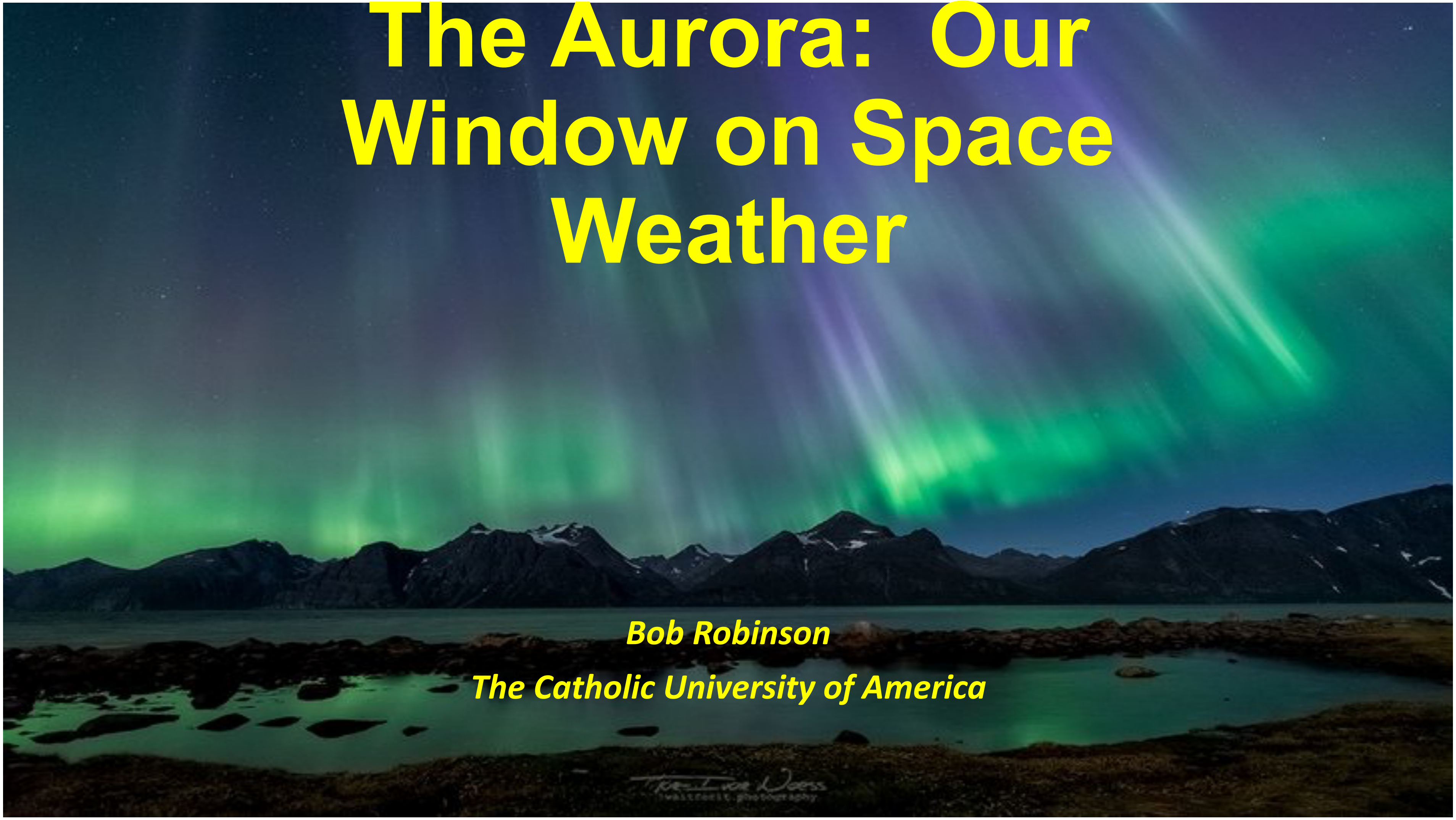
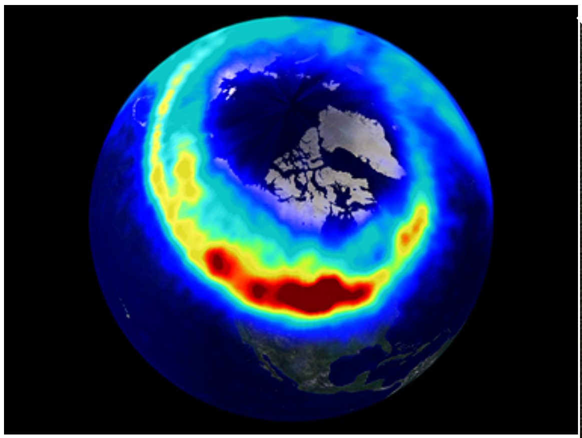


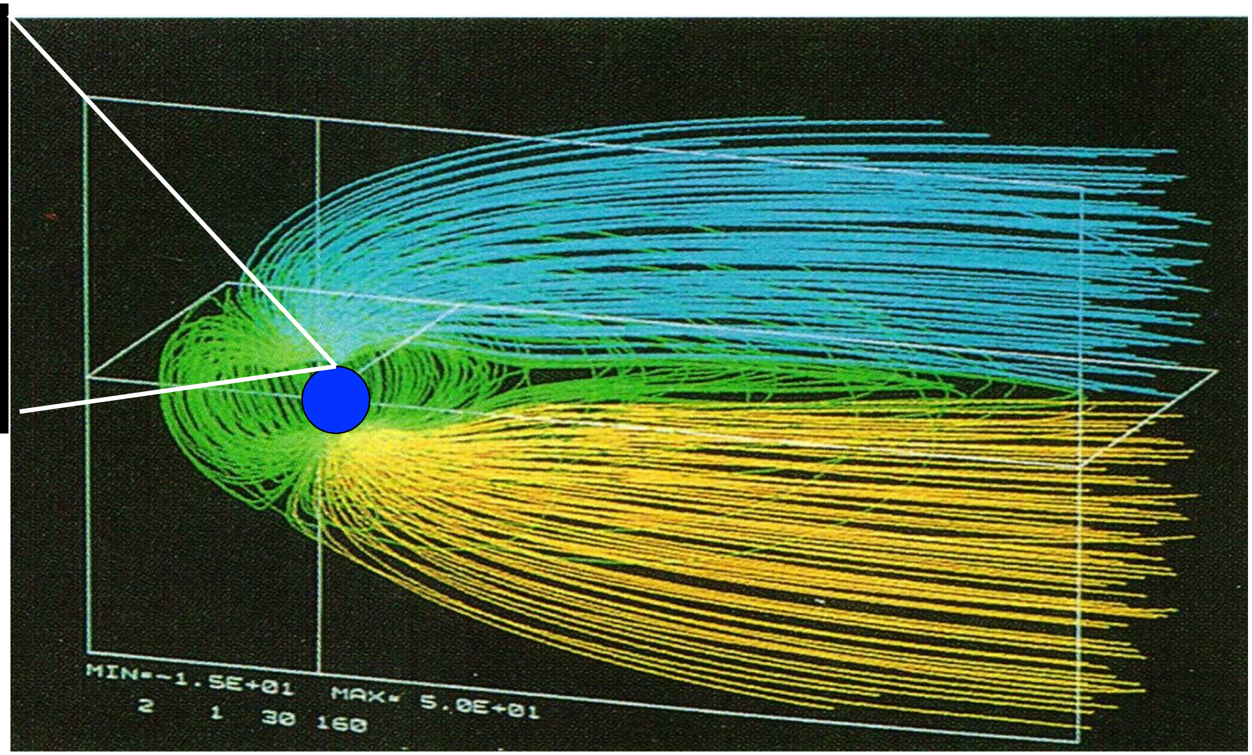
The Aurora: Our Window on Space Weather

Bob Robinson

The Catholic University of America

The aurora allows us to ‘see’ the magnetosphere and observe geospace processes





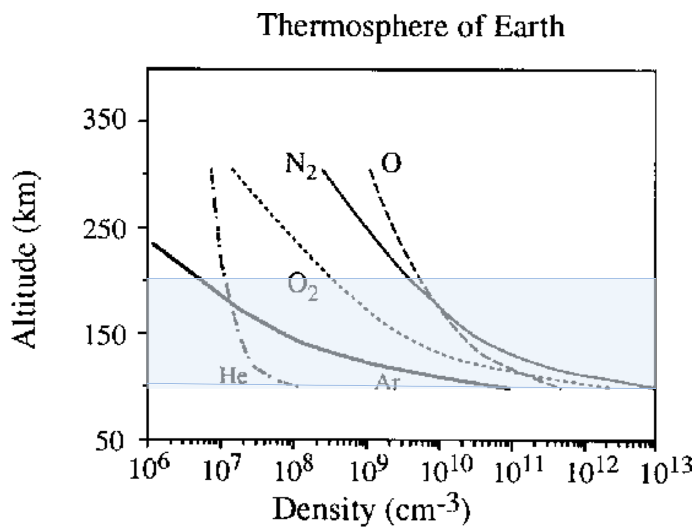
The magnetosphere is threaded by magnetic fields, which very quickly and efficiently transfer information along the length of the field lines

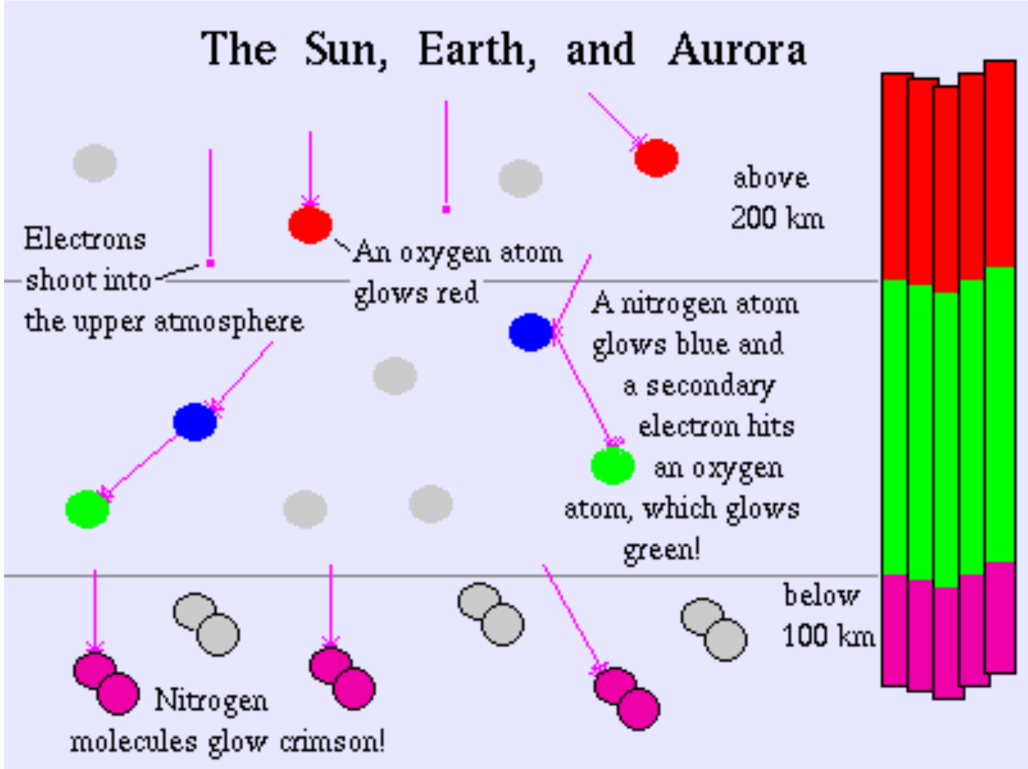
Decoding the Aurora

What can the properties of the aurora tell us about the magnetosphere, the geospace system, and space weather?

