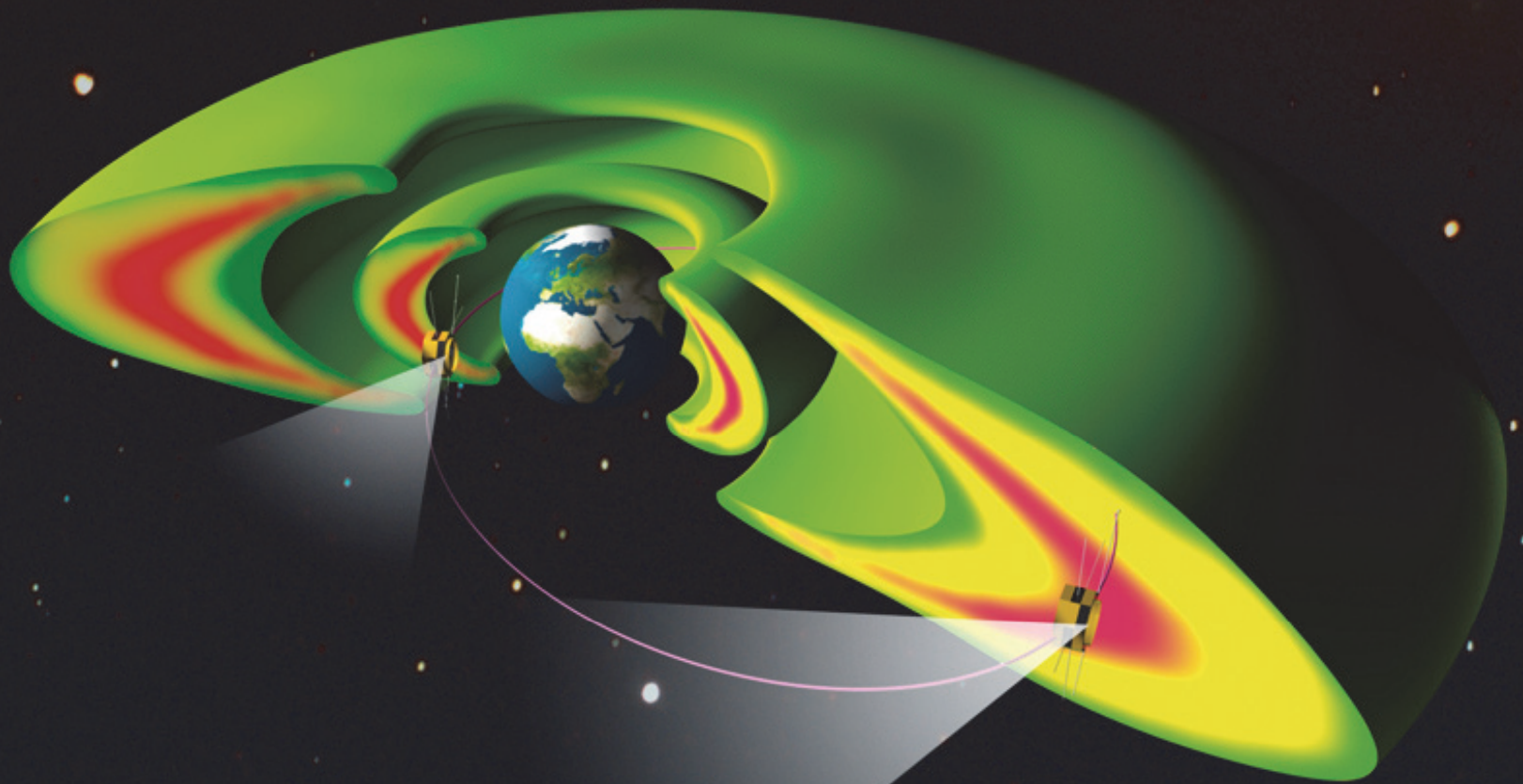


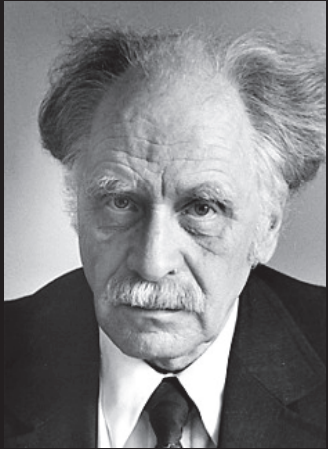
# RBSP Mission: Understanding Particle Acceleration and Electrodynamics of the Inner Magnetosphere



