# Science of NASA's Radiation Belt Storm Probes

Mona Kessel, NASA HQ

Contributions by

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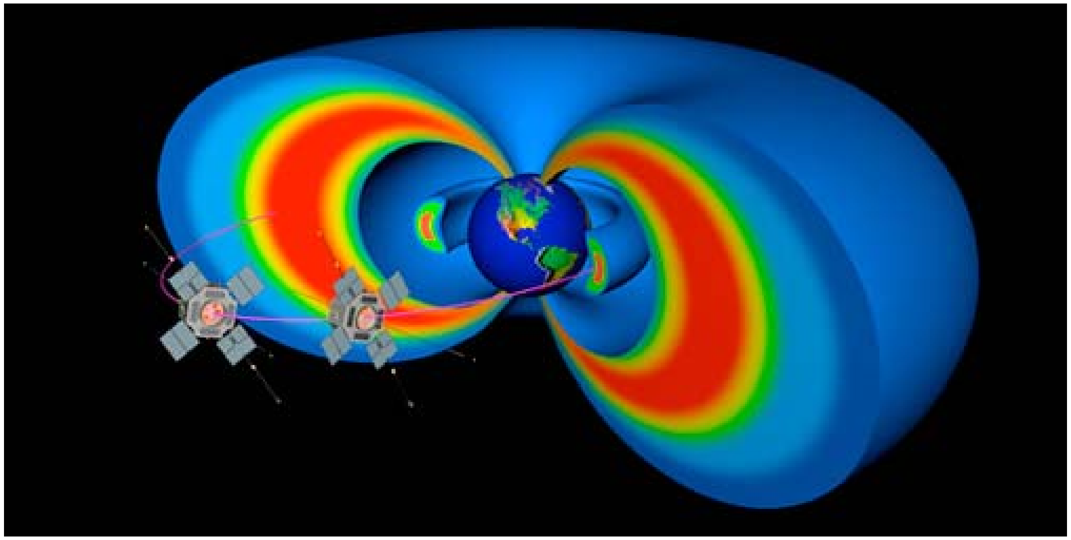
# The broad objectives of RBSP

Provide understanding, *ideally to the point of predictability,* of how populations of relativistic electrons and penetrating ions in space form or change in response to variable inputs of energy from the Sun.

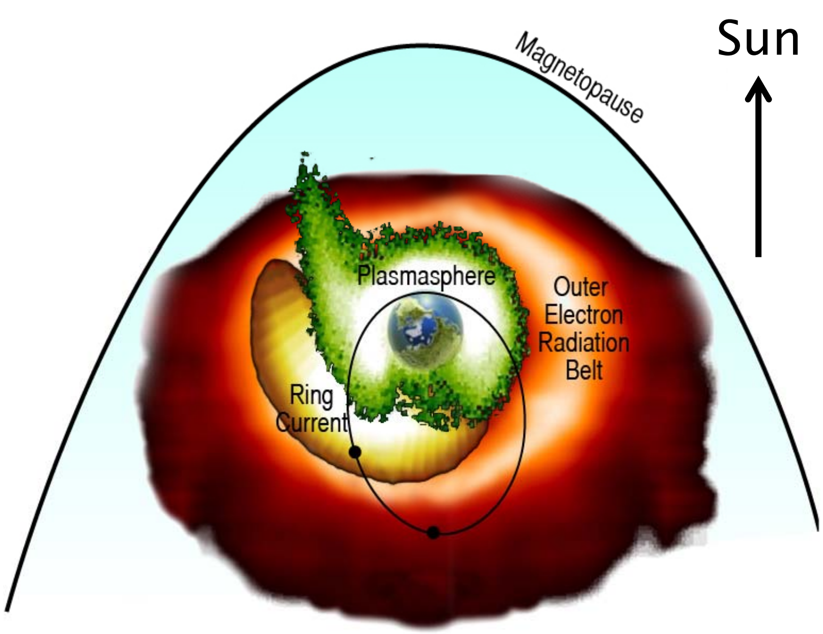
- Which Physical Processes Produce Radiation Belt Enhancement Events?
- What Are the Dominant Mechanisms for Relativistic Electron Loss?
- How do Ring Current and other geomagnetic processes affect Radiation Belt Behavior?



The instruments on the two RBSP spacecraft will measure the properties of charged particles that comprise the Earth's radiation belts and the plasma waves that interact with them, the large-scale electric fields that transport them, and the magnetic field that guides them.

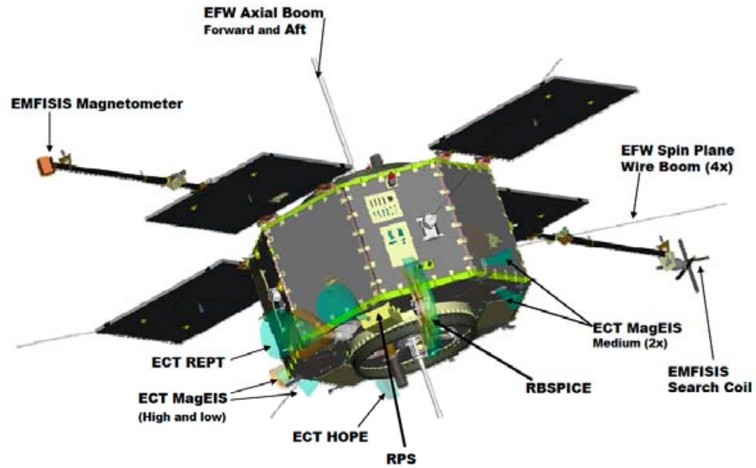
# Multiple spacecraft will target key radiation belt regions with variable spacing

- 2 identically-instrumented spacecraft for space/time separation.
- Lapping rates (4-5 laps/year) for simultaneous observations over a range of s/c separations.