- Ionospheric effects
  - Light
  - Electron Density
- Motion
- Electrical Properties
- Morphology

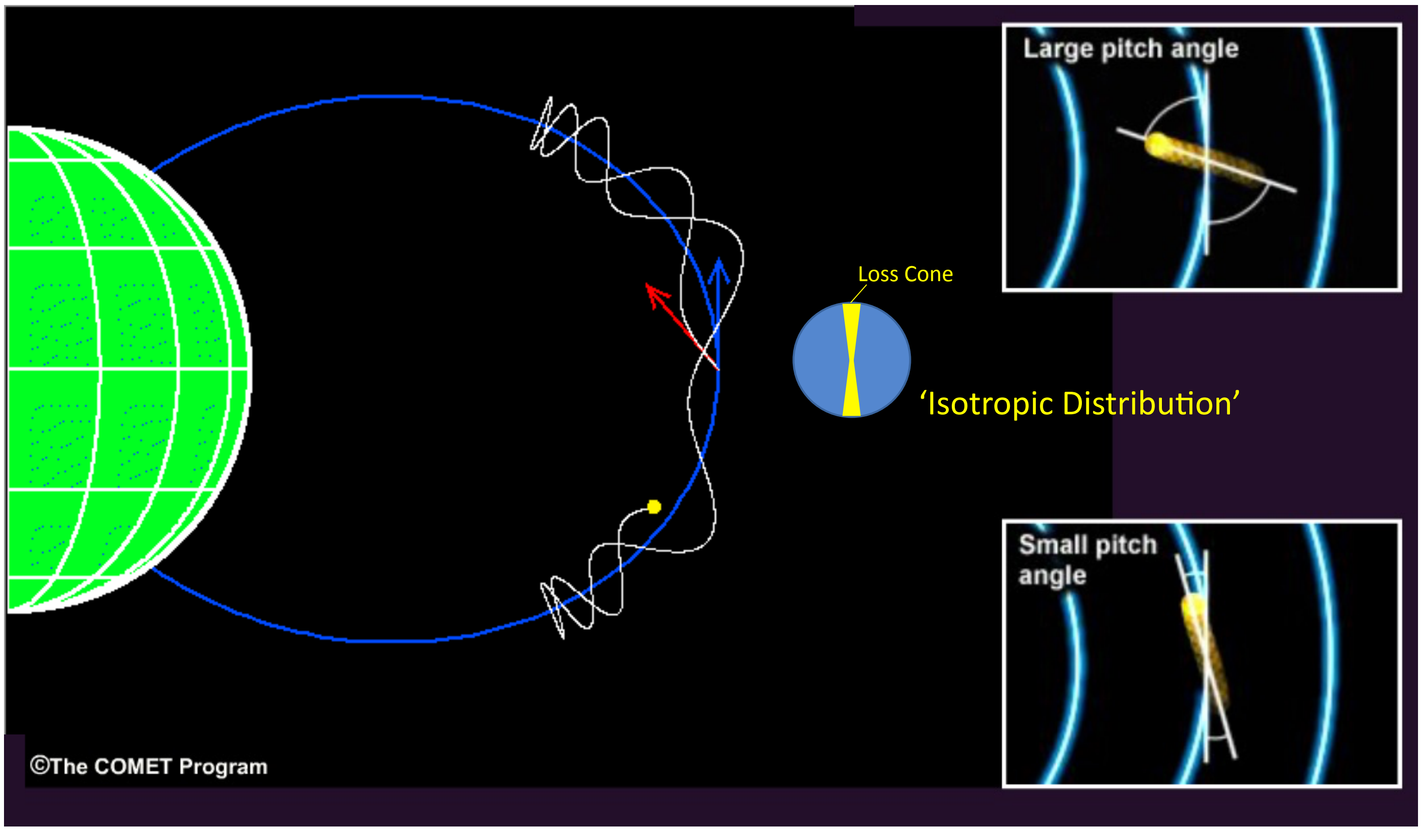
The color of the aurora tells us about the type and energy of the precipitating particles that cause it.





Auroral color tells us about the energy of the precipitating particles producing the light

Magnetospheric Origin of Auroral Particles



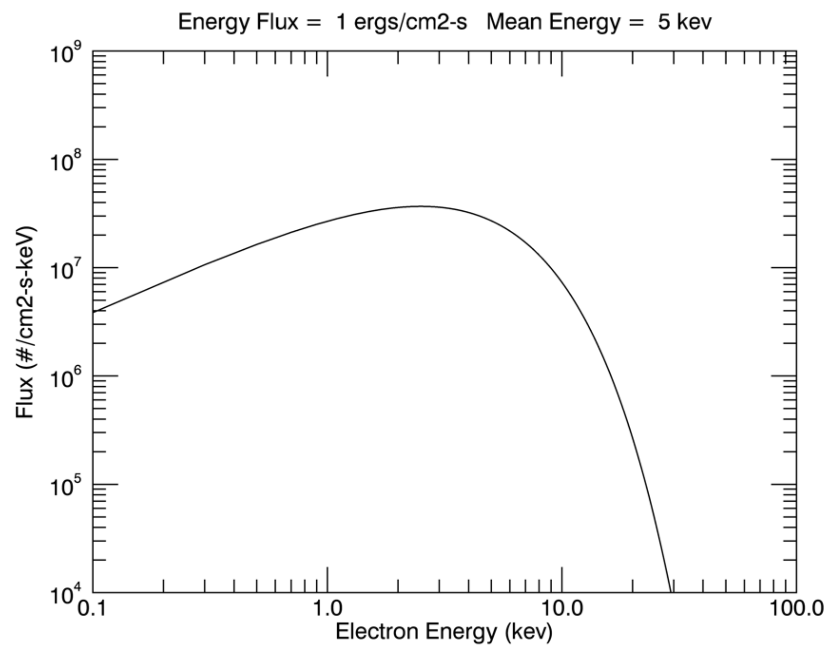
Auroral electrons (to first approximation) are characterized by a Maxwell-Boltzmann distribution

$$f(v) = n\left(\frac{m}{2\pi kT}\right)^{\frac{3}{2}} \exp\left(-\frac{mv^2}{2kT}\right)$$

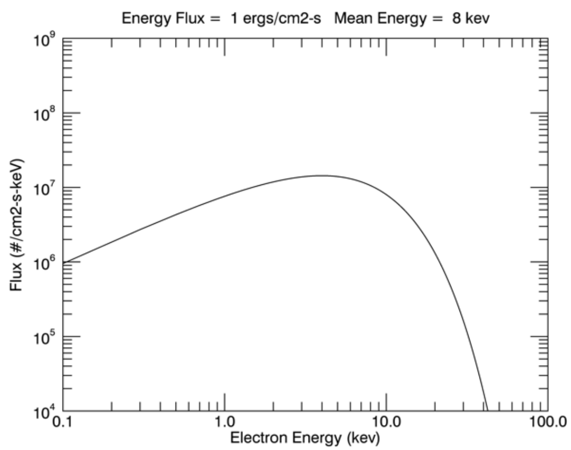
$$F(E) = \frac{2E}{m^2} n\left(\frac{m}{2\pi kT}\right)^{3/2} \exp\left(-E/kT\right)$$

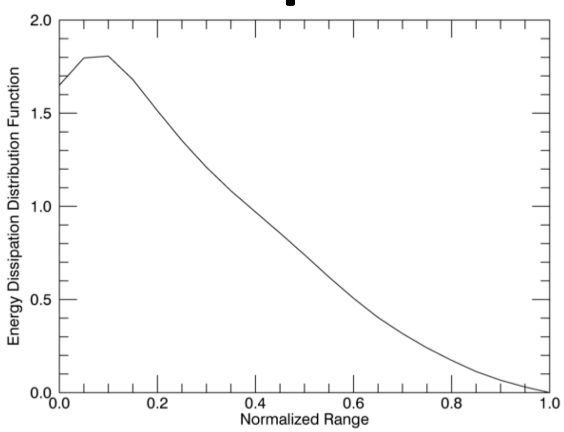
$$F(E) = \frac{\Phi_E}{(\bar{E})^3} \exp\left(-E/kT\right)$$

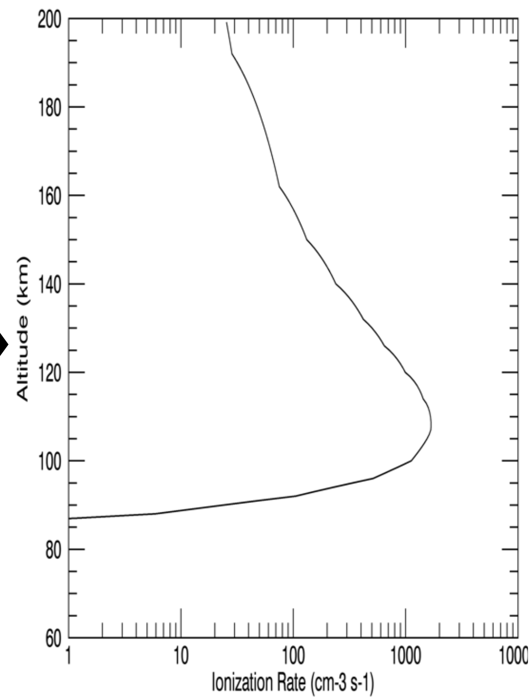
where Φ_E is the total energy flux and
kT is the temperature and
E is the mean energy (= 2*kT)



