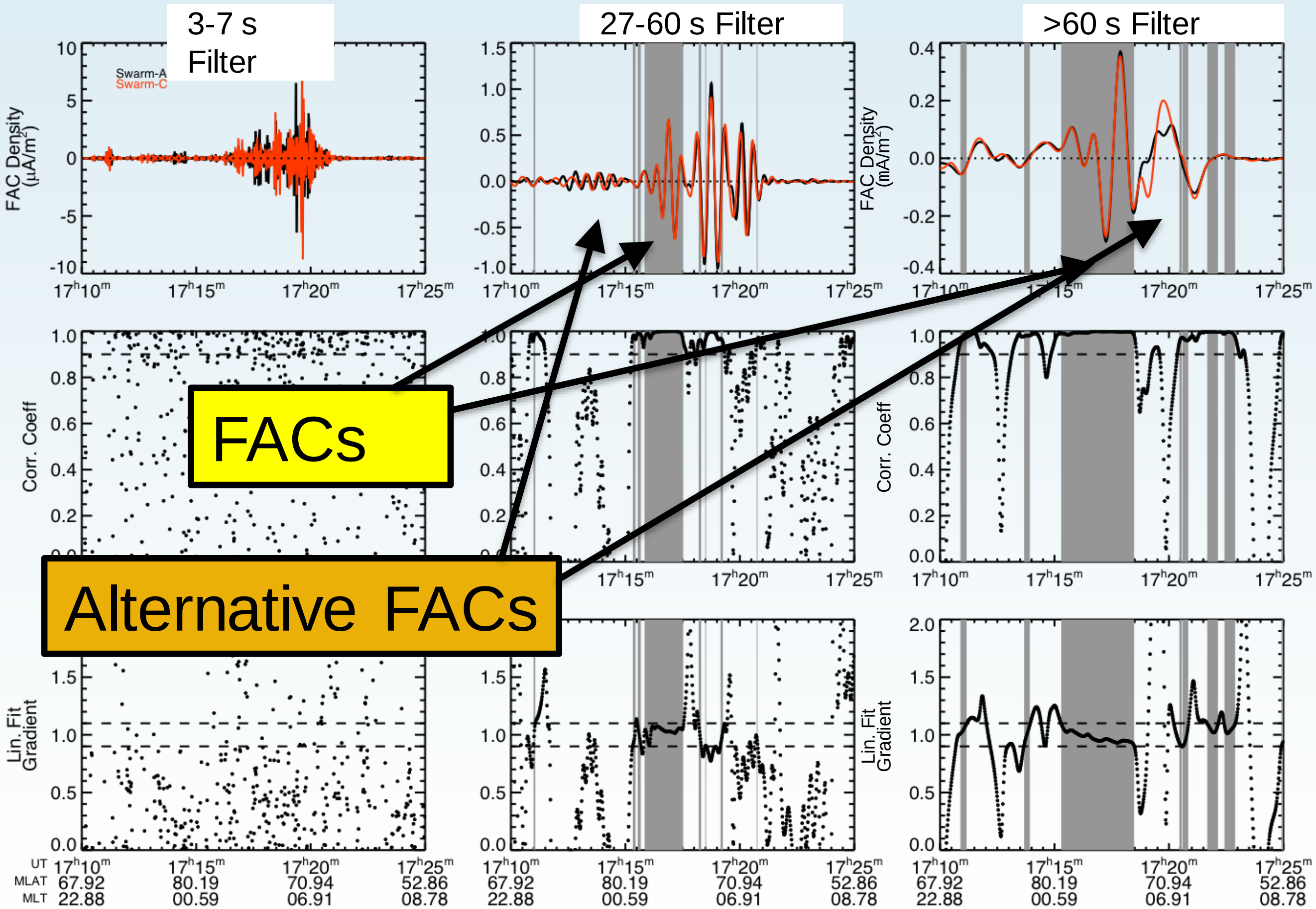




Pearson's r = 1

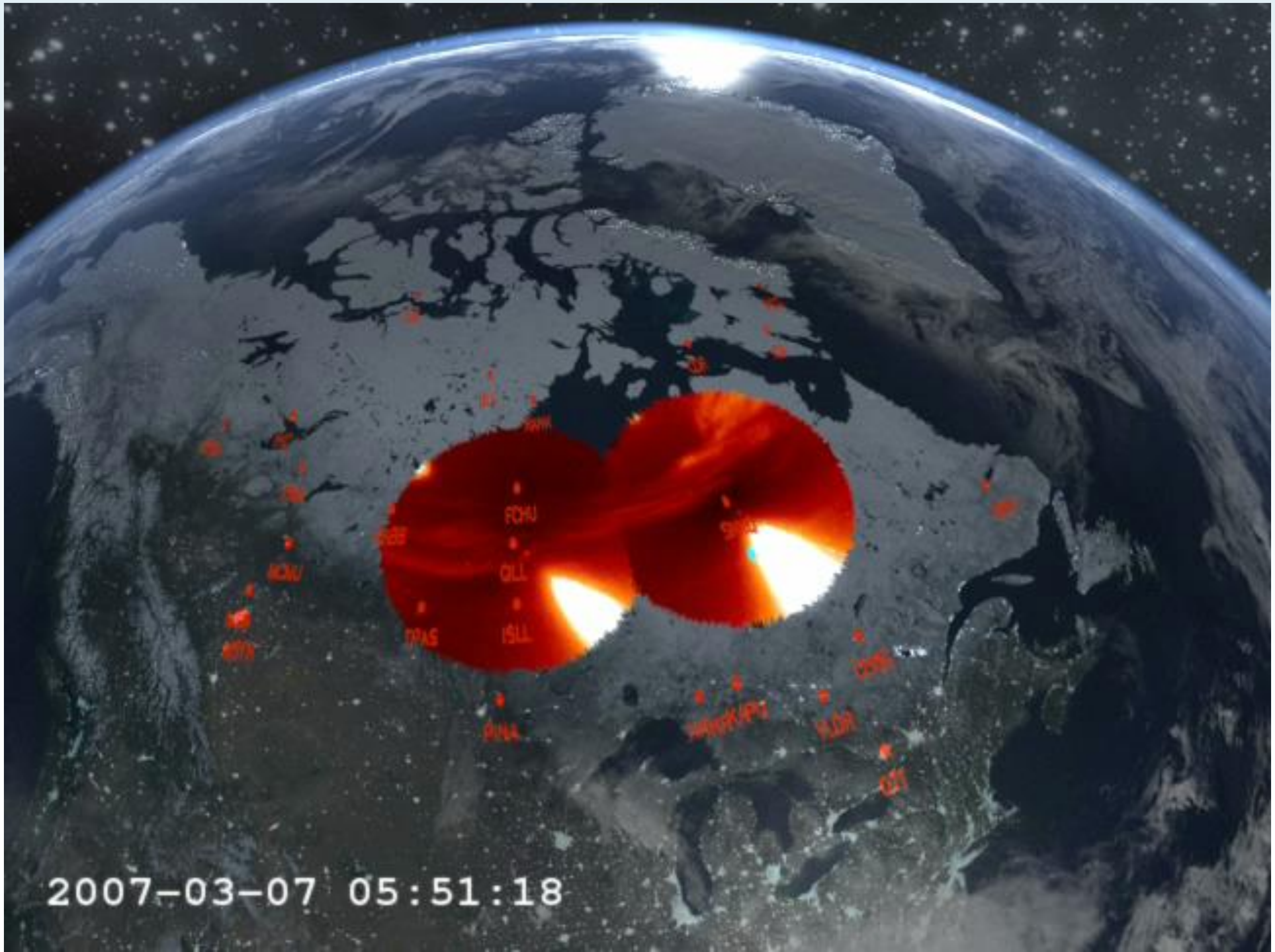


Fit gradient > 1



Forsyth et al. [2014]

The magnetospheric substorm: explosive energy release into the ionosphere

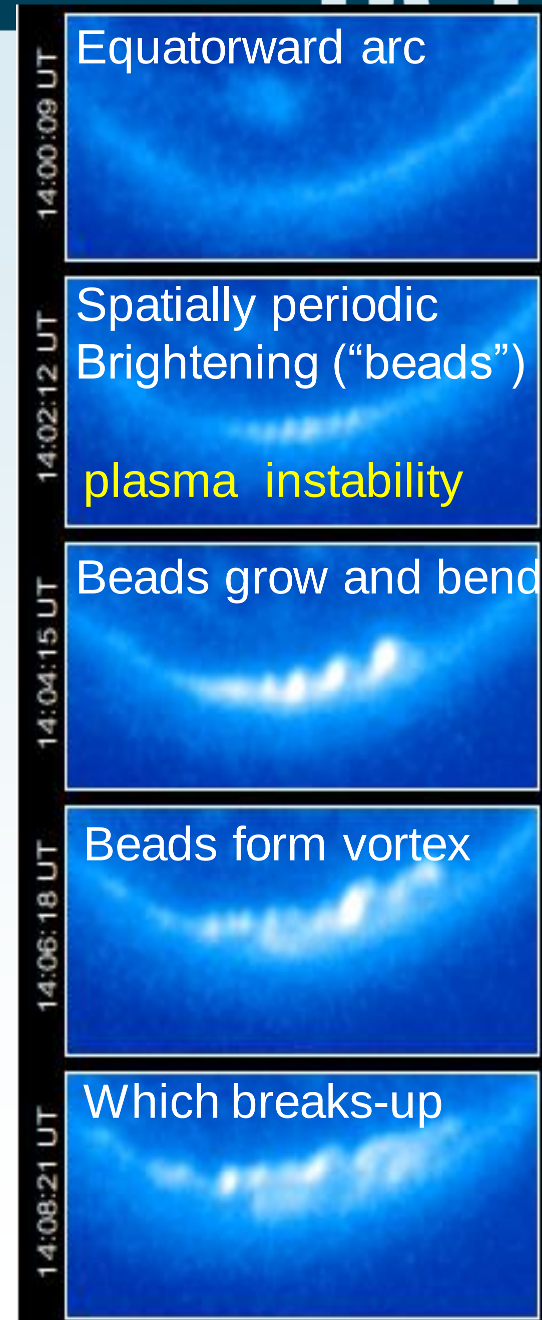


Rae et al. [2009]

Primary: Diagnosing substorm auroral acceleration

- From ground measurements, we have shown that substorm onset starts with auroral and magnetic waves
  - Same time, same place,same frequency, same characteristics
- We know the particle characteristics of wave-driven auroral acceleration

- Require observations of aurora with simultaneous particle measurements of the precipitating electrons (and ions) that cause it