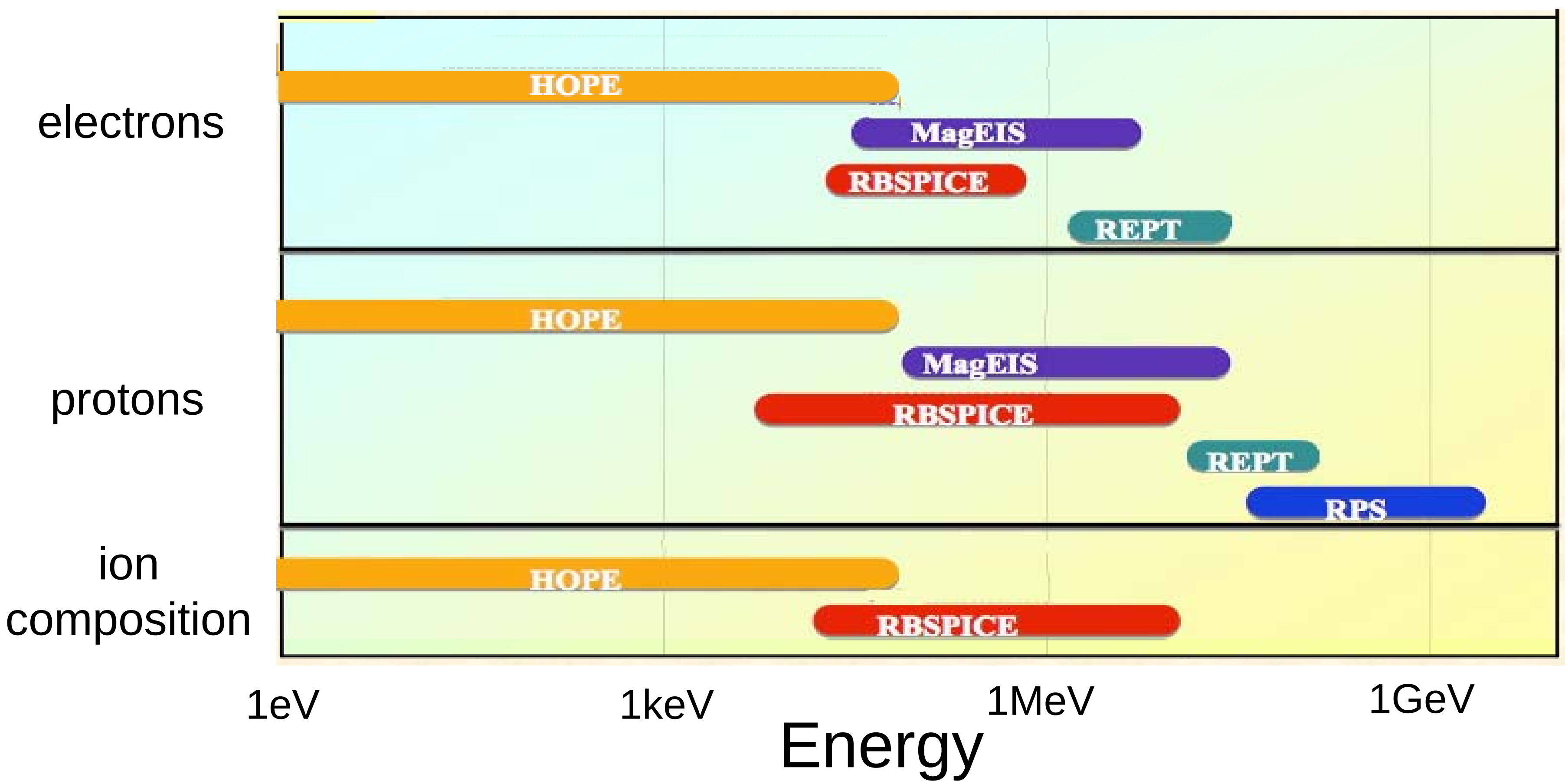

- 600 km perigee to 5.8 $R_E$ geocentric apogee for full radiation belts sampling.
- Orbital cadences faster than relevant magnetic storm time scales.
- 2-year mission for precession to all local time positions and interaction regions.
- Low inclination (10°) to access all magnetically trapped particles
- Sunward spin axis for full particle pitch angle and dawn-dusk electric field sampling.
- Space weather broadcast

# Radiation Belt Storm Probes

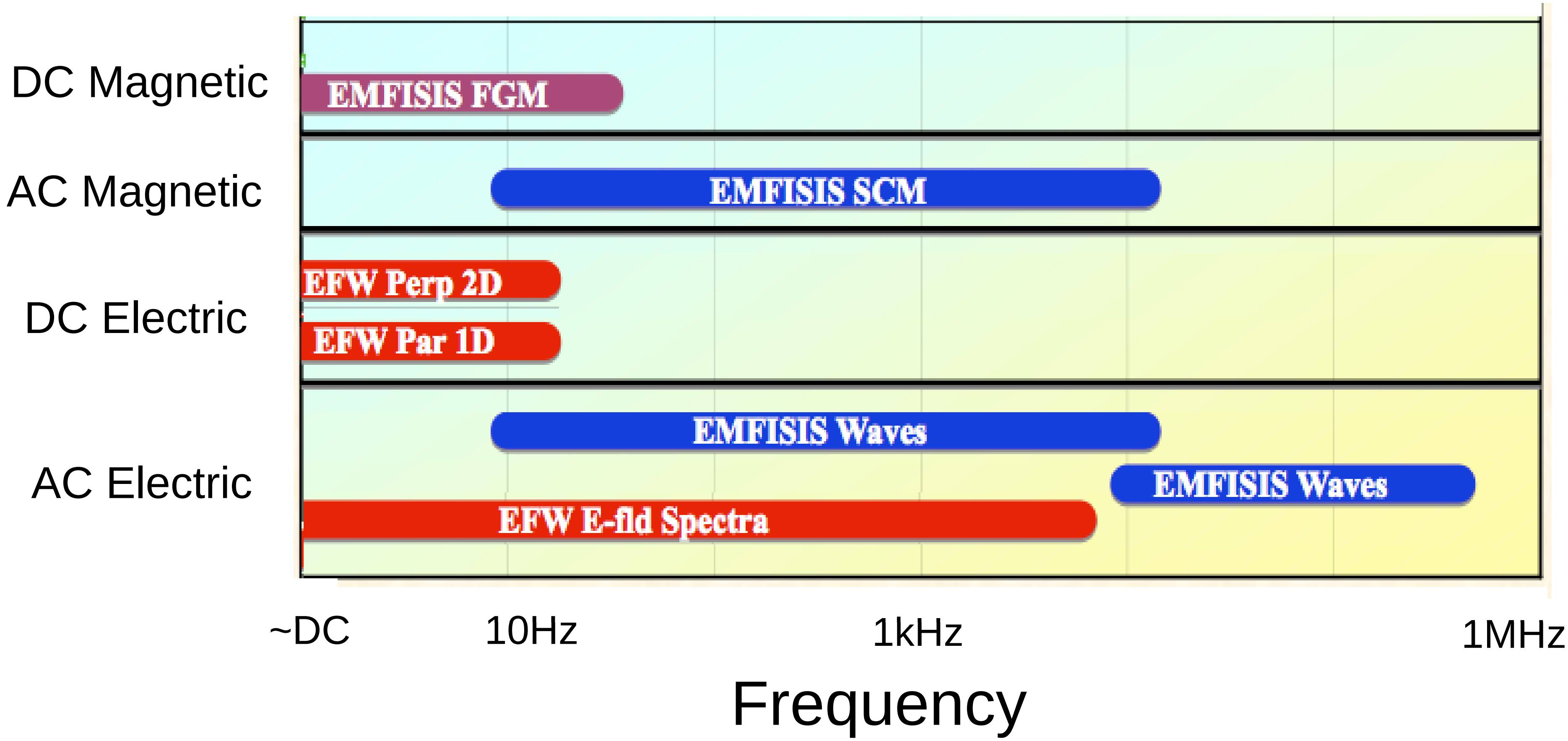



| Investigation | Instruments | PI |
|---|---|---|
| Energetic Particle Composition and Thermal Plasma Suite (ECT) | Helium Oxygen Proton Electron Spectrometer (HOPE)<br>Magnetic Electron Ion Spectrometer (MagEIS)<br>Relativistic Electron Proton Telescope (REPT) | H. Spence<br>UNH |
| Electric and Magnetic Field Instrument Suite and Integrated Science (EMFISIS) | Low-Frequency Magnetometer (MAG)<br>High-Frequency Magnetometer and Waveform Receiver (Waves) | C. Kletzing<br>University of Iowa |
| Electric Field and Waves Instrument for the NASA RBSP Mission (EFW) | Electric Field and Waves Instrument for the NASA RBSP Mission (EFW) | J. Wygant<br>University of Minnesota |
| Radiation Belt Storm Probes Ion Composition Experiment (RBSPICE) | Radiation Belt Storm Probes Ion Composition Experiment (RBSPICE) | L. Lanzerotti<br>New Jersey Institute of Technology |
| Proton Spectrometer Belt Research (PSBR) | Relativistic Proton Spectrometer (RPS) | D. Byers<br>NRO |