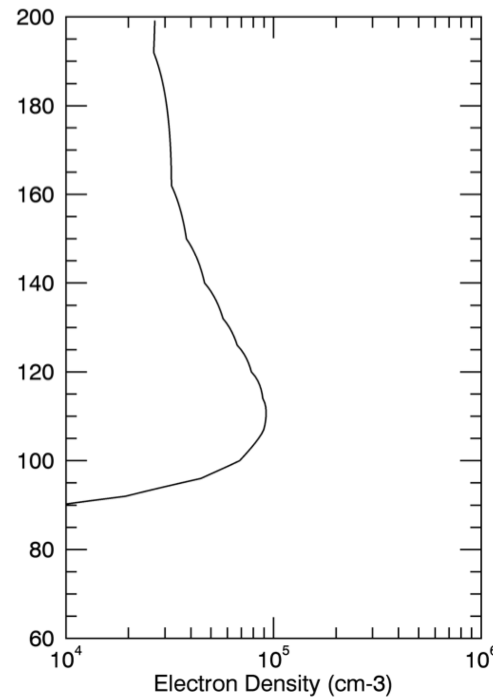
Auroral Energy Deposition







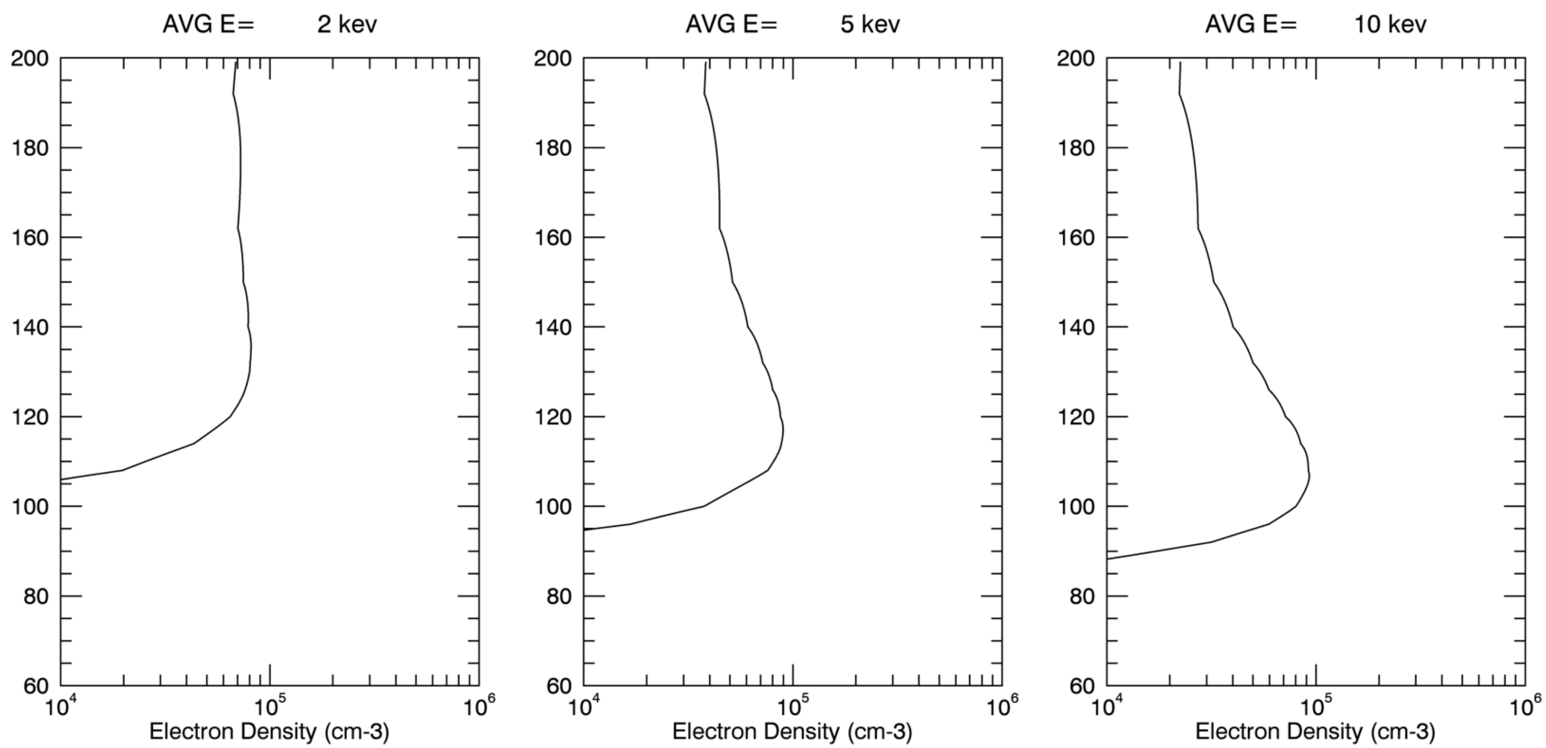
$$q(z) = F(E)\frac{E}{\Delta ER}\lambda\left(\frac{z}{R}\right)G(\rho, n)$$



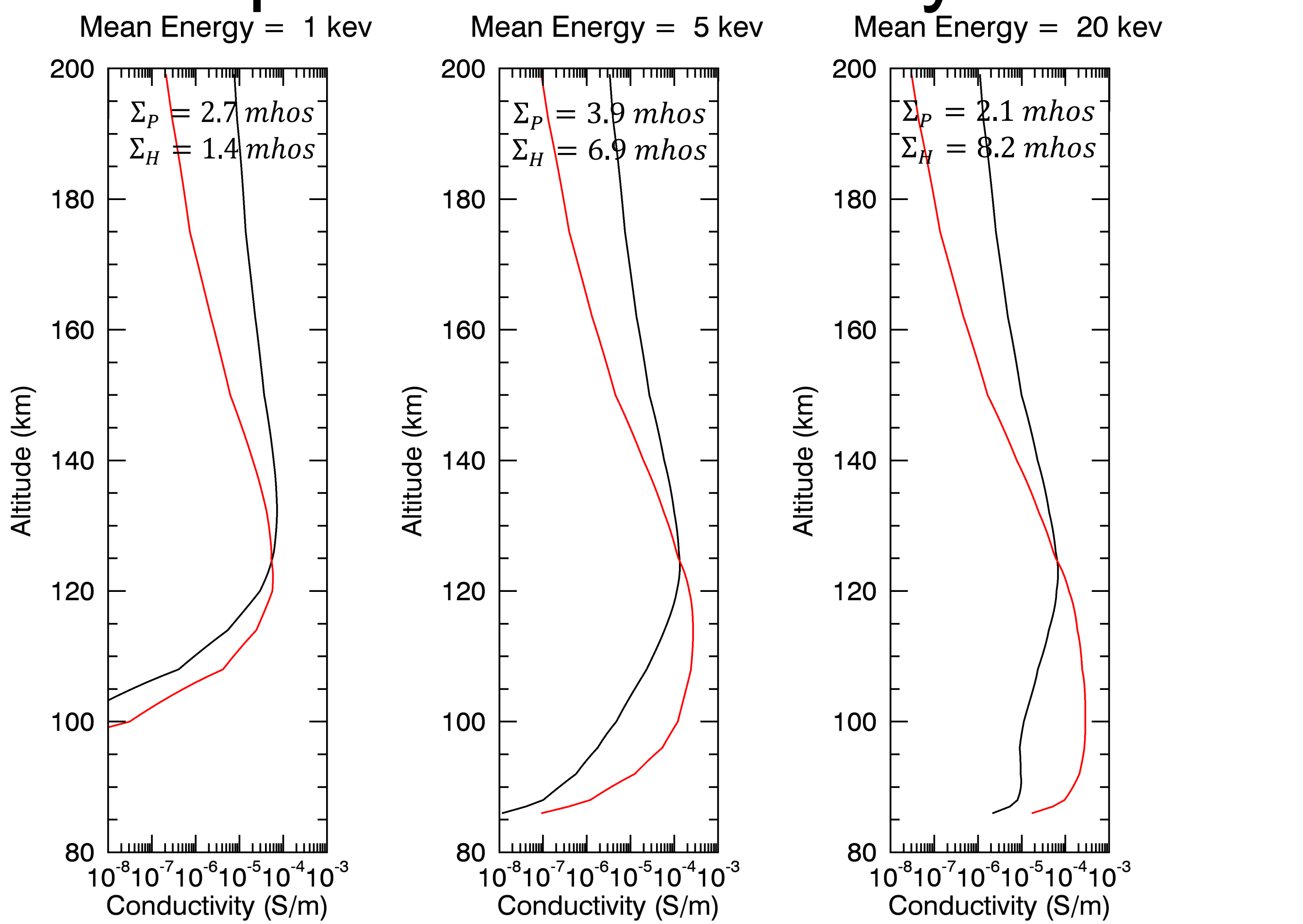
$$\frac{\partial n_e}{\partial t} + \nabla \cdot (n_e \boldsymbol{v_e}) = q - l$$

$$\frac{\partial n_e}{\partial t} = q - \alpha n_e^2$$ below 200 km altitude

Examples of altitude distributions of energy deposition for Maxwellian energy distributions.