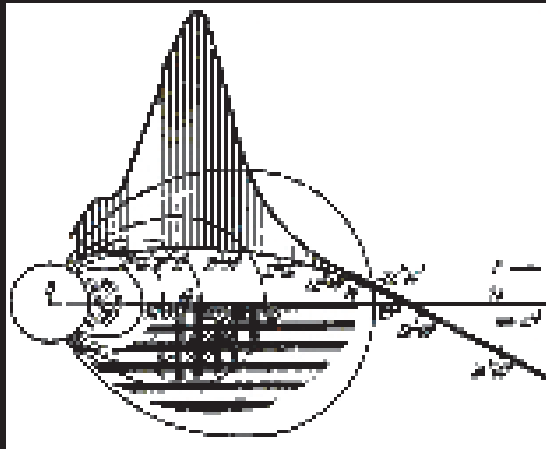
A. Y. Ukhorskiy<sup>1</sup>, B. Mauk<sup>1</sup>, N. Fox<sup>1</sup>, D.G. Sibeck<sup>2</sup>  
<sup>1</sup>JHU/APL, <sup>2</sup>NASA GSFC

# “My God, space is radioactive!”

Ernie Ray, 1958



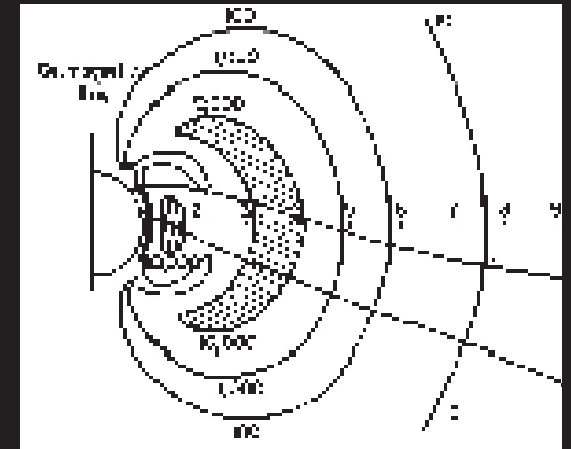
Спутник II, III



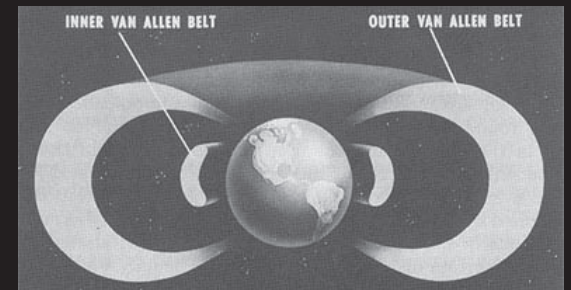
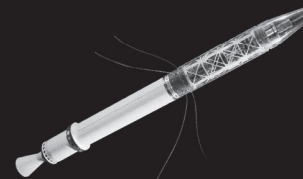
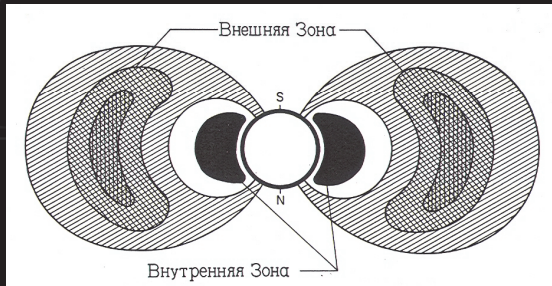
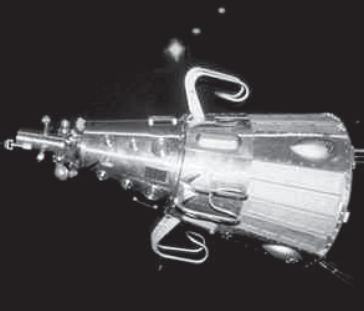
[Vernov et al., 1959]



Explorer 1



[Van Allen, 1959]



# Dynamic Evolution of the Belts

## SAMPEX 2002 Daily Averaged >1 MeV Fluxes

QuickTime™ and a  
decompressor  
are needed to see this picture.