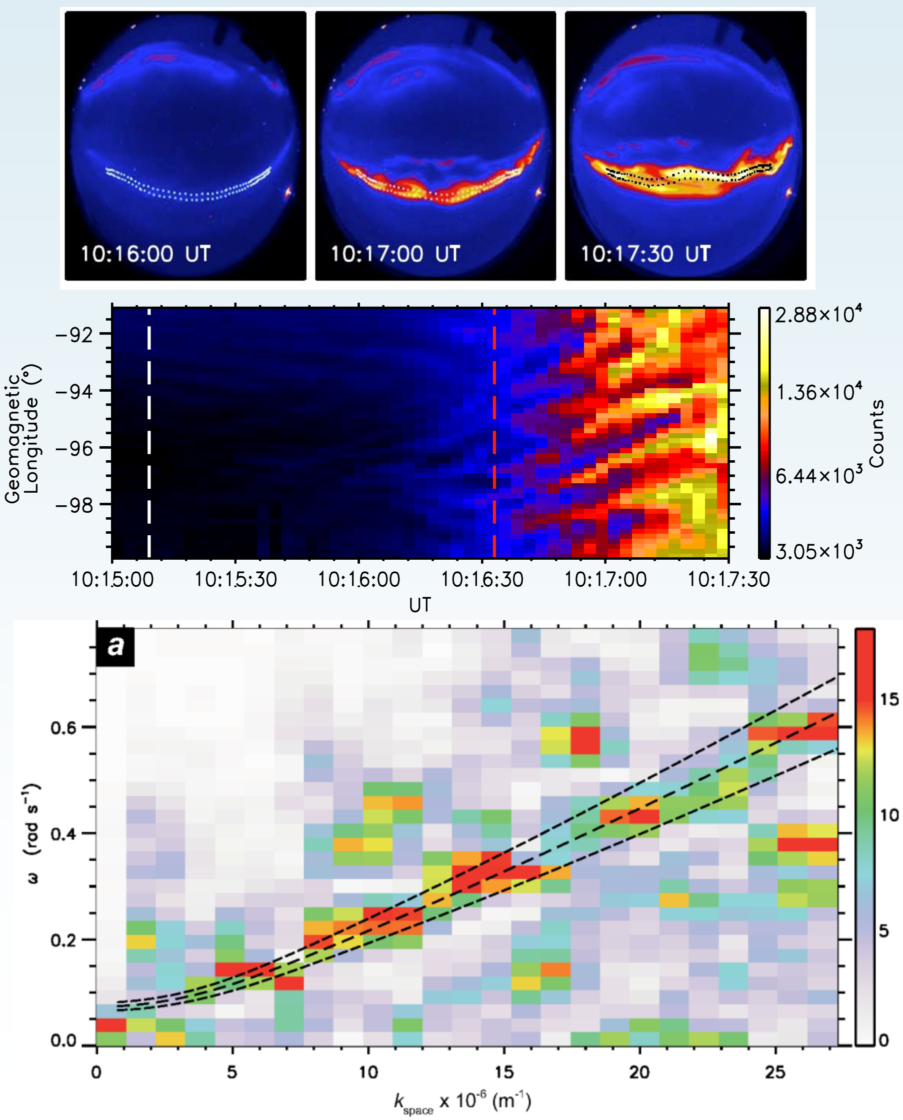


Henderson et al. [2009]

Substorm physics from the ground and lessons

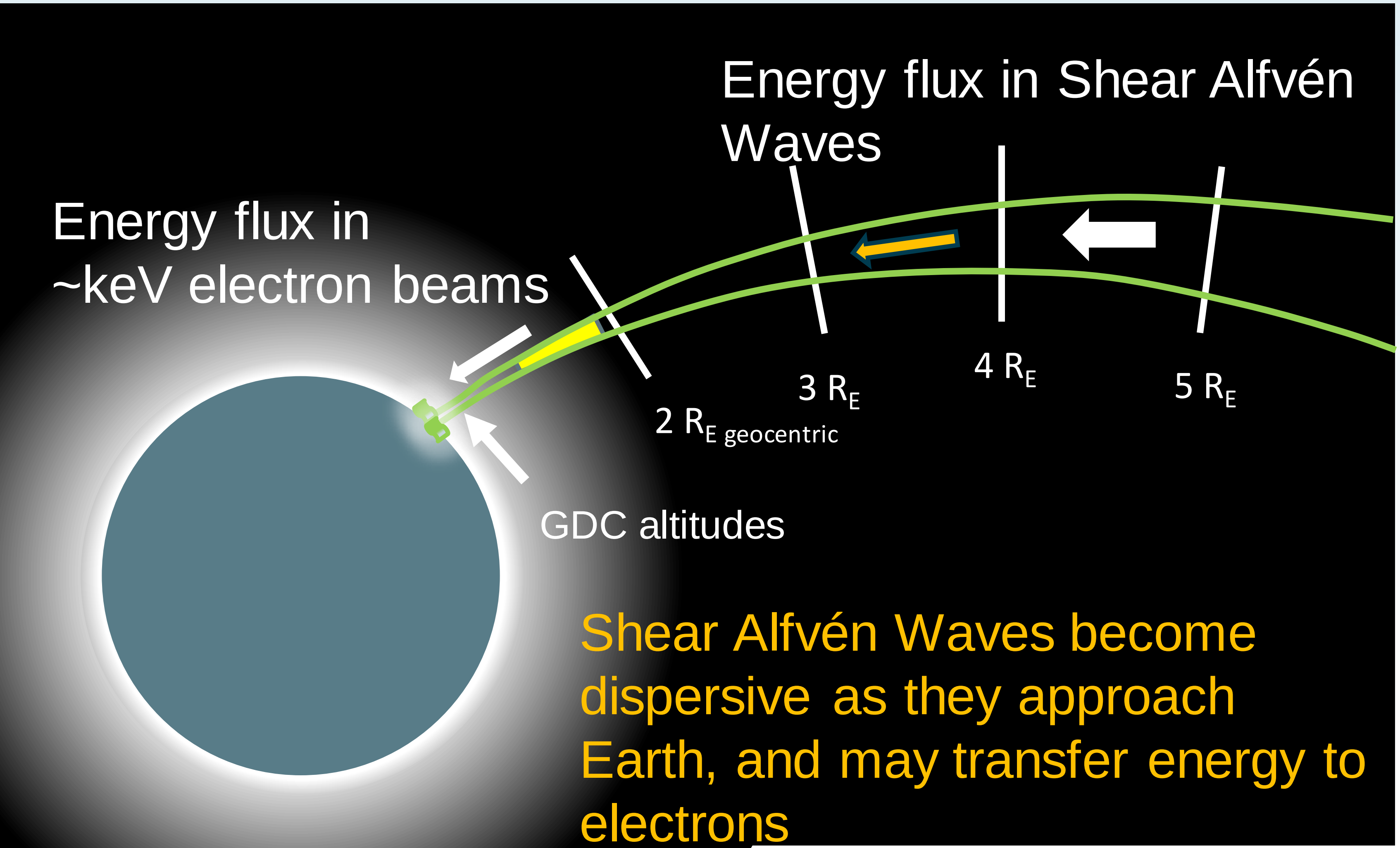
- One of the great successes of the THEMIS mission is the clear ground-based component that puts spacecraft into context