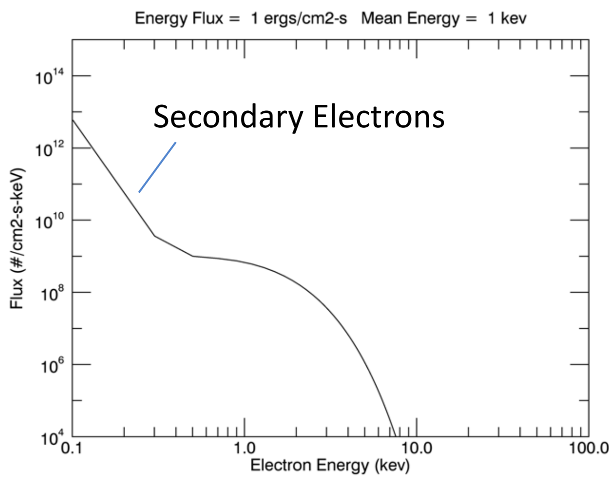


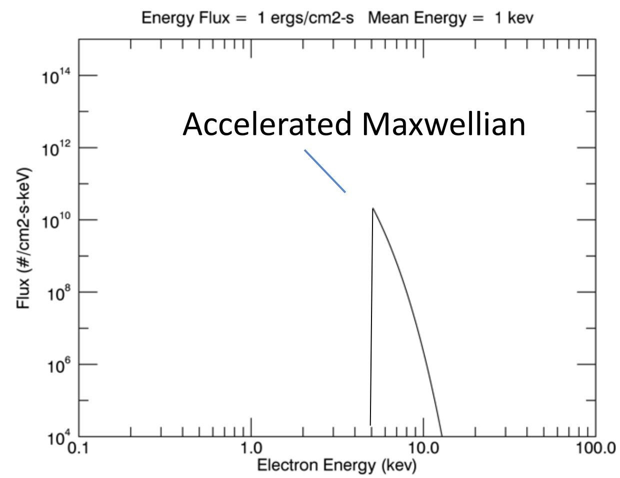
Ionospheric Conductivity Profiles

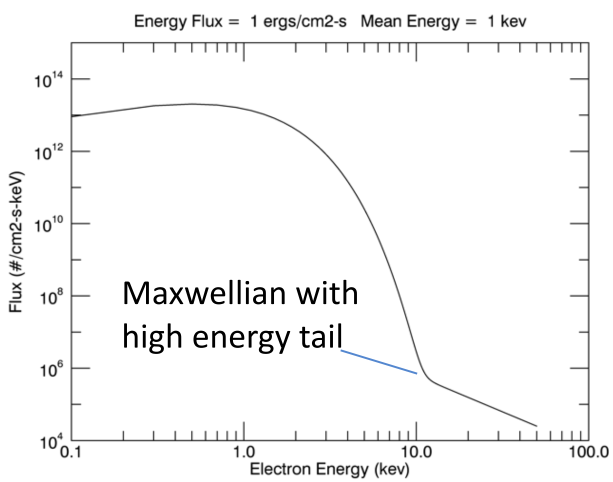


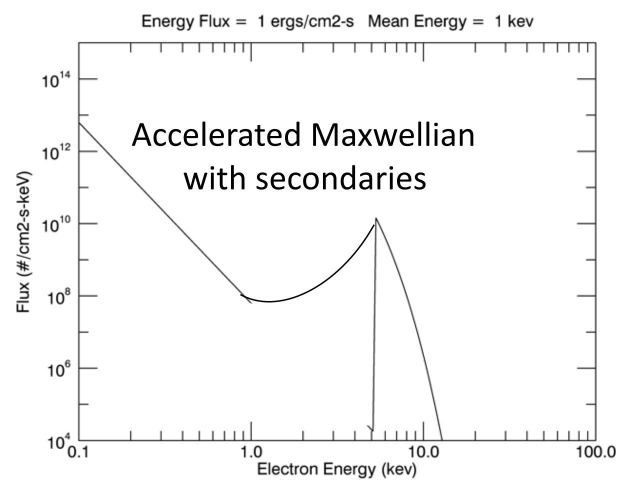
Two-Parameter Specification of Aurorally-Related Properties

- Magnetospheric: electron number density and temperature
- Ionospheric: total electron density and height of the E-region peak
- Thermospheric: integrated light emission and ratio of two emissions with different altitude dependences
- Auroral: Average energy and flux of electron precipitation
- Electrodynamic: Hall and Pedersen conductance

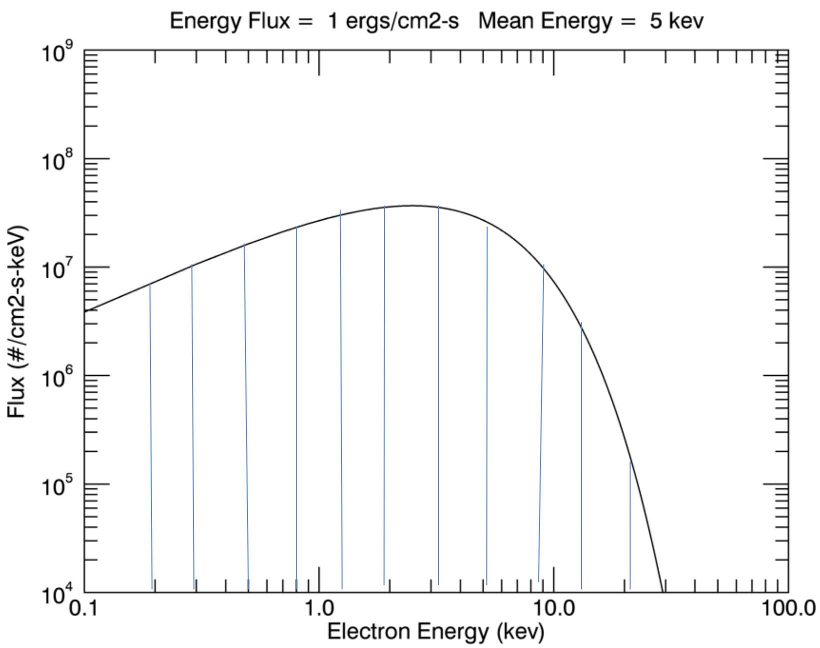

Energy Flux = 1 ergs/cm2-s Mean Energy = 1 kev
Secondary Electrons
Flux (#/cm2-s-keV)
Electron Energy (kev)

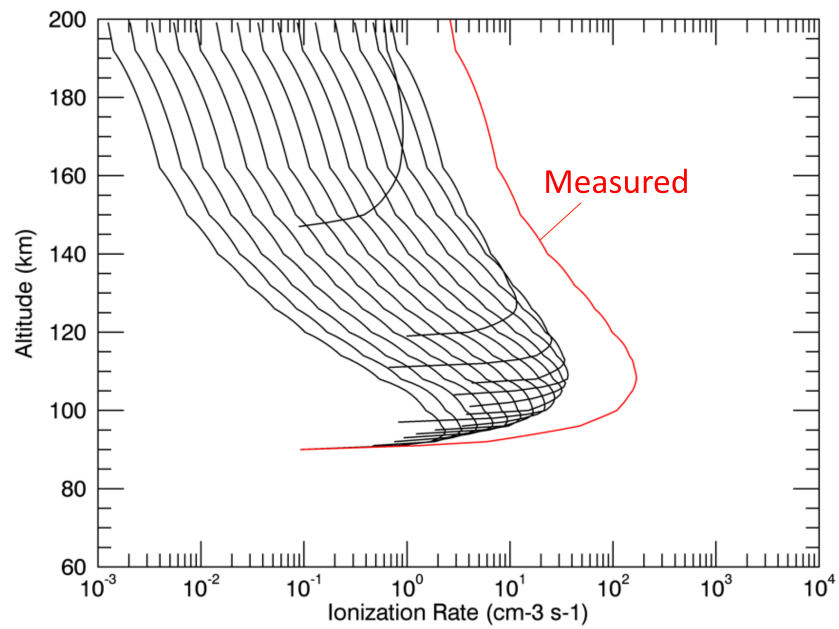

Energy Flux = 1 ergs/cm2-s Mean Energy = 1 kev
Accelerated Maxwellian
Flux (#/cm2-s-keV)
Electron Energy (kev)

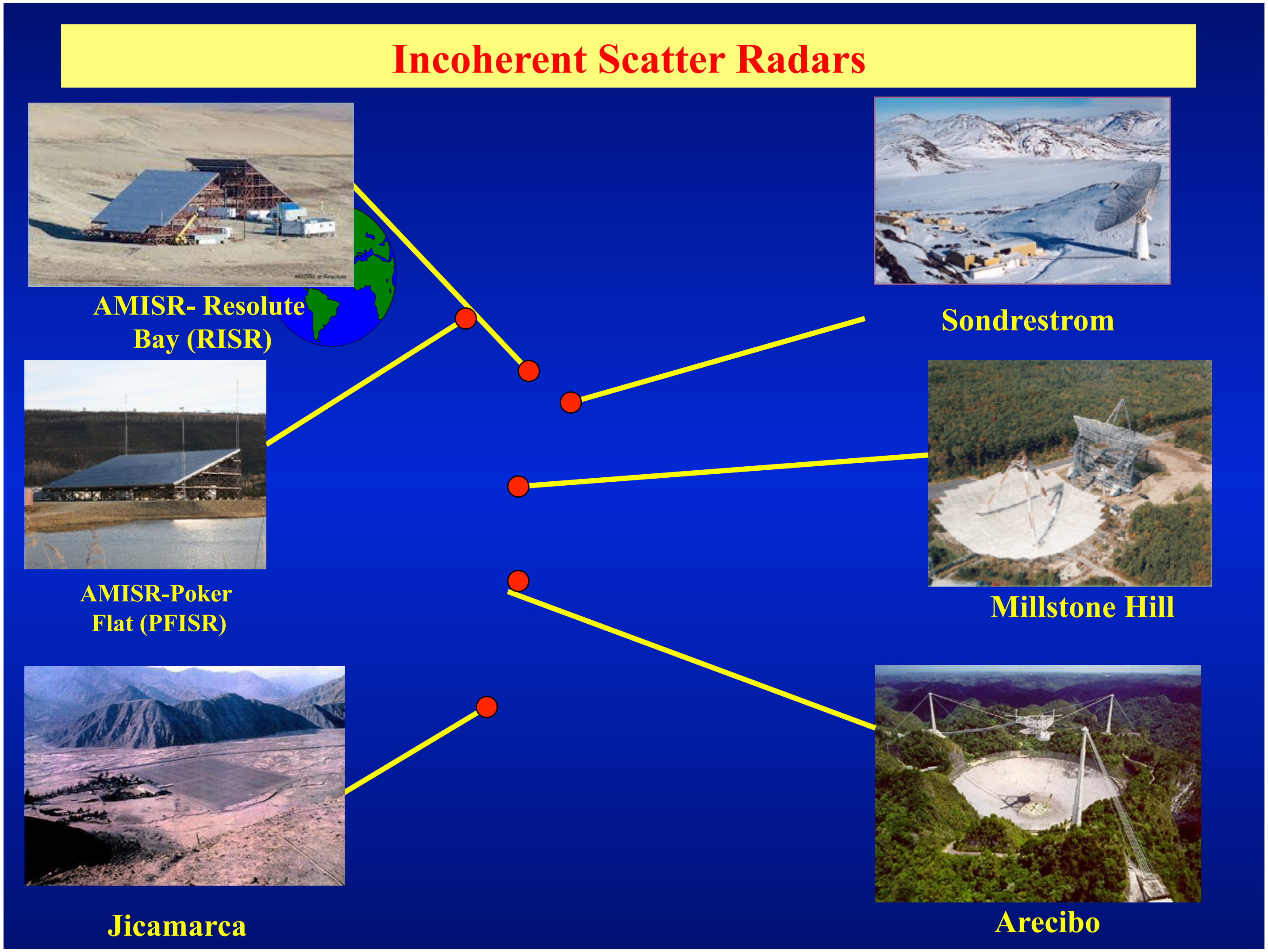

Energy Flux = 1 ergs/cm2-s Mean Energy = 1 kev
Maxwellian with
high energy tail
Flux (#/cm2-s-keV)
Electron Energy (kev)


Energy Flux = 1 ergs/cm2-s Mean Energy = 1 kev
Accelerated Maxwellian
with secondaries
Flux (#/cm2-s-keV)
Electron Energy (kev)