# Comprehensive Particle Measurements



# Comprehensive E and B Field Measurements



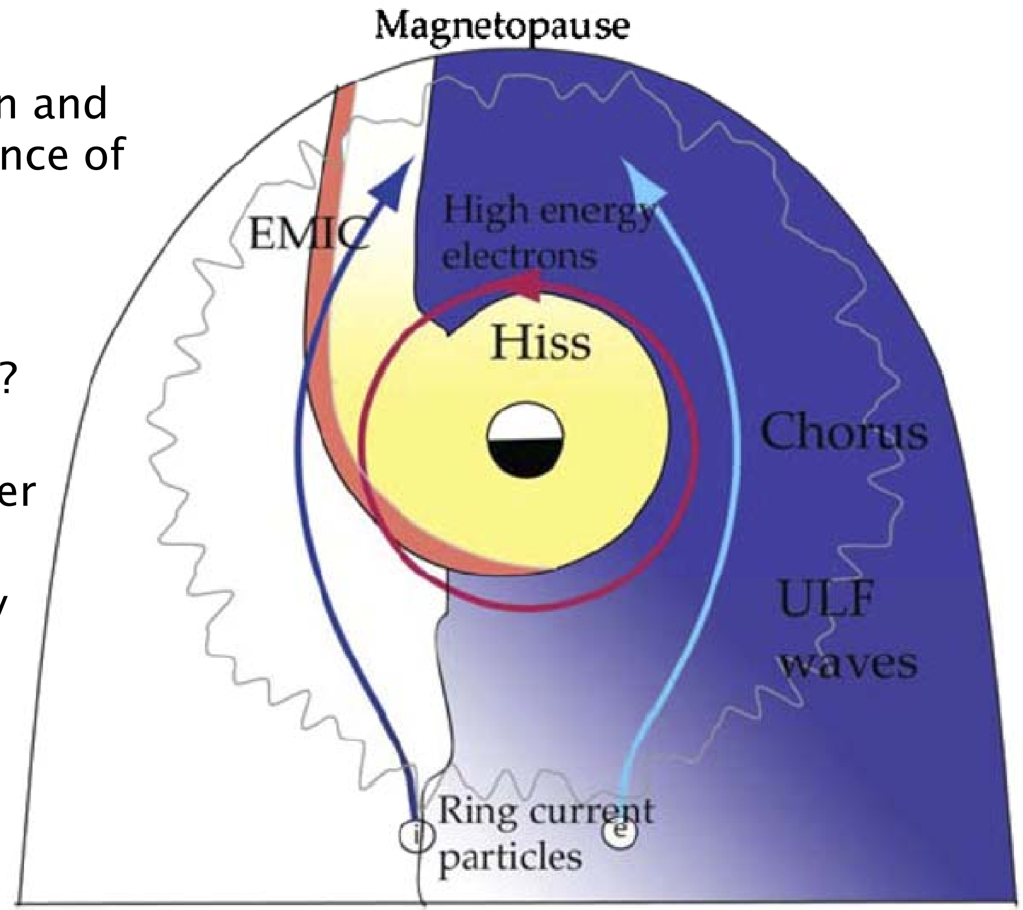
# RBSP First Science Endeavors

1. What issues can be resolved about strong and weak whistler mode interactions and their roles in electron energization and loss in the first 3 months?
2. What issues can be resolved about the large scale dynamics and structure with just the first few major geomagnetic storms?
3. What issues can be resolved about the source, structure, and dynamics of the inner ($L<2$) ion and electron belts in the first 3 months?

# EMFISIS Science

1. Correlations between various wave modes using varying separations between the two satellites. By start of normal operations (~60 days after launch) the satellites should be well separated.

- What wave modes happen at both satellites as a function of separation and location? What is the spatial coherence of chorus for small separation?
- Use cross-correlation to establish relationships between Chorus and hiss. Is chorus parent wave for hiss?
- Are micro-bursts on SAMPEX and BARREL correlated to chorus or other wave modes?
- Does Chorus modulate with density changes? (HOPE or MagEIS)

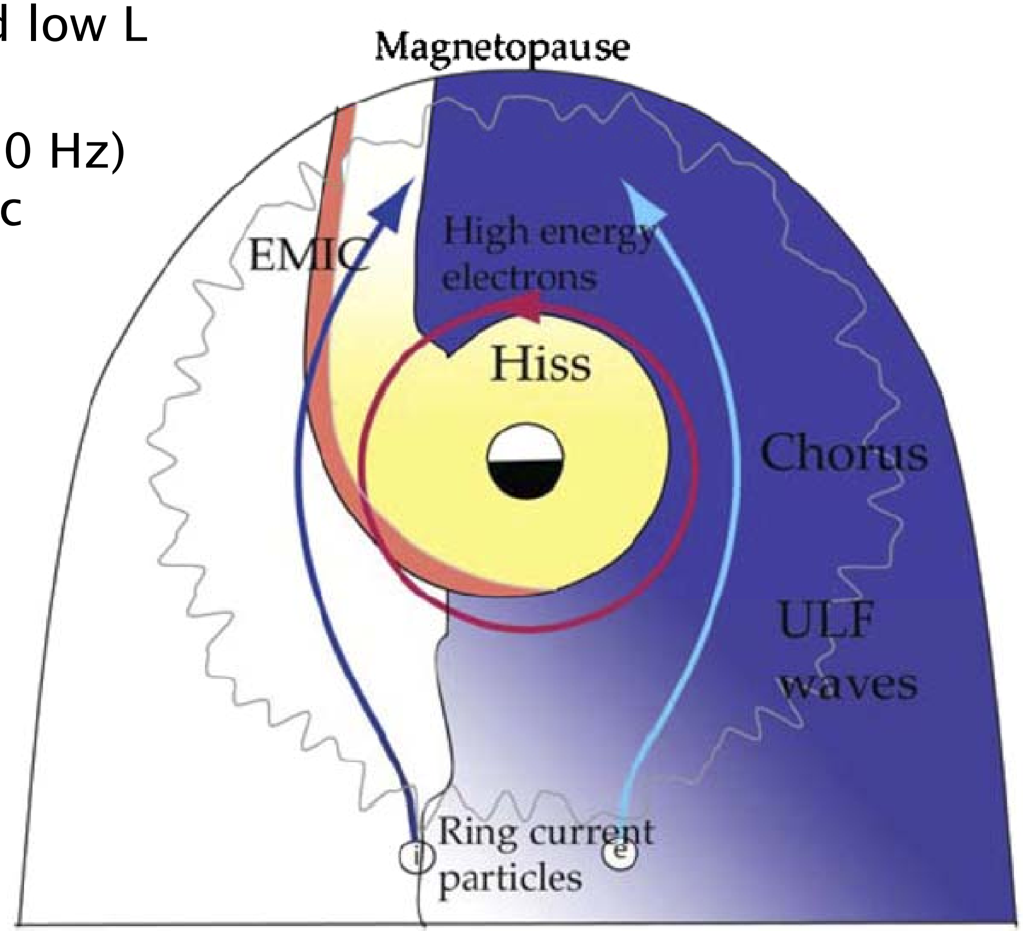



Shprits et al., 2006

Contribution by
Craig Kletzing

# Plasmaspheric Hiss   100Hz → few kHz

- Confined primarily to high density regions: plasmasphere, dayside drainage plumes.
- Generation mechanism not yet understood.
- At high frequency (>1kHz) and low L source could be lightning
- At typical frequencies (100–300 Hz) source is likely magnetospheric