- But also provides new insight into magnetospheric processes!



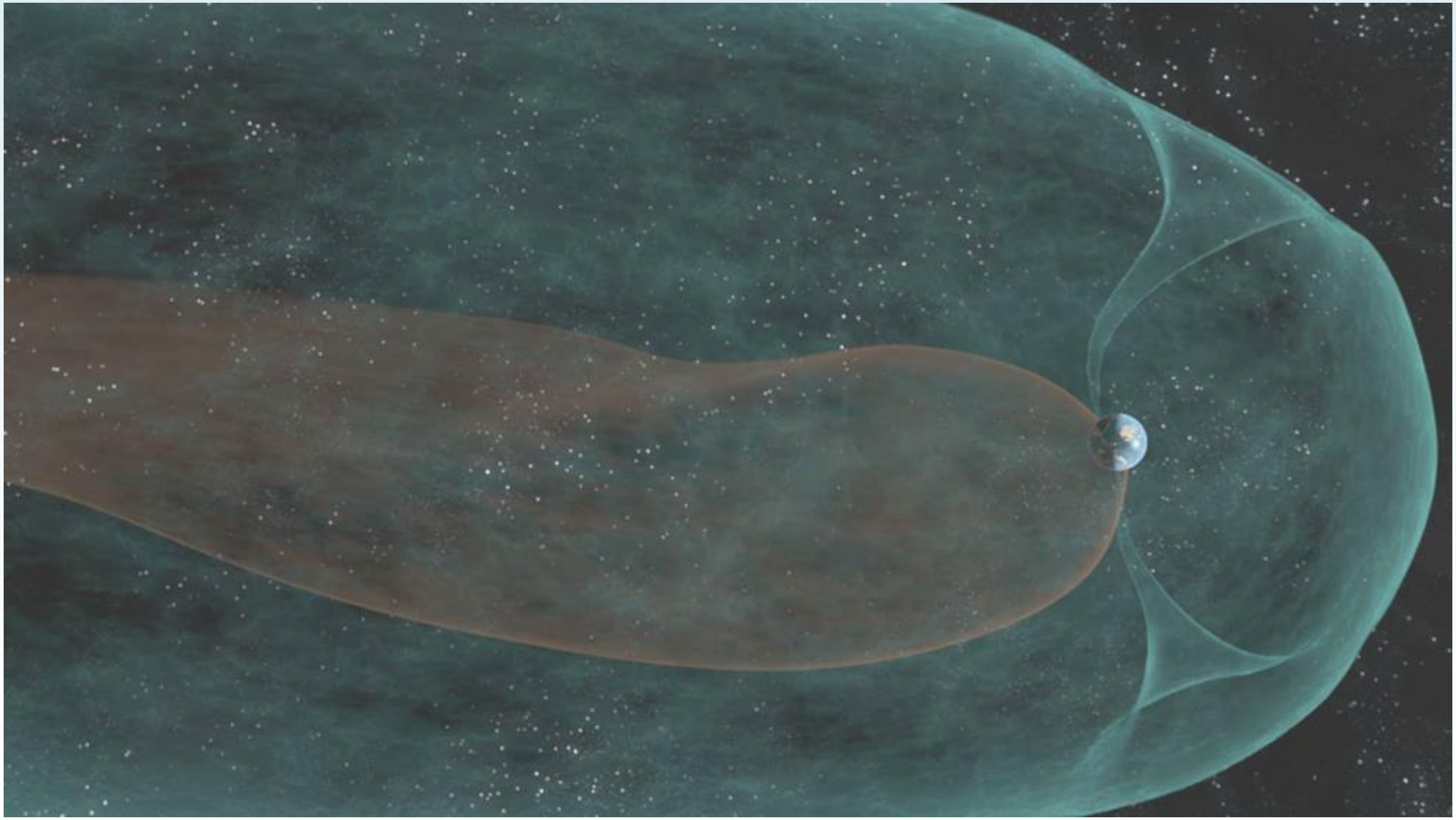
Kalmoni et al. NatComms [2018]