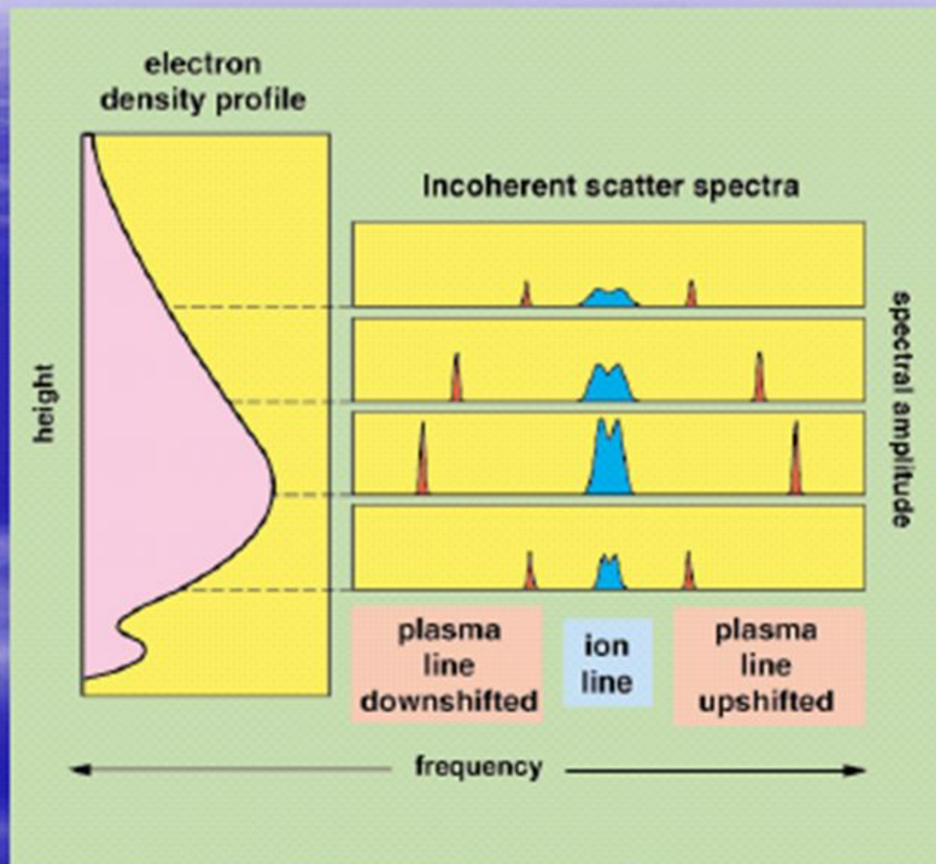
Deconvolving electron density profiles to determine the spectra of energetic particles



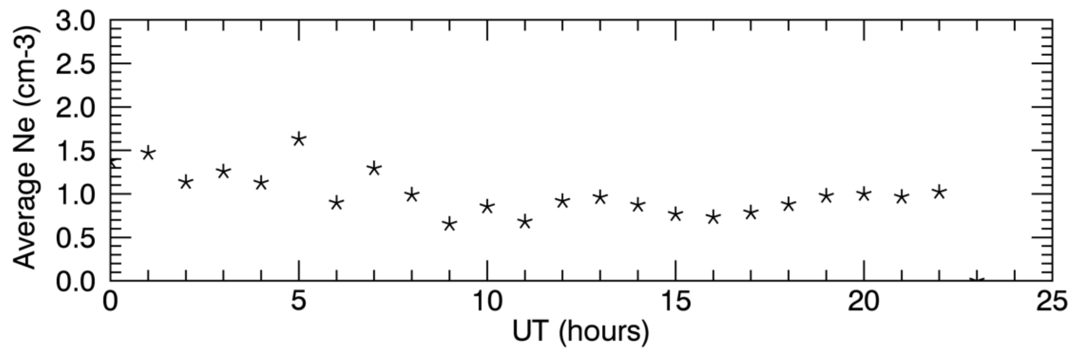


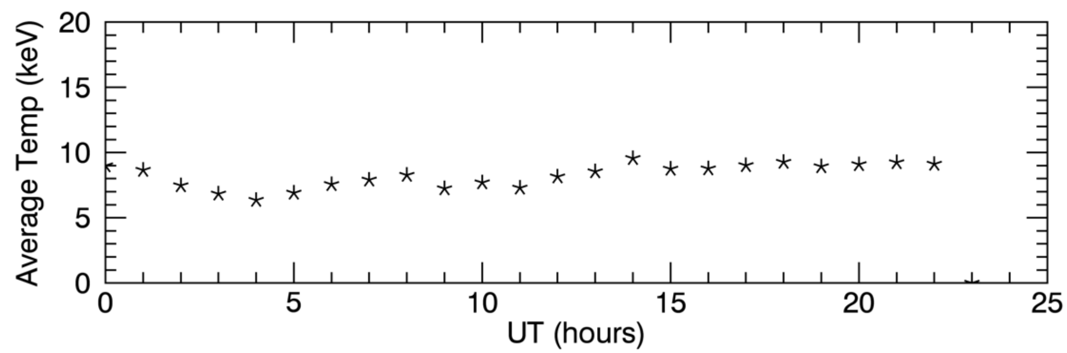

Incoherent Scatter Radars
AMISR- Resolute
Bay (RISR)
AMISR-Poker
Flat (PFISR)
Jicamarca
Sondrestrom
Millstone Hill
Arecibo

The ISR Spectrum



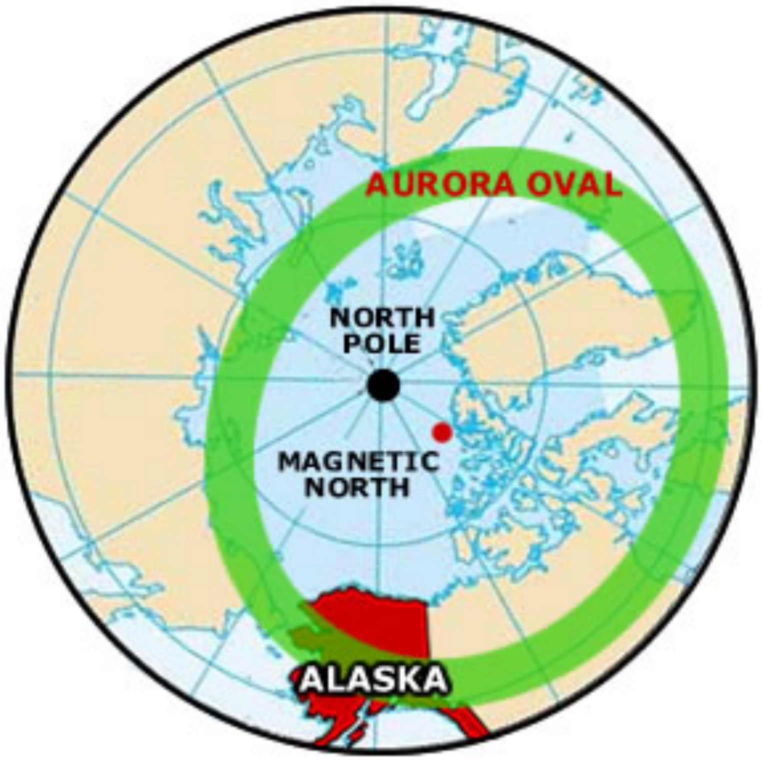
Magnetospheric Densities and Temperature Derived from Incoherent Radar Measurements of Electron Density Profiles



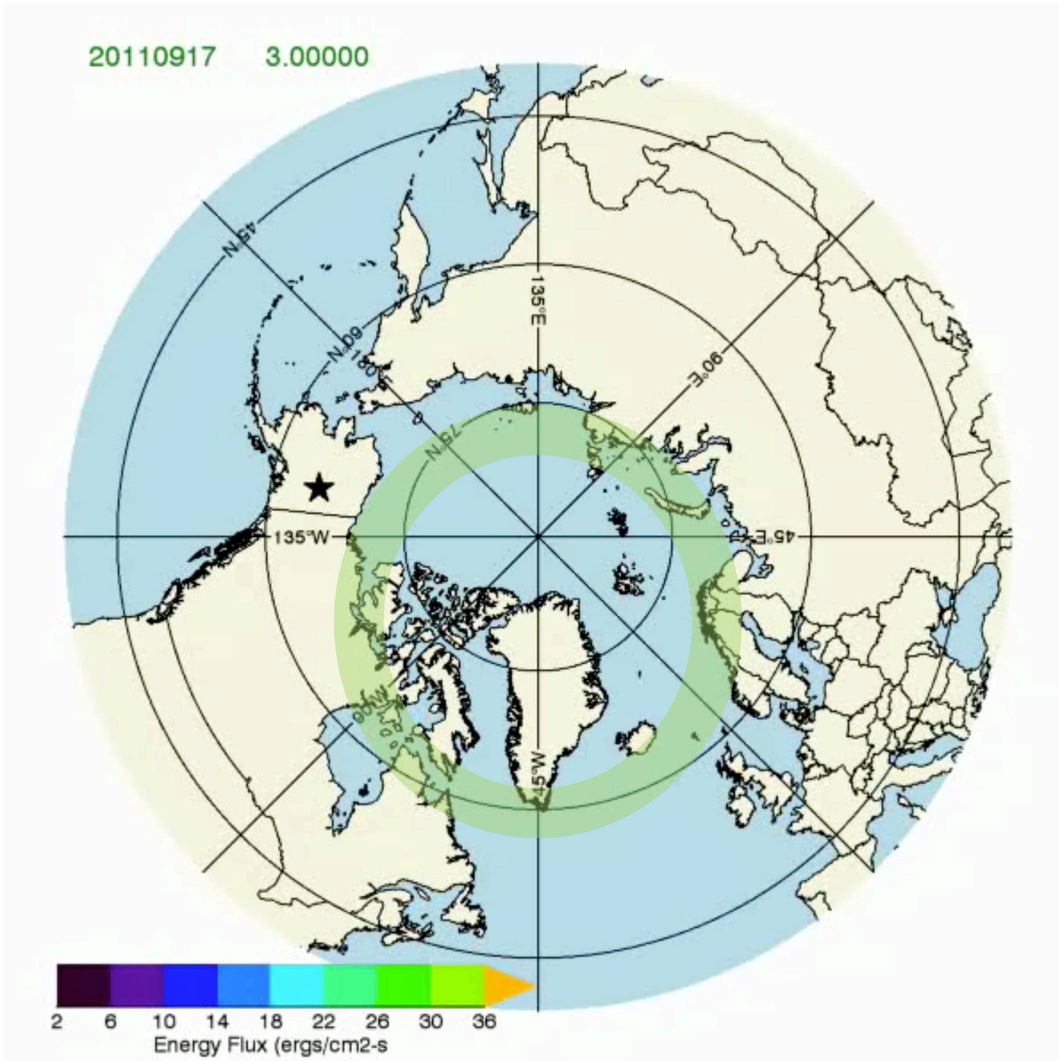


Auroral Motions

- Apparent motion due to Earth rotation
- Apparent motion due to changing magnetic fields
- Apparent motion due to dynamics of auroral particles