### Inner belt

\*  $\lesssim 2.5 R_E$

\* electrons:  $\gtrsim 0.5 - 10$ s MeV

\* protons:  $\gtrsim 1$  MeV - 1GeV

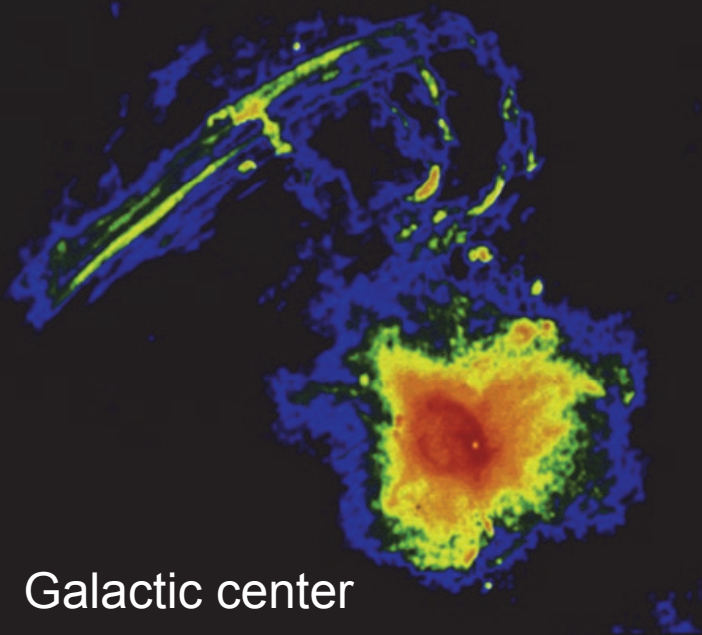
### Outer belt

\*  $\gtrsim 2.5 R_E$

\* electrons:  $\gtrsim 0.5$  MeV

# Particle Acceleration in Space

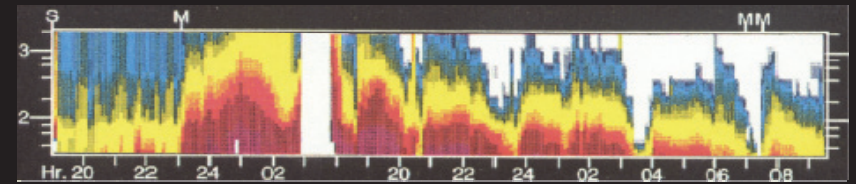
ISEE and Voyager results suggest that radiation belts exist at all strongly magnetized planets



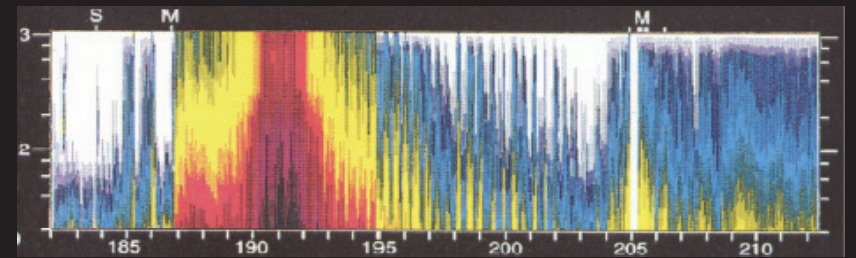
Galactic center

Particle acceleration to relativistic energies is observed in other space plasma systems