Distinguishing between drivers - Alfvén wave driven aurora



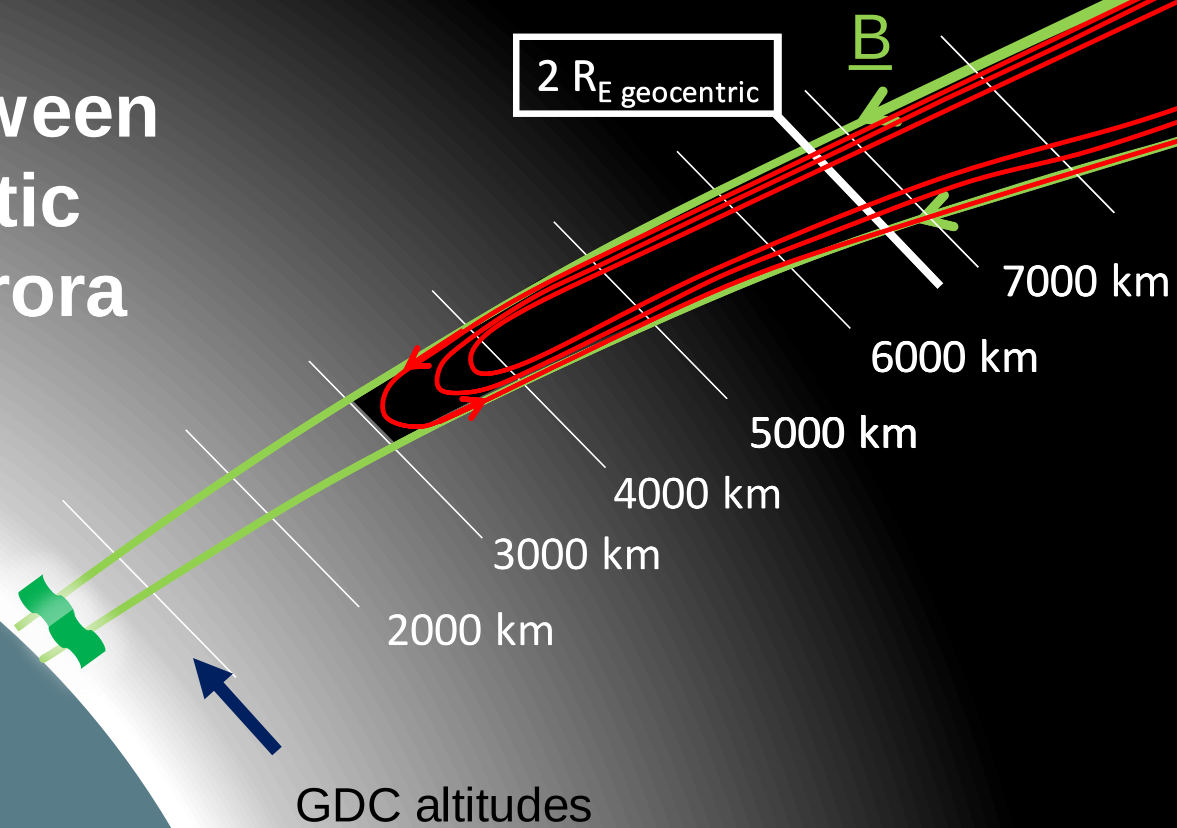
Shear Alfvén Waves become dispersive as they approach Earth, and may transfer energy to electrons