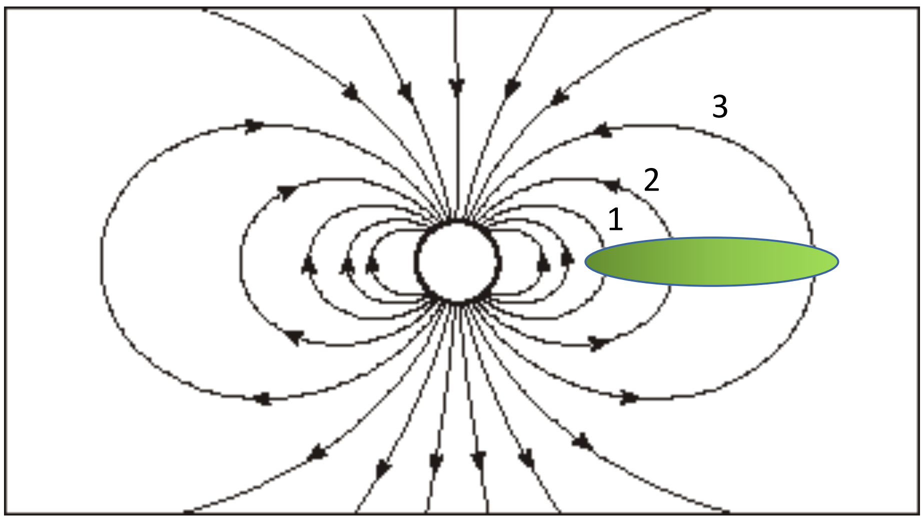


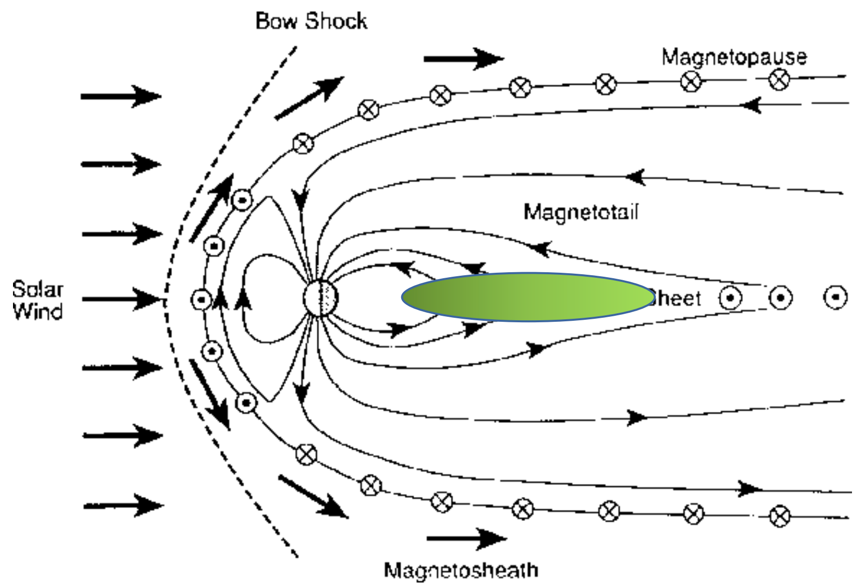
Apparent motion
due to
Earth rotation



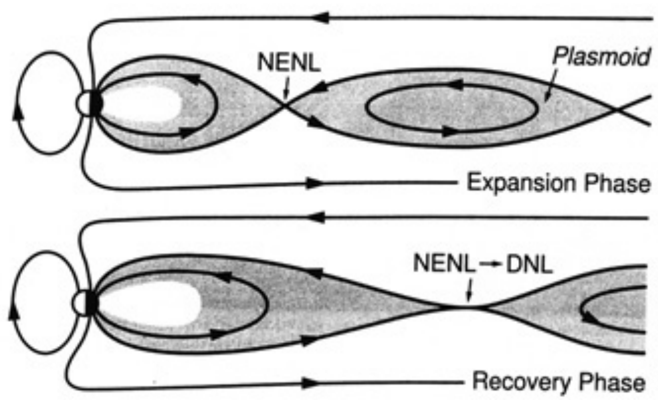
20110917 3.00000
45°N
60°N
75°N
135°E
90°E
45°E
135°W
90°W
45°W
180°
2 6 10 14 18 22 26 30 36
Energy Flux (ergs/cm2-s

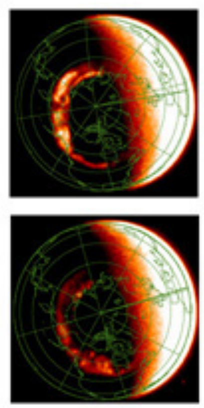
Motion due to changing magnetic fields





Auroral Breakup





Motion due to dynamics of auroral particles

Auroral Electrical Properties

Ohm's Law: $V = IR$

In the ionosphere: $\bar{J} = \tilde{\Sigma}\,\bar{\mathrm{E}}$

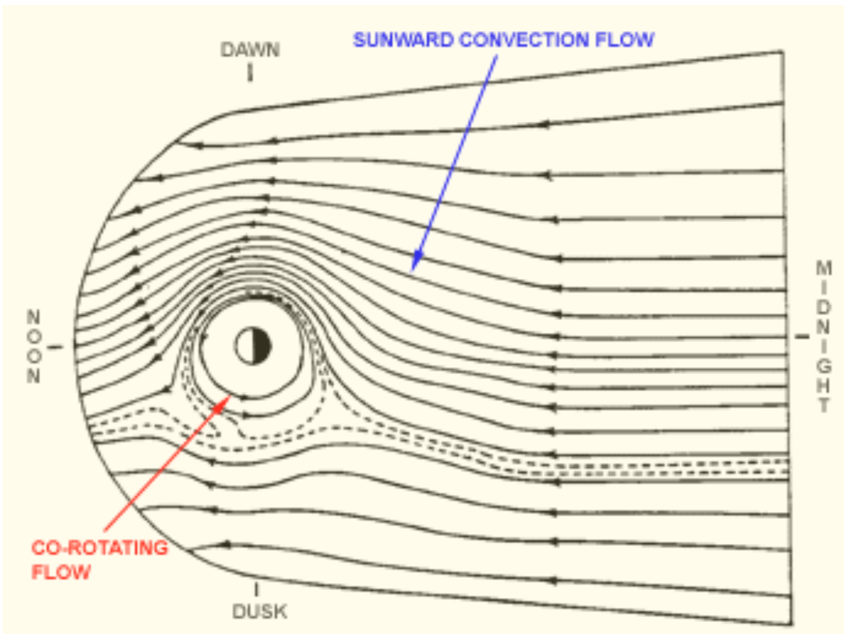
where $\tilde{\Sigma}$ is the tensor, height-integrated conductivity.

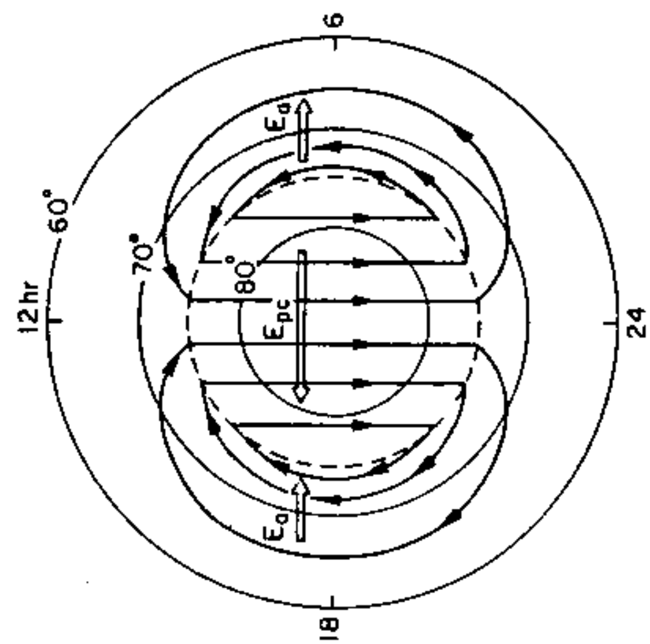
$$\bar{J} = \begin{bmatrix} \Sigma_{\mathrm{P}} & -\Sigma_{\mathrm{H}} \\ \Sigma_{\mathrm{H}} & \Sigma_{\mathrm{P}} \end{bmatrix} \bar{E}$$

$$\bar{J} = \Sigma_P \bar{E} - \Sigma_H (\bar{E} \times \bar{B}) / |B|$$

Electric fields, conductivities, and currents are needed for a complete specification of auroral electrodynamics