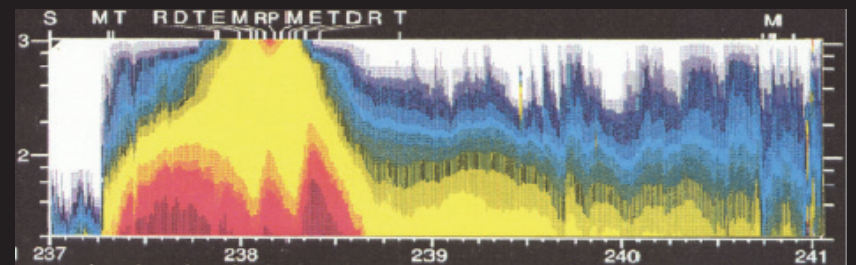
Earth



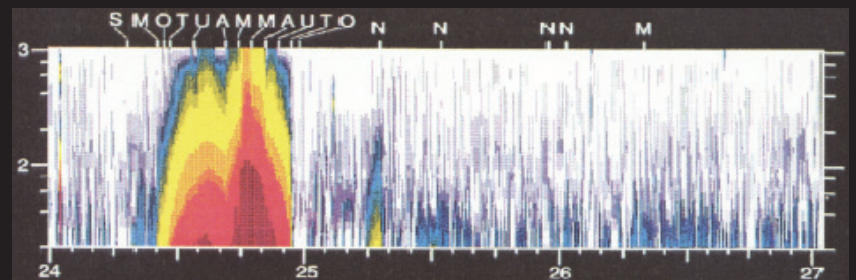
Jupiter



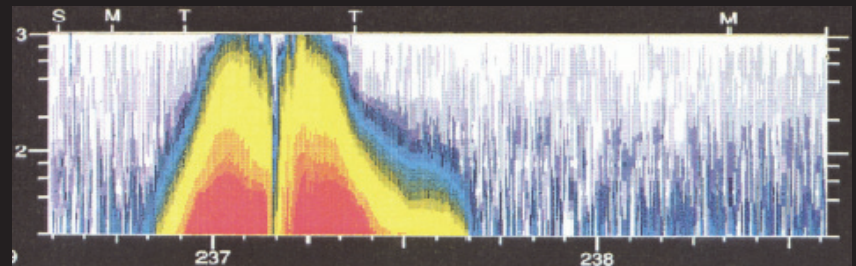
Saturn



Uranus



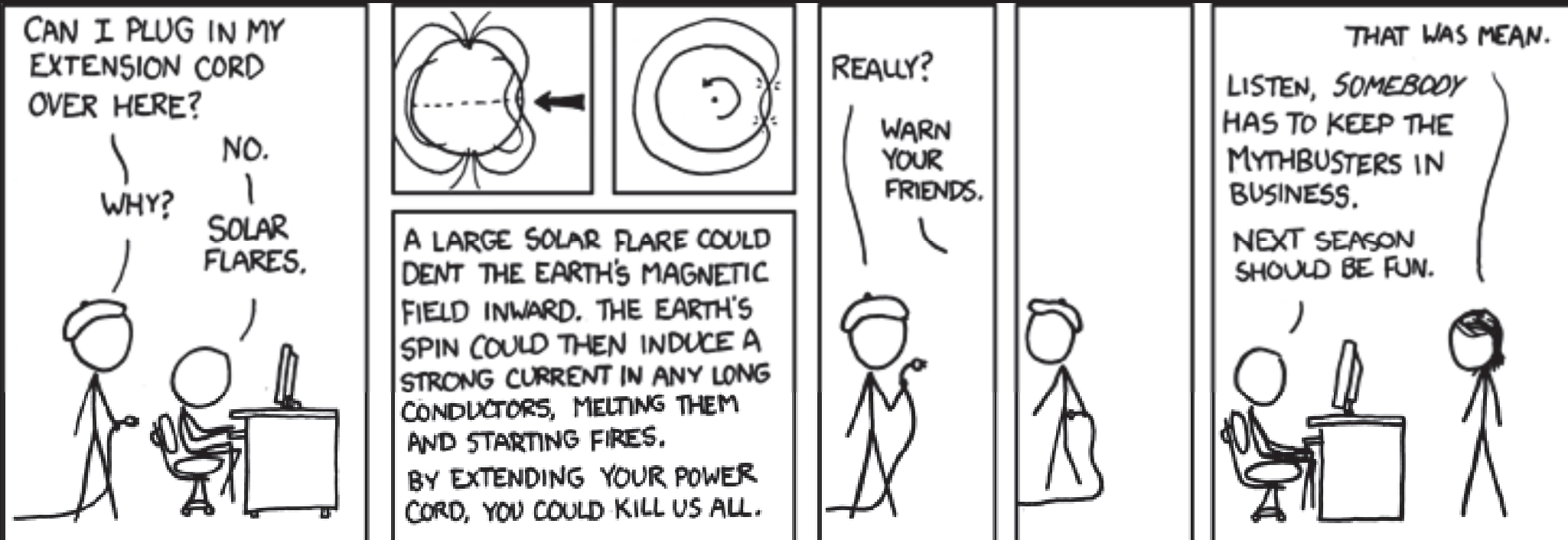
Neptune



Encounter Time [days/hr]

Log Energy [keV]