Wave-driven acceleration



Courtesy: Andy Kale

Distinguishing between drivers – Quasi-static potential driven aurora



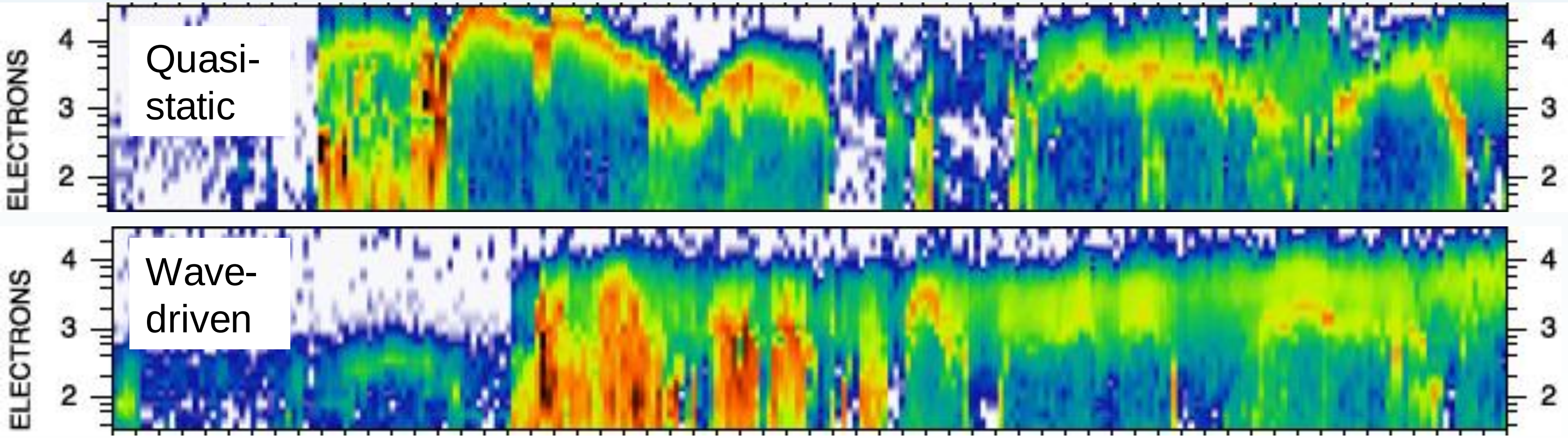
Dense ionosphere
< 300 km

Auroral density cavity: 3-6,000 km

Quasi-static electric potential structures linked to density cavity

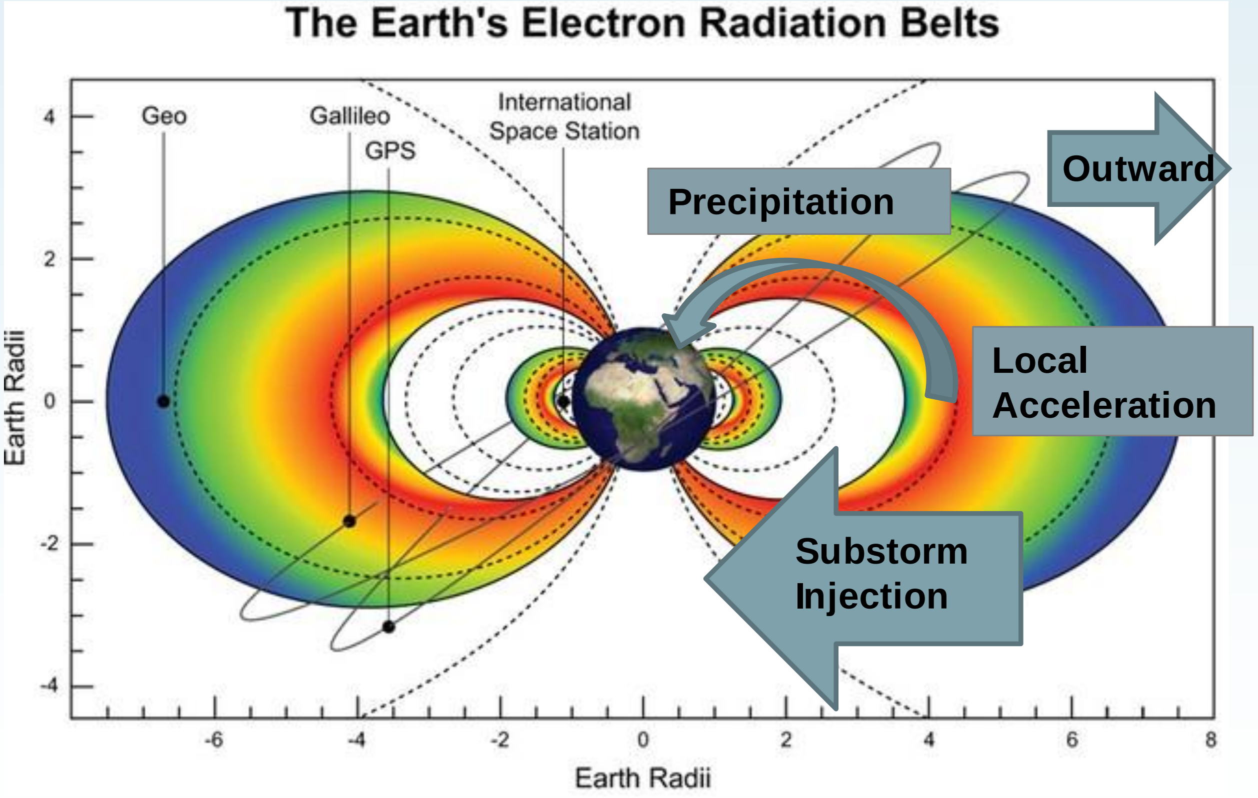
Distinguishing between auroral drivers

- Quasi-static potential drops
  - mono-energetic electron acceleration
- Shear Alfven Waves
  - broadband electron acceleration



Newell et al. [2009]

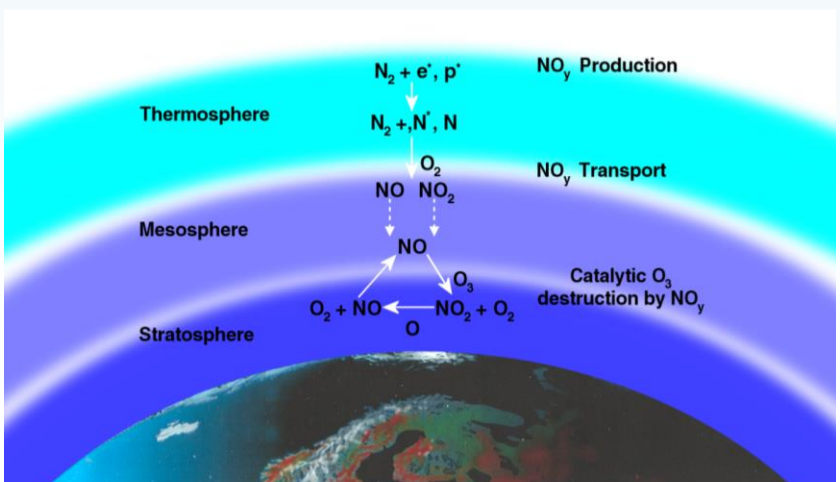
Energetic Particle Precipitation: where do electrons go?