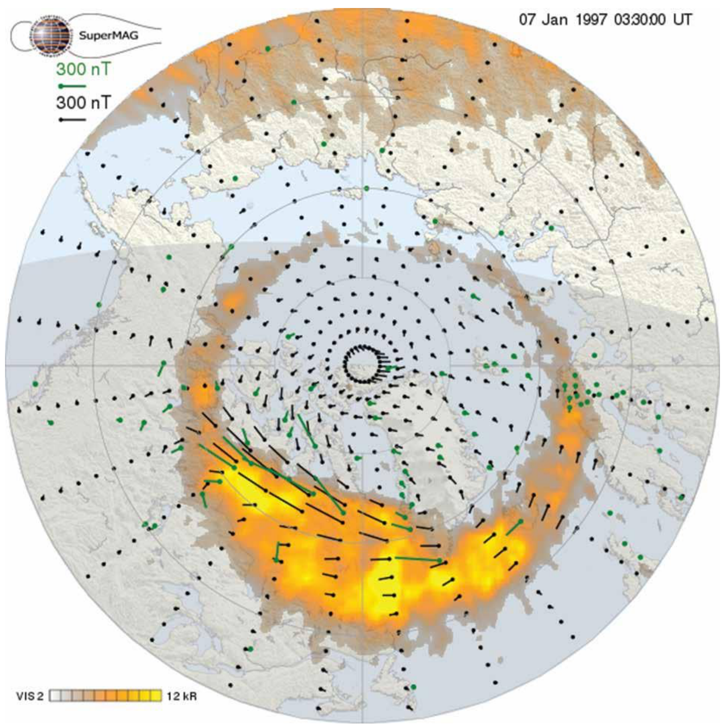
Electric fields and convection



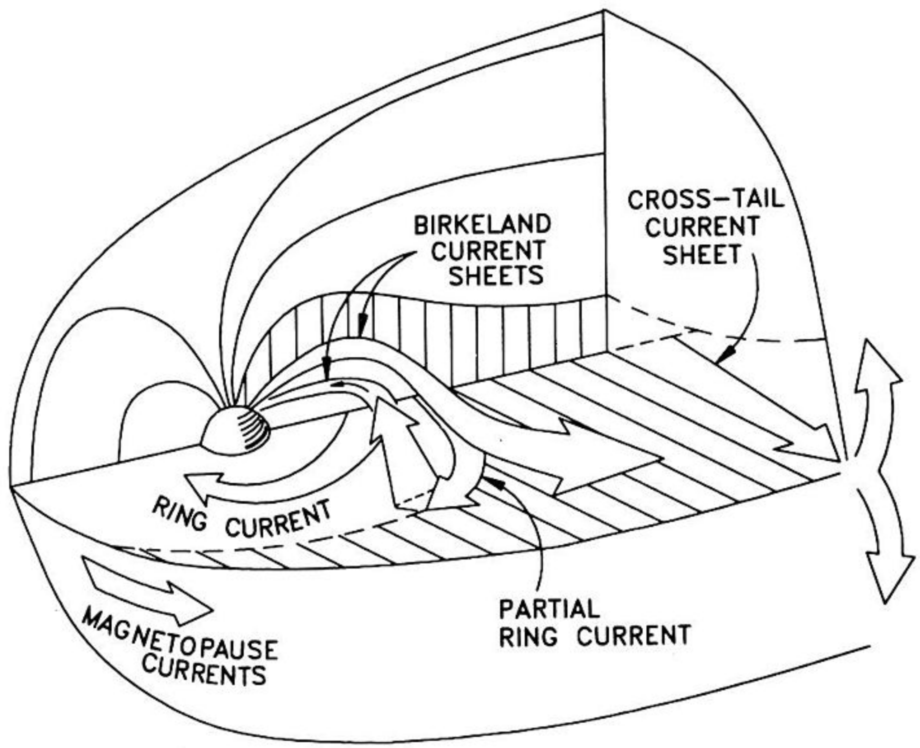


Techniques for measuring electric fields, conductivities and currents

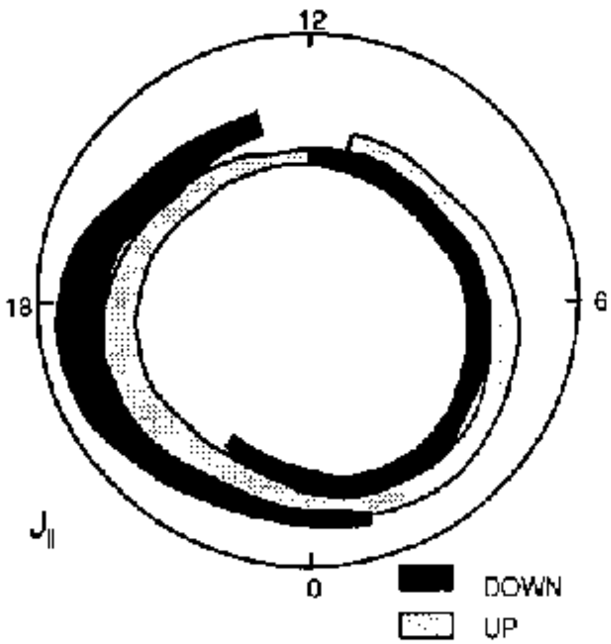
- Electric fields: Satellites and ground-based radars
- Conductivities: Observations of optical emissions or electron densities
- Currents: Ground-based magnetometers



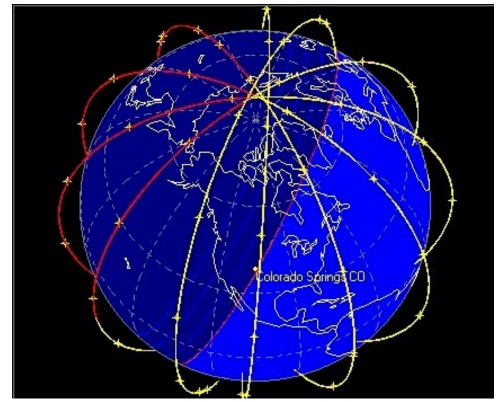
Birkeland (Field-Aligned) Currents

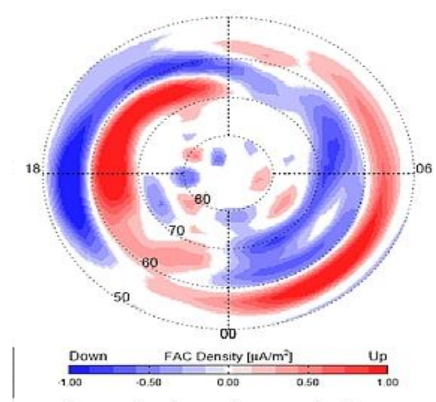


Large-scale Birkeland Currents in the High Latitude Ionosphere



AMPERE Measurements of Field-Aligned Currents





A solution based on field-aligned currents

$$\bar{J} = \Sigma_P \bar{E} - \Sigma_H (\bar{E} \times \bar{B})/|B|$$

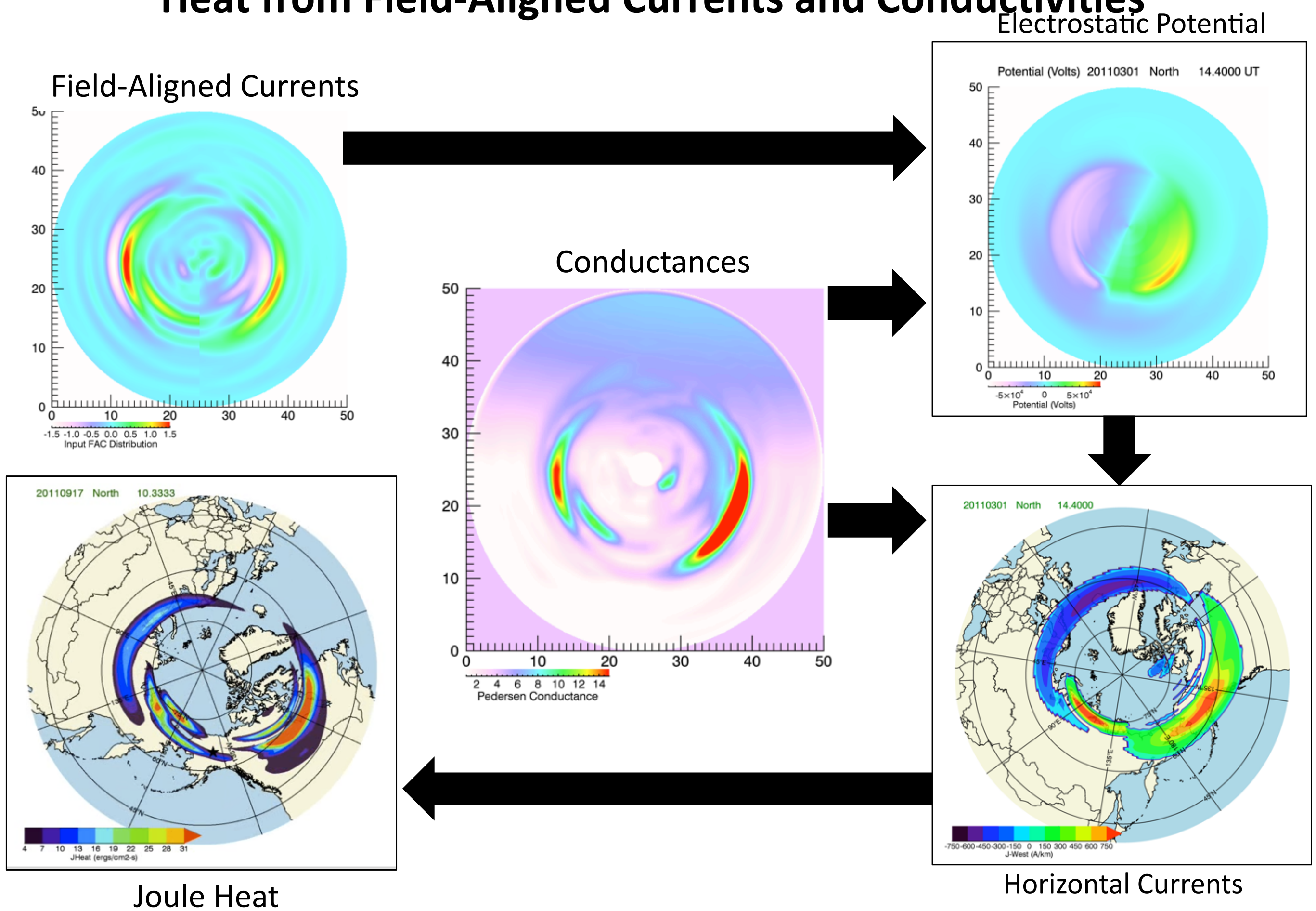
From current continuity:

$$\nabla \cdot \ \bar{J} = 0$$

$$J_{\parallel} = \nabla \cdot J_{\perp}$$

$$J_{\parallel} = \nabla \cdot (\bar{\bar{\Sigma}} \bar{E})$$

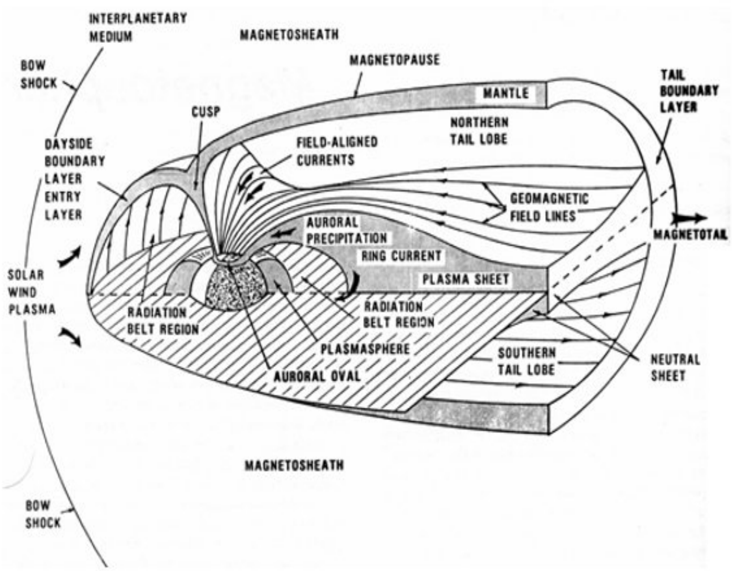
Calculation of Electric Fields,Horizontal Currents and Joule Heat from Field-Aligned Currents and Conductivities