Shprits et al., 2006

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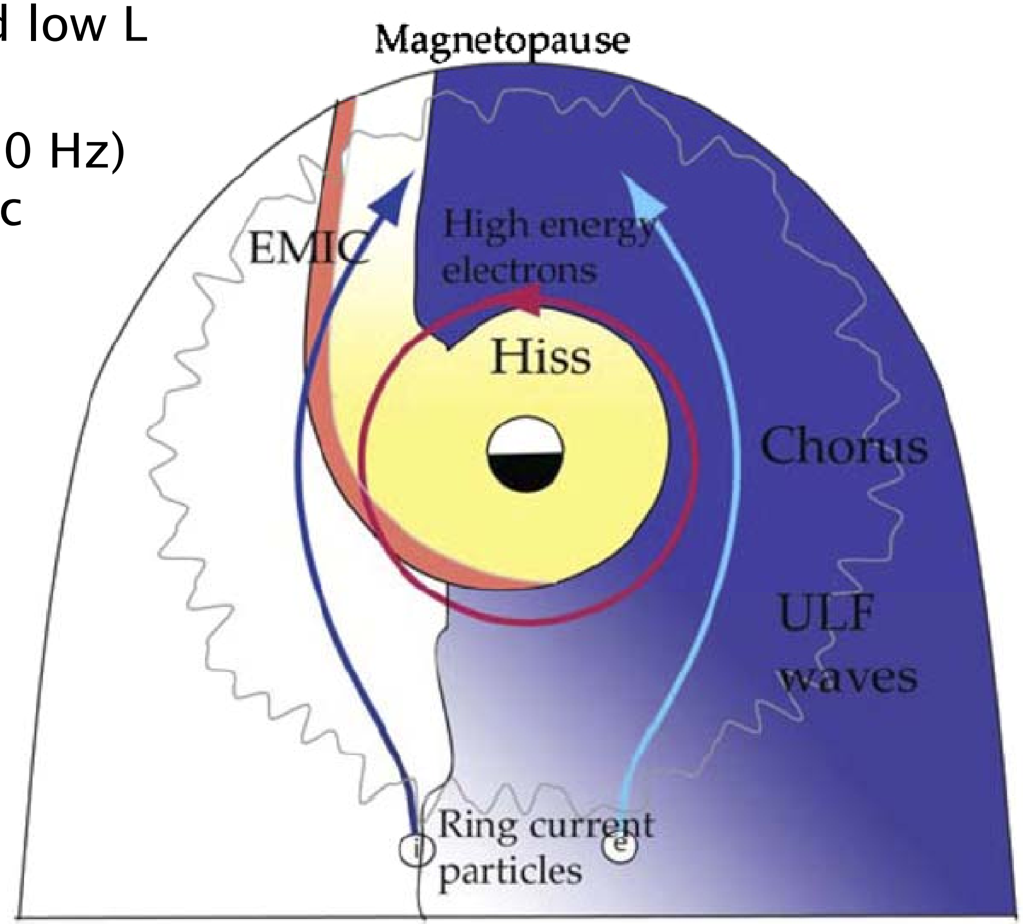
## Why do we care?

Hiss depletes the slot region by pitch angle scattering.




Shprits et al., 2006

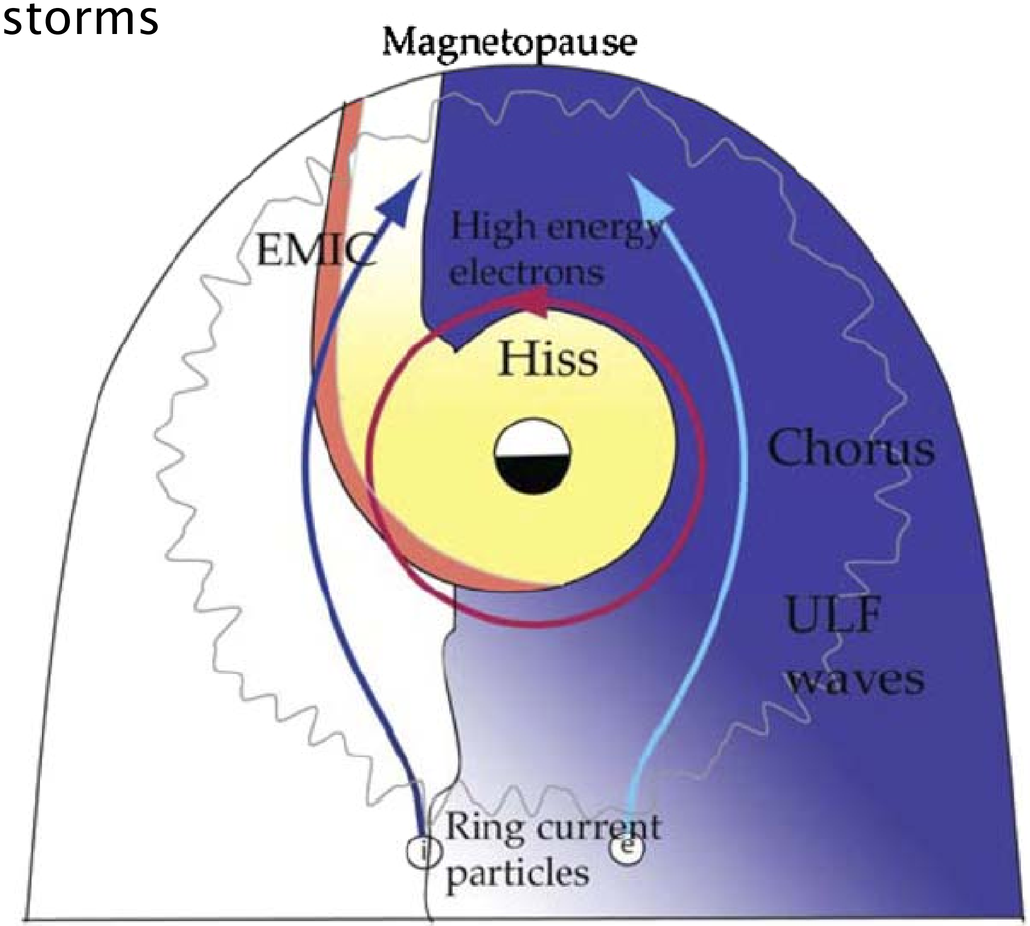
# Whistler mode Chorus 100Hz → 5 kHz

- Outside plasmasphere primarily on dawn side near equator.
- Generated by electron cyclotron instability near equator in association with freshly injected plasmasheet electrons.
- Increased intensity during substorms and recovery.
- Associated with microburst precipitation.

## Why do we care?

Capable of emptying the outer belt in a day or less.

Major potential mechanism for electron acceleration.