Horne [2007], *Nature Physics*

The importance of energetic particle (EPP) precipitation on atmospheric chemistry

- Understanding a 60 year physics problem
- Understanding the natural variation in global temperatures
- Understanding the role of EPP in the destruction of ozone
- EISCAT 3D



Particle precipitation

↓

Production of NO_x and HO_x

↓

Destruction of mesospheric and upper stratospheric O_3

↓

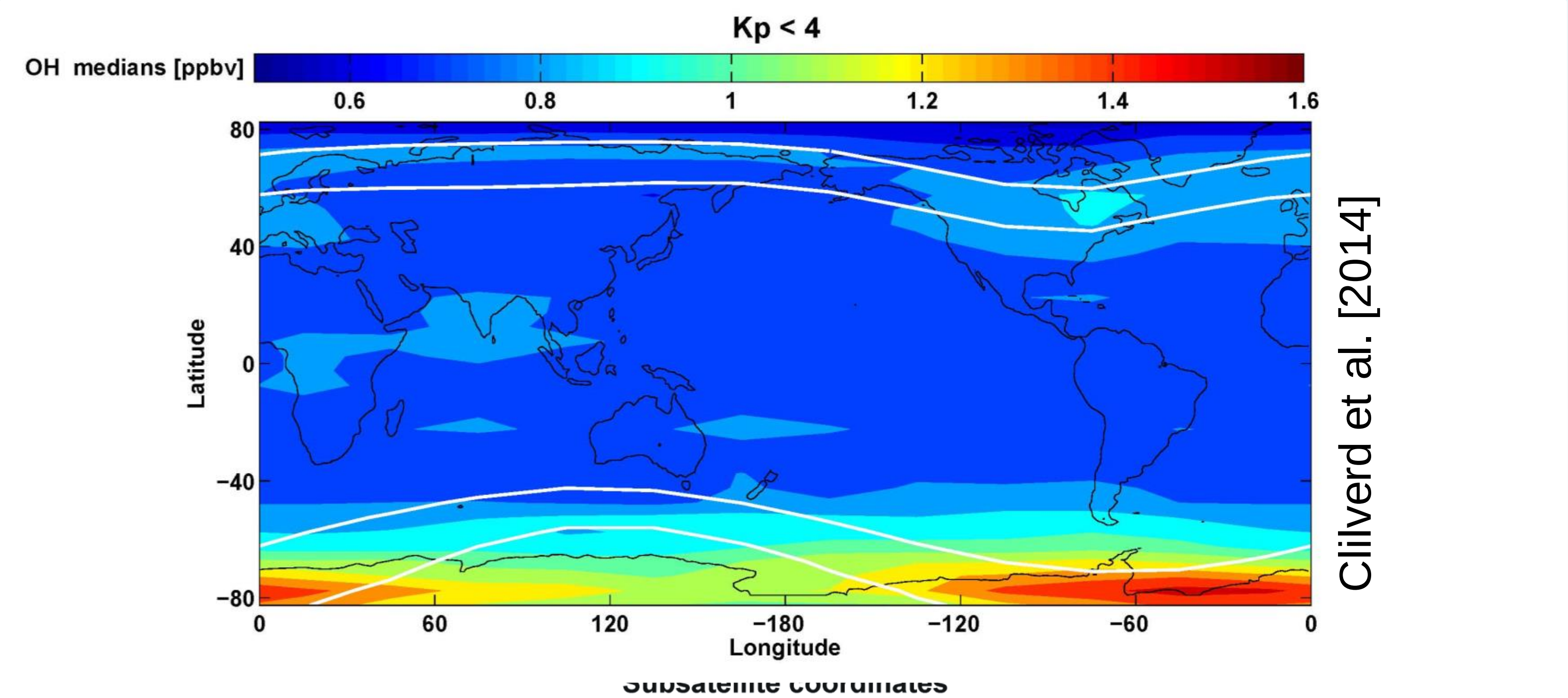
Change in dynamics mesosphere & <u>stratosphere</u>

↓

Implications for Climate

In-situ EPP and HOx measurements

- NOAA POES measurements usually used to estimate particle precipitation
- ~835 km Sun synchronous orbit
- Numerous approximations required for scientifically useful data
- Close relationship between EPP and HOx
- Input into chemistry climate models reveal surface temperature redistribution through EPP

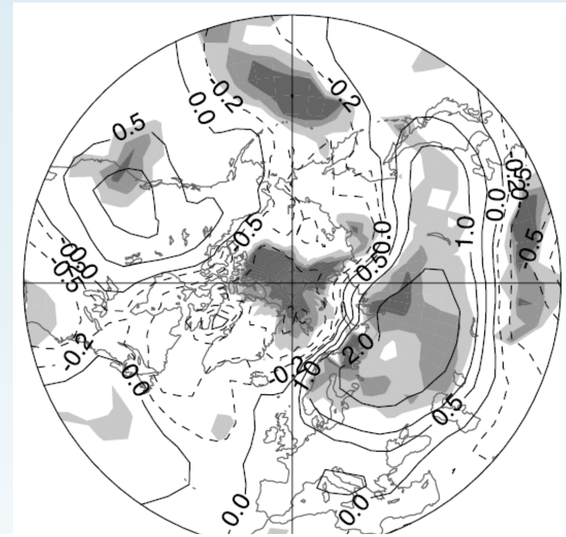


Clilverd et al. [2014]