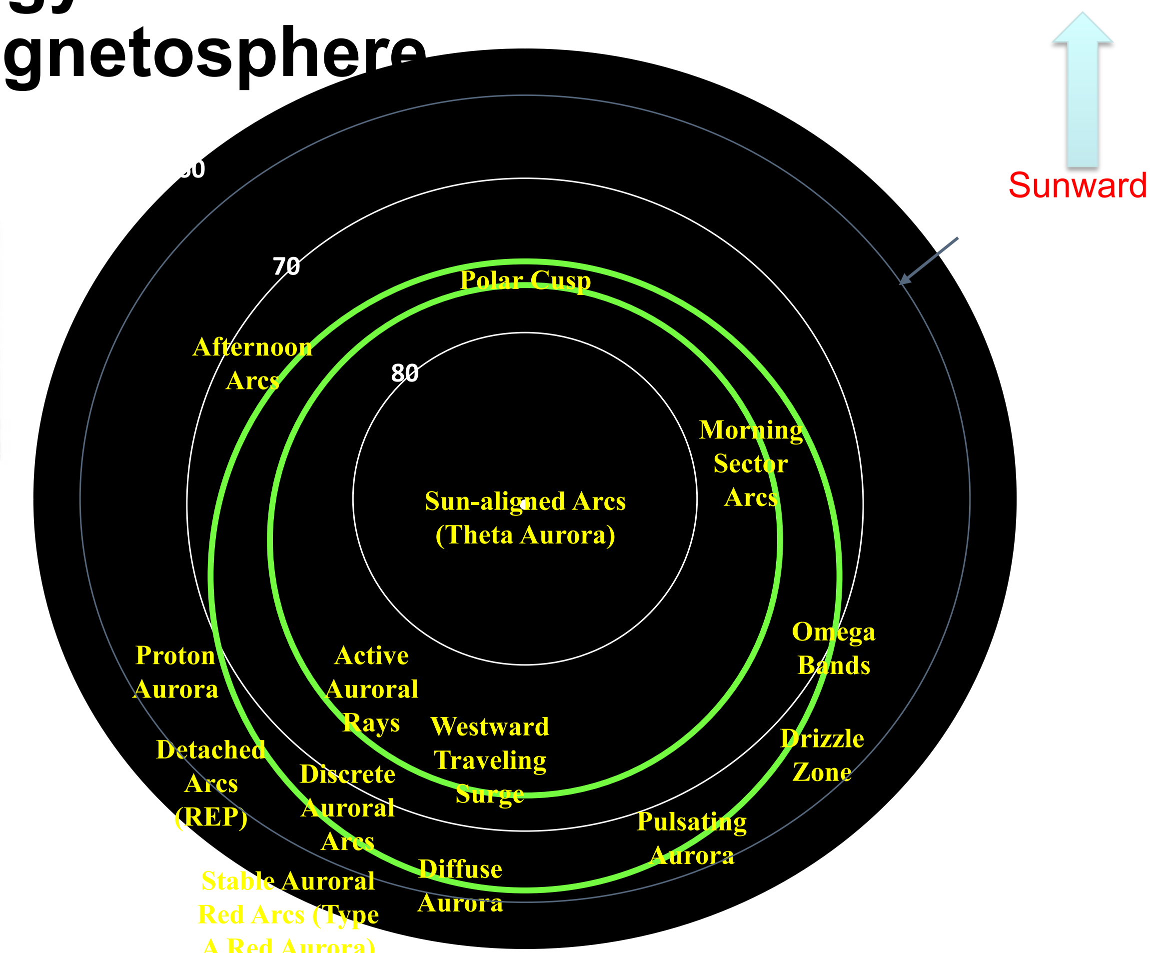


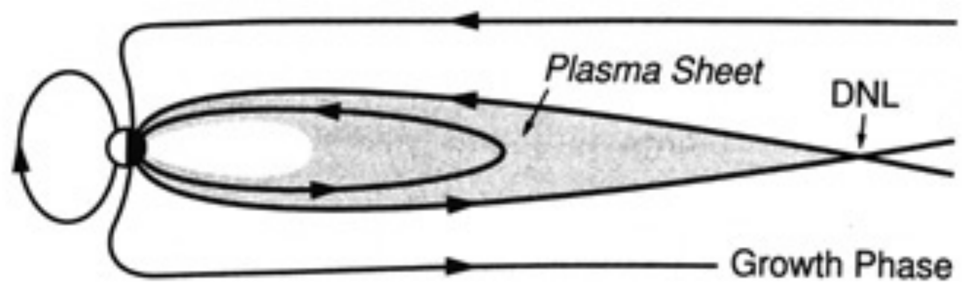
The Importance of Auroral Conductances

- Give information about the energy flux and average energy of precipitating electrons
- Can be combined with field-aligned currents to determine electric fields and convection
- Are used with electric fields to calculate currents and Joule heating

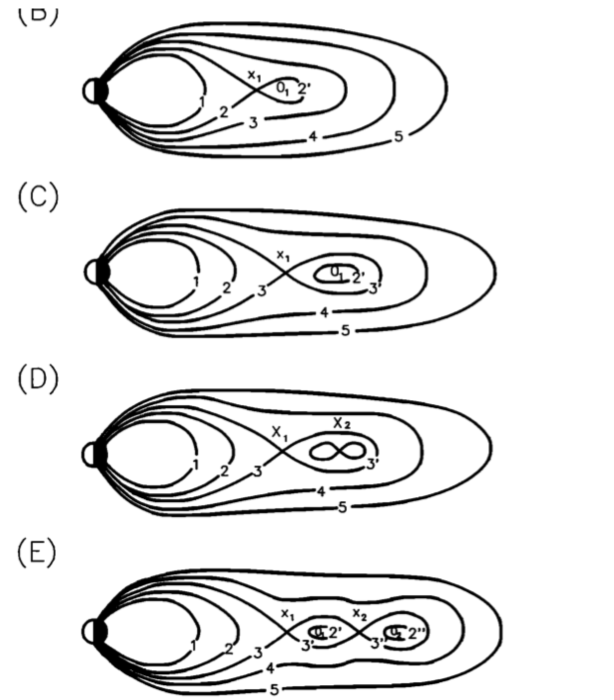
Auroral morphology and how it relates to the magnetosphere






Plasma Sheet
DNL
Growth Phase

Observing the structure of the magnetotail from Earth



	Appearance from Below	Appearance from Above	Appearance from the Side	Geophysical Context	Magnetospheric Connection
Discrete Arcs	Very narrow, sharp boundaries, often with moving ray structure, waves and folds, predominantly green and magenta	Thinness Is not apparent from satellite altitudes because usually embedded in broader region of luminosity.	Folded curtains with ray structure within a region of more diffuse luminosity.	Relatively straight and steady during quiet times, but increasingly wavy and dynamic under disturbed conditions	Boundary of Plasma Sheet
Evening Diffuse Aurora	Broad, diffuse, and stable. Predominantly green line emissions.	Broad and faint, with little structure.	Stable band of diffuse luminosity with gradual upper and lower boundaries.	Almost always present, but moves equatorward during substorm growth phase and poleward at substorm onset.	Dusk-side Plasma Sheet
Morning Diffuse Aurora	Broad, diffuse, faint, with irregular structure, occasionally pulsating.	Almost invisible. Energetic particles produce little green line emission.	Almost invisible; may produce a faint irregular band.	Always present, but intensifies during disturbed conditions.	Dawn-side Plasma Sheet
Westward Traveling Surge	A localized group of active discrete aurora that moves westward from the midnight sector toward dusk.	A very intense, localized region of luminosity near local midnight that expands toward dusk.	Multiple curtains of discrete aurora, often showing large-scale loop structures.	Occurs at substorm onset.	Probably maps to the region of reconnection out in the magnetotail.
Pulsating Aurora	Faint patches that change in luminosity over times from 5 to 15 seconds, predominantly in green line.	Difficult to see because requires staring at the same location for several minutes (many cycles)	Difficult to see because side view integrates light through the entire layer.	Recovery phase of storms or substorms; thought to be caused by wave-particle interactions in magnetosphere.	Dawn-side Plasma Sheet.
Omega Bands	Large 'omega' shaped loops in the morning diffuse aurora. Green line dominant.	Striking periodic structures along the equatorward boundary of a region of diffuse luminosity.	Difficult to see because of the overlapping segments of the feature seen from the side.	Disturbed conditions. Thought to be due to Kelvin-Helmholtz instabilities in the magnetosphere.	Inner boundary of Plasma Sheet.
Stable Auroral Red Arcs	Extended regions of diffuse red luminosity near the equatorward edge of the auroral oval.	Difficult to see from above because of faintness of red line emissions.	Very dramatic red glow because of extended path length of emissions.	Recovery phase of large magnetic storms, caused by hot electrons in ring current and plasmasphere.	On dipolar field lines at inner edge of auroral zone.
Proton Aurora	Very faint and difficult to see. Difficult to separate proton aurora from diffuse aurora without spectroscopic measurments.	A broad, faint, steady band of luminosity, difficult to separate from diffuse aurora.	A broad, faint, steady band of luminosity, difficult to separate from diffuse aurora.	Geophysical context not established, but presumably more intense during active times.	Inner edge of Plasma Sheet.
Sun-aligned Arcs	Arc-like structures extending in north-south direction, predominantly in red line, but some faint green line as well.	A line of luminosity extending from noon to midnight (sun-aligned). Called theta aurora when it connects to auroral oval luminosity.	A faint discrete arc in red line, distinguishable from evening arcs by being predominantly red-line emissions.	Associated with extremely quiet times when interplanetary magnetic field is northward.	Uncertain, but probably connected to boundary of a plasma sheet distorted by weak coupling between solar wind and magnetosphere.
Rays	Filamentary auroral luminosity extended in altitude, often embedded in a discrete arc, but can be isolated. When overhead, can appear as a corona. Rays are red at the top and green at the bottom.	Difficult to see individual rays because of motion, temporal variations, and integration of luminosity along line of sight.	Very distinct because of extended altitude of emissions and characteristic red and green line distribution.	Active conditions, often at the poleward edge of discrete auroral emissions. The altitude distribution of luminosity suggests broad energetic electron spectrum.	Most often at poleward edge of plasma sheet, at boundary between auroral oval and polar cap.
Detached Arcs	Faint, arc-like structures extending equatorward from the equatorward edge of diffuse aurora.	Faint appendages extending off equatorward boundary of diffuse precipitation region.	Difficult to separate from diffuse aurora with side-view perspective.	Believed to be precipitation from radiation belts, probably after a large storm when radiation belt particles have been energized.	Radiation belts on night-side; maybe day-side too.

Summary

- Studying the aurora provides quantitative information about:
  - The type and energy distribution of the precipitating particles
  - The density and temperature of the magnetospheric plasma associated with the auroral particle precipitation
  - The spatial and temporal properties of magnetospheric domains to which the aurora is magnetically connected
  - The changes in the magnetospheric magnetic fields resulting from magnetosphere-solar wind coupling
  - The convective motion of magnetospheric plasma
  - Resistive heating of the ionosphere and thermosphere