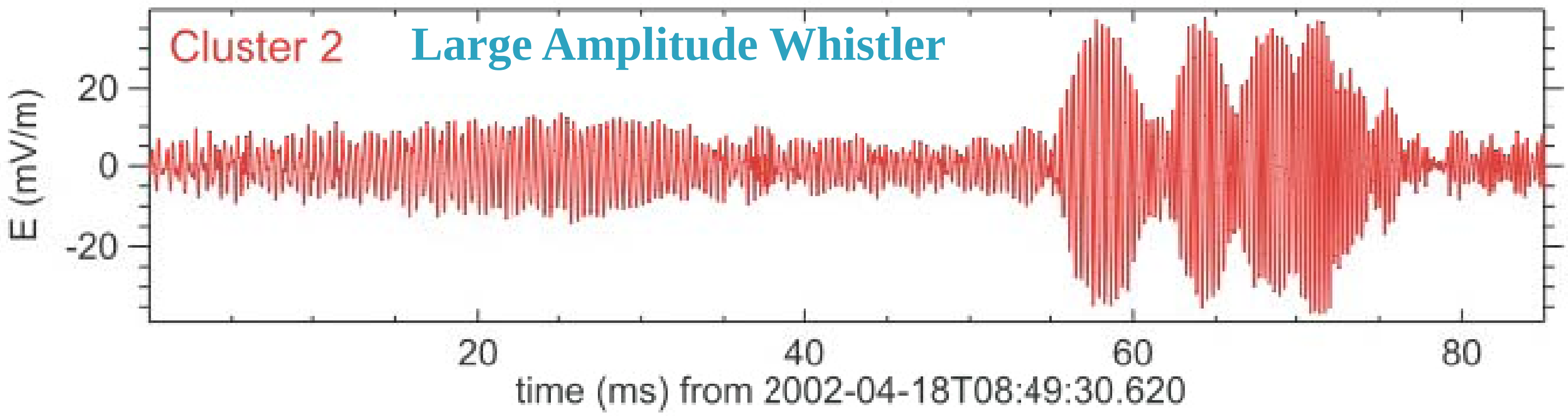



Shprits et al., 2006

# EFW Science

1. Explore the connection between large amplitude whistler waves and microburst precipitation.

Contribution by John Wygant, Kris Kersten




- Santolik, et al. (2003) - first report of large amplitude chorus elements
- Lower band chorus (<0.5fce) wave electric fields approaching 30mV/m

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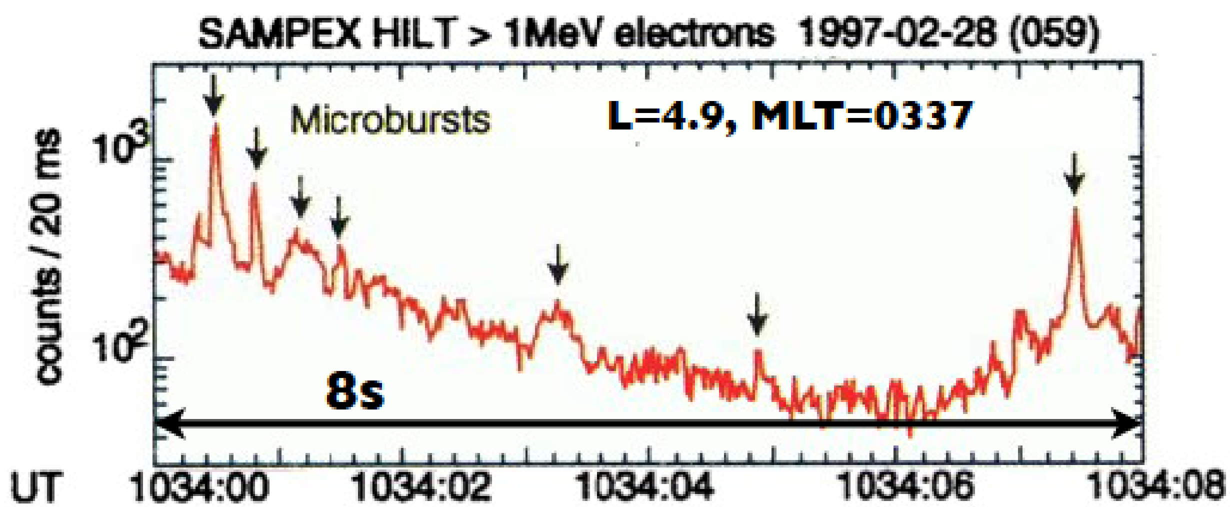
- Brief (<1s) increases in the flux of precipitating MeV electrons, first reported by Imhof, et al. (1992).
- Usually observed near dawn, but may extend from near midnight past dawn.
- Most commonly observed from L~4–6.