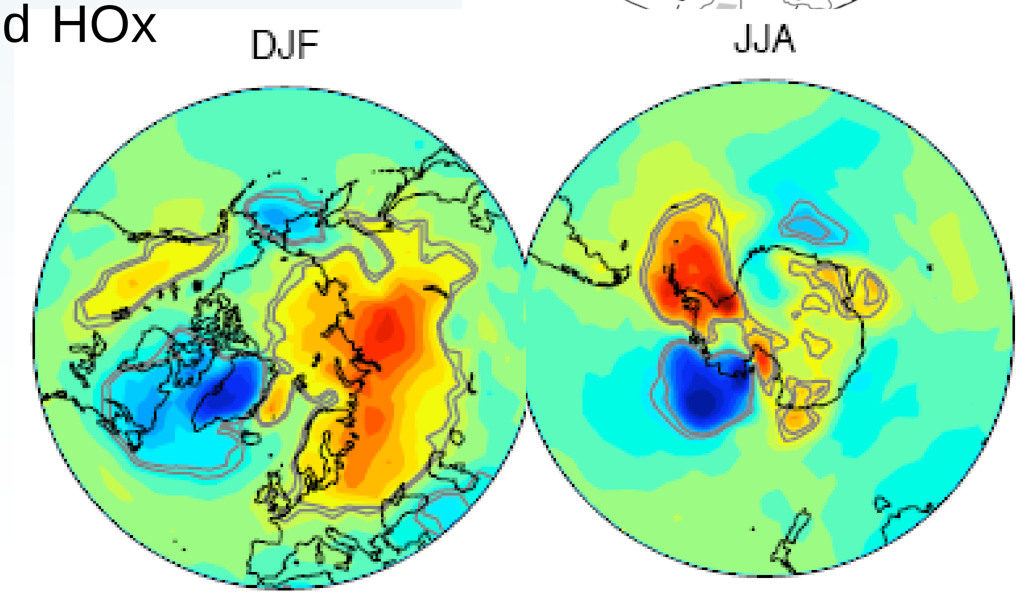
Energetic Particle Precipitation and Polar Surface temperatures

- Chemistry Climate models show that when EPP are included, surface temperature variations of -0.5 to +2 K, relative to the no precipitation case.

- Experimentally verified during the winter months when NOx and HOx are long-lived



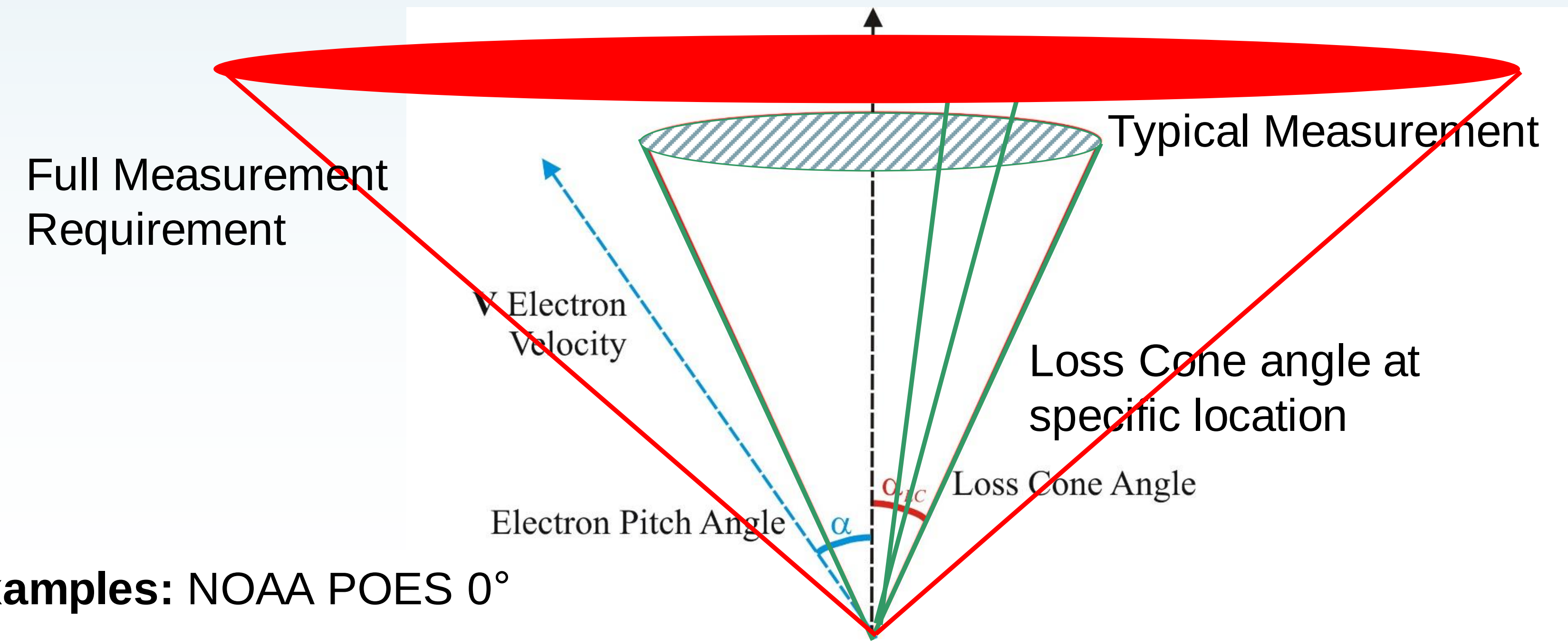
Rozanov et al. [2005]



Seppälä et al. [2009]

Secondary: Particles inside the loss cone

- All* currently flying instruments measure only a small fraction of precipitation, and assume symmetry
- Able to only measure ***strong*** precipitation events
- Weak precipitation thought to be ***crucial***



Examples: NOAA POES 0°

Courtesy: Craig Rodger

Feedback on magnetospheric dynamics

- Reconnection, energy loading and electromagnetic wave penetration and radiation belt morphology
- Don't forget EISCAT 3D