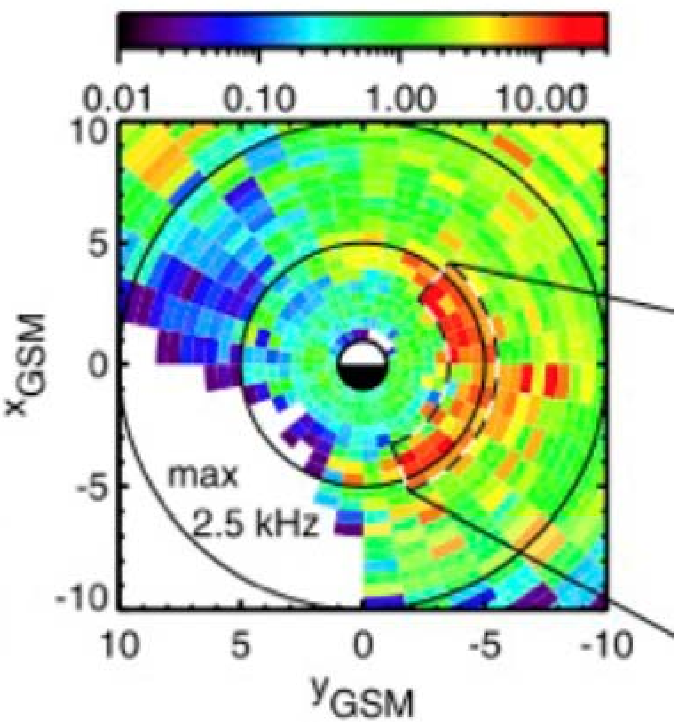



Contribution by John Wygant, Kris Kersten

# EFW Science

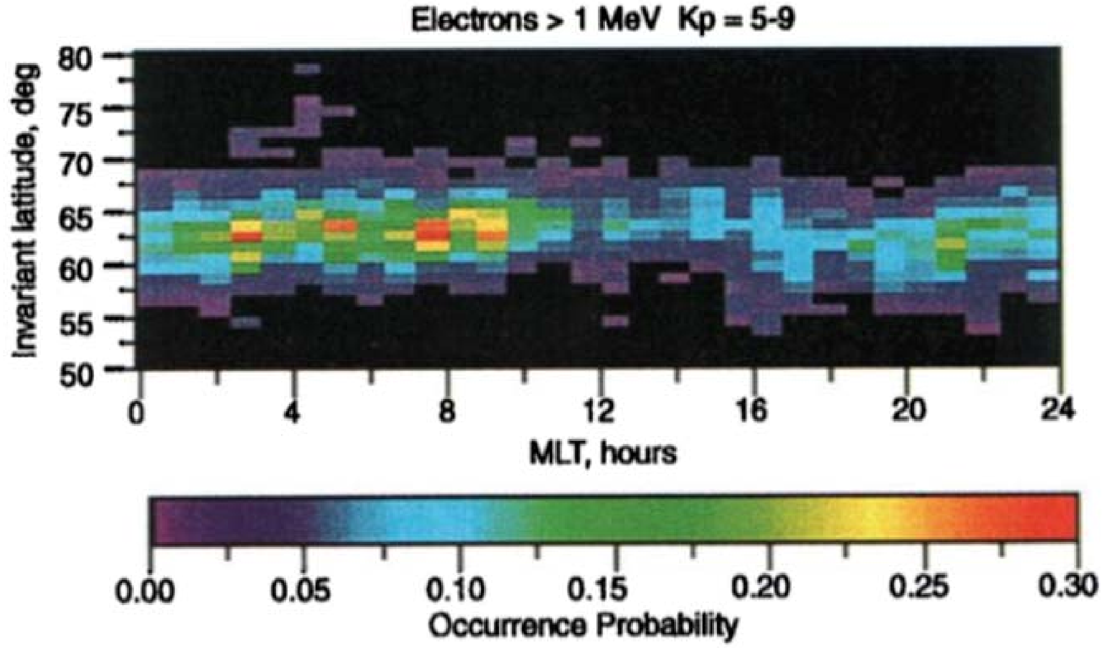
1. Explore the connection between large amplitude whistler waves and microburst precipitation.

**Large Amplitude Whistler Occurrence**




Cully et al., 2008

**Microburst precipitation occurrence**




Lorentzen et al., 2001

Statistically the connection is strong.

Contribution by John Wygant, Kris Kersten

# ECT Science

2. Identify the processes responsible for the precipitation and loss of relativistic and near relativistic particles, determine when and where these processes occur, and determine their relative significance.

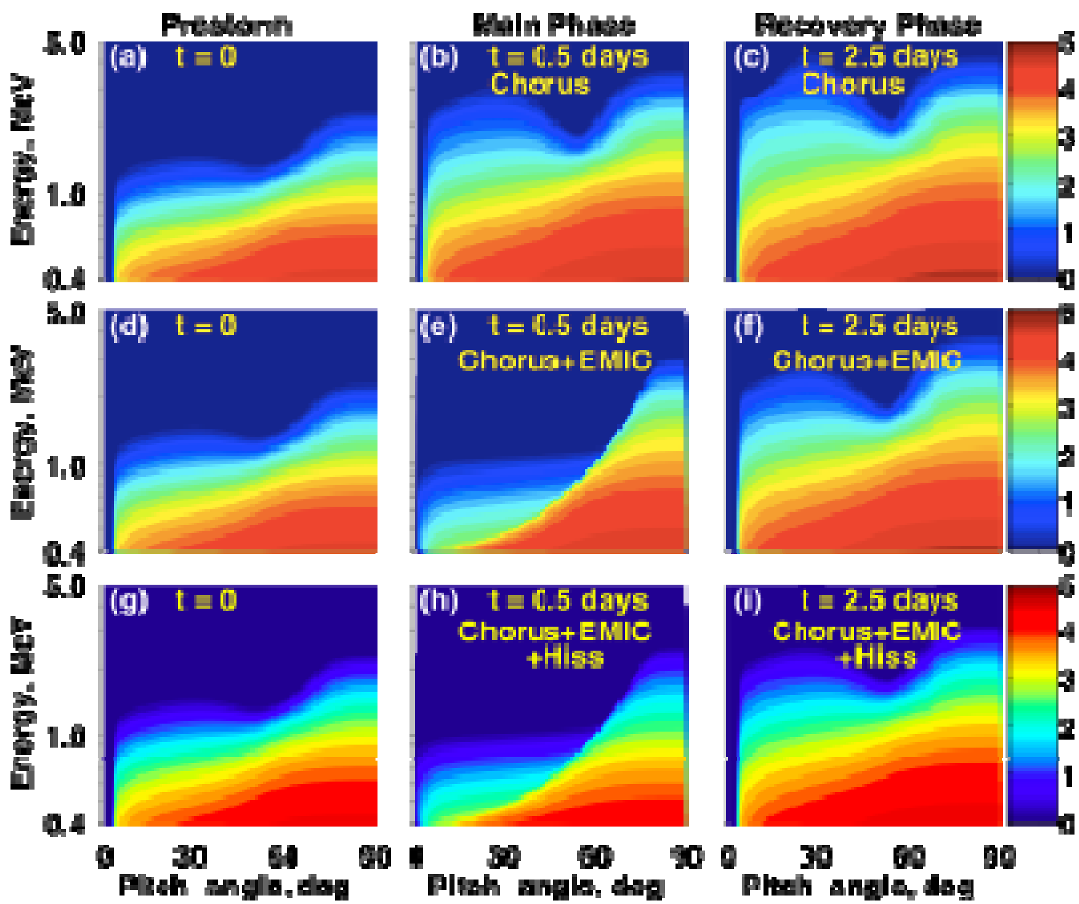
**Quick Science Study:**
Comparison of theory and observations for characteristic signatures of EMIC waves

Compare PSD as a function of E and PA during a dropout.

2D Energy-pitch angle diffusion model at fixed L

Do observations show expected signatures?

Expected Electron Distributions




Li et al., 2007

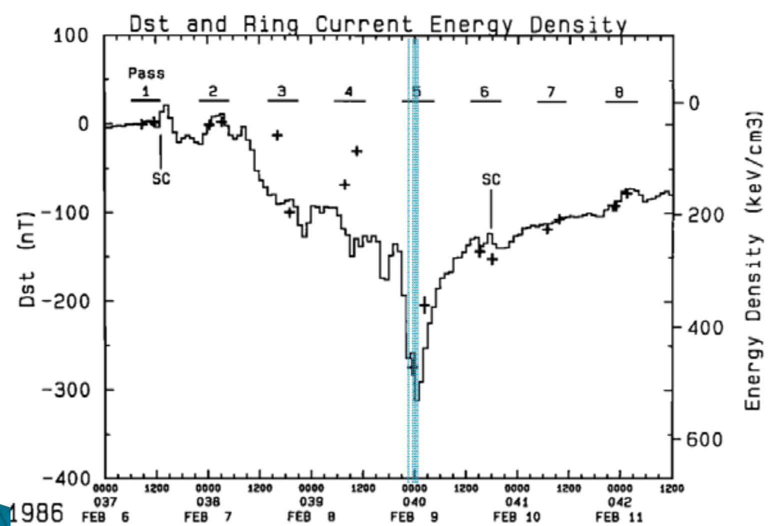
Contribution by
Geoff Reeves

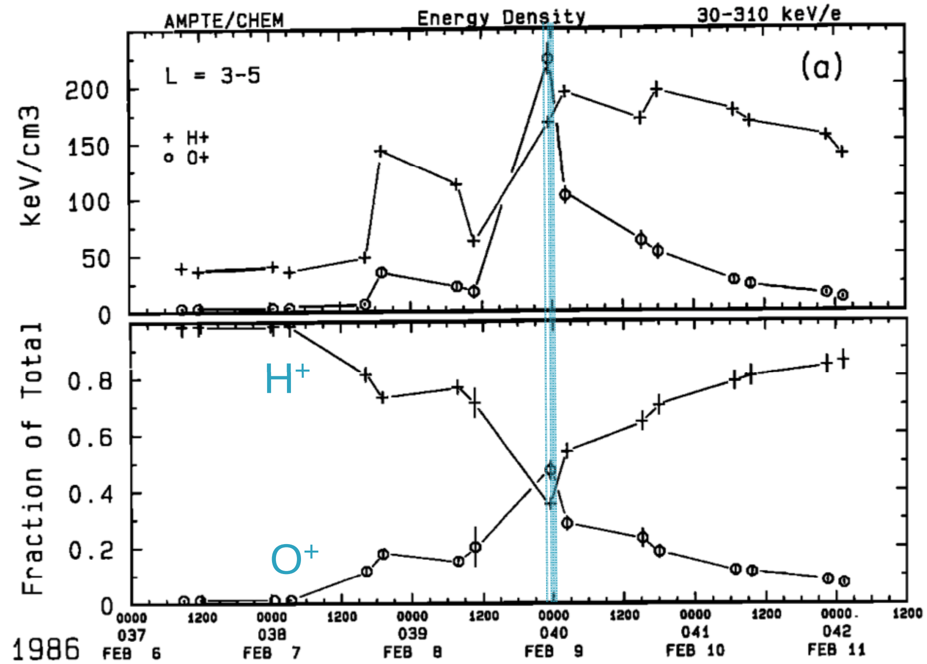
# RBSPICE Science

2. If we have some geomagnetic storms during the first few months of RBSP operation, then we can address the following question.

- How is current density from protons, helium ions, and oxygen ions compared during weak and strong geomagnetic storms?

**Energy density of oxygen ions can dominate that of protons during intense geomagnetic storms**




Hamilton et al., 1988

Contribution by
Tony Lui

# RPS Science

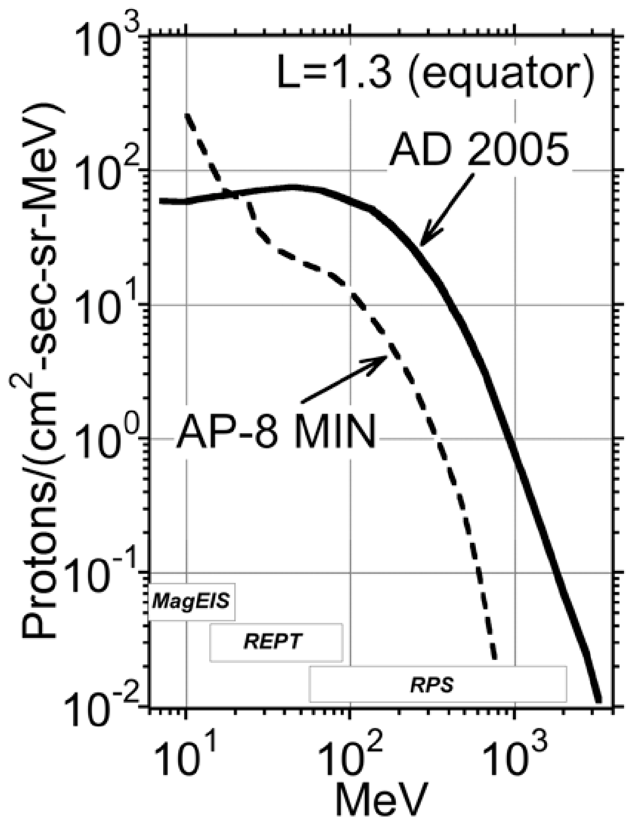
3. Discovery: What is the energy spectrum of the inner belt protons?

**Few satellites have spent significant time near the magnetic equator and at the peak intensities of the inner belt.**

The dominant source for protons above ~50 MeV in the inner belt is the decay of albedo neutrons from galactic cosmic ray protons that collide with nuclei in the atmosphere and ionosphere (Cosmic Ray Albedo Neutron Decay, or CRAND).

- Ion energy spectrum is known to extend beyond 1 GeV, but the spectral details are not well established: shape, maximum energy, time dependence
- Electron spectrum unknown. How do electrons get to the inner belt?

Example of the wide variation in modeled inner belt spectra




*AP8 MIN: Sayer & Vette 1976; AD2005: Selesnick, Looper, & Mewaldt 2007*

Contribution by
Joe Mazur

# BARREL Mission

The proposed investigation will address the RBSP goal of, "differentiating among competing processes affecting precipitation and loss of radiation particles" by directly measuring precipitation during the RBSP mission.

- Launch 20 balloons each in January 2013 and January 2014 from Antarctica.
- BARREL will simultaneously measure precipitation over 8-10 hours of magnetic local time.
- Combine the measurements of precipitation with the RBSP spacecraft measurements of waves and energetic particles.


Contribution by
Robyn Millan

# BARREL/RBSP Coordinated Science

1. What is theloss rate due to precipitation versus magnetopause losses?

**Motivation: Recent results of Turner et al., 2012 vs earlier results from e.g., Selesnick 2006, O'Brien 2004.**

Measurements

- **RBSP**: measure changes in in-situ trapped electron intensity
- **BARREL**: quantify precipitation at range of local times
- **POES, SAMPEX, riometer**: precipitation at other local times
- **THEMIS**: magnetopause losses

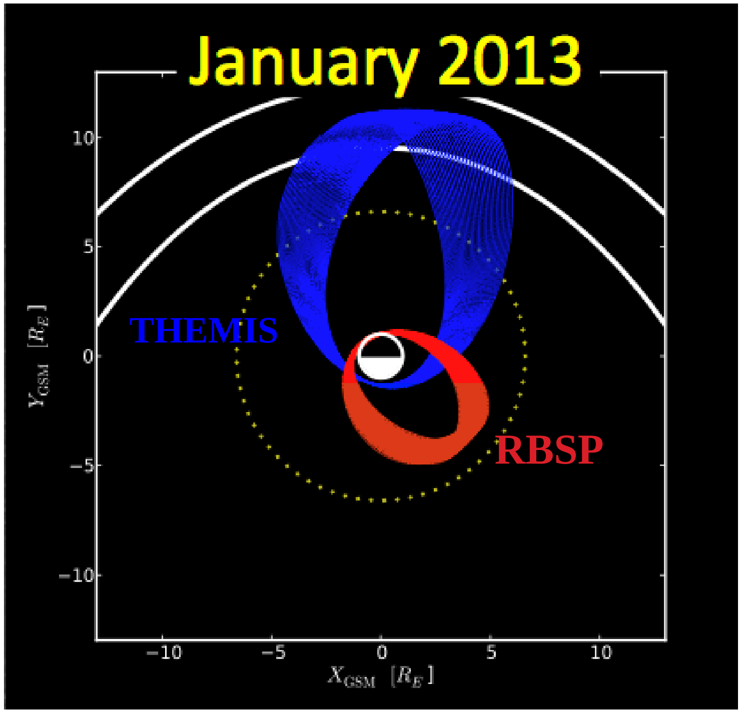
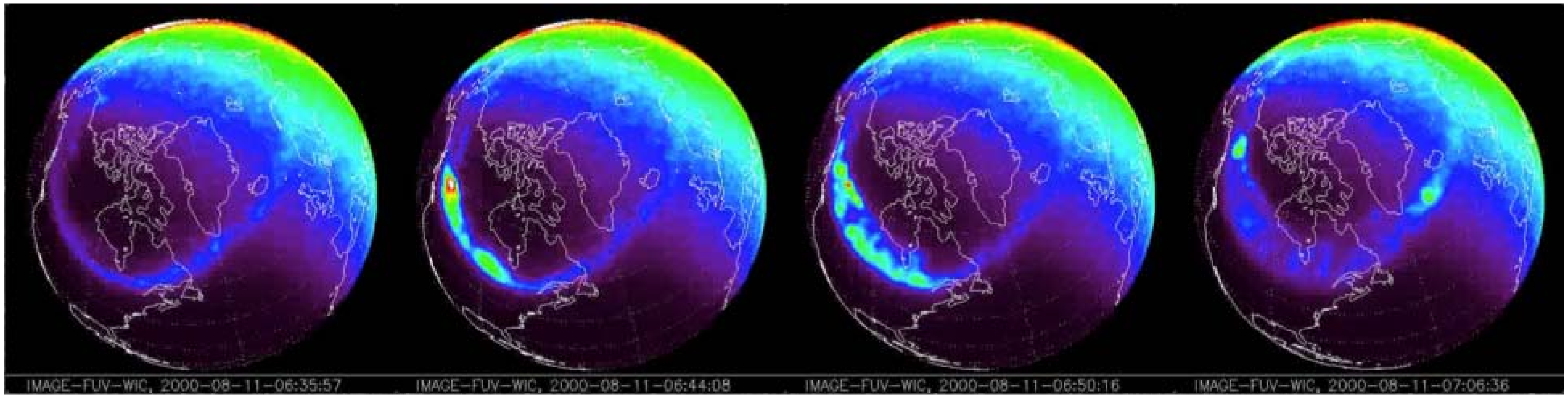



Figure courtesy of A. Ukhorskiy

Contribution by
Robyn Millan

# BARREL/RBSP Coordinated Science

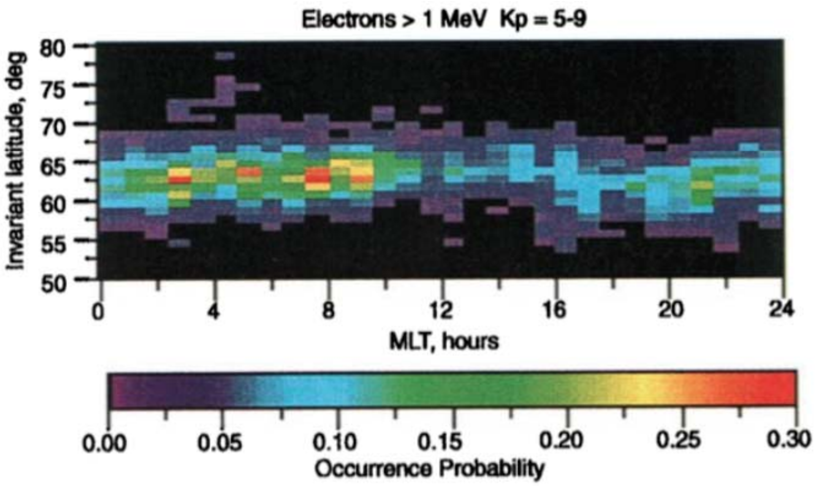
**IMAGE FUV reveals temporal evolution of auroral precipitation**




1. How does the spatial scale of relativistic electron precipitation evolve in time?

Motivation: Discovery – We don't know how it evolves!

**Statistical distribution of microbursts from SAMPEX**



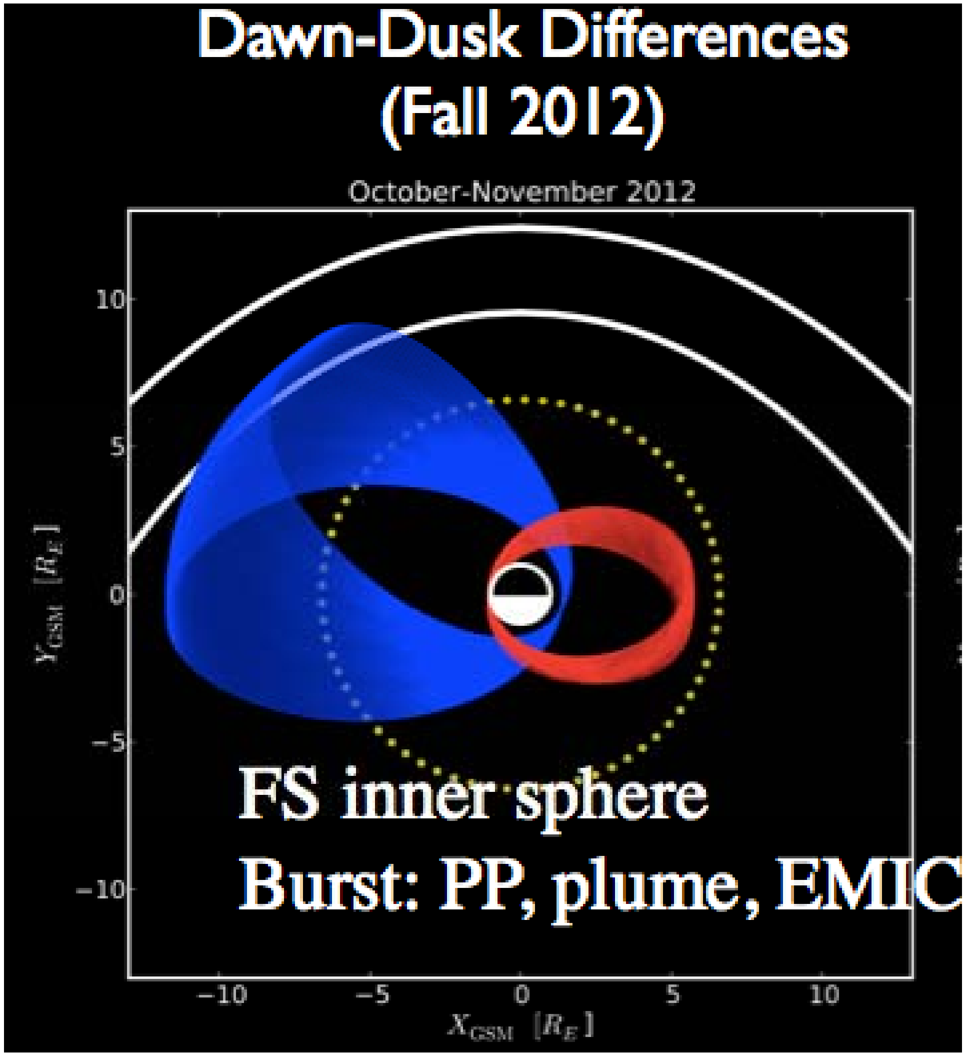

Lorentzen et al., 2001

Contribution by
Robyn Millan

# THEMIS/RBSP Coordinated Science

First Planned Science Campaign
Science Objectives:

- What are the cause(s) of dawn-dusk differences in ion fluxes during geomagnetic storms?
- What role does the Kelvin-Helmholtz instability play in particle energization, transport, and loss?
- What are the relative roles of EMIC waves in the dusk magnetosphere, chorus waves in the dawn magnetosphere, and hiss deep within the magnetosphere?




THEMIS has 4-8-12 hours separation of the 3 satellites along the orbit.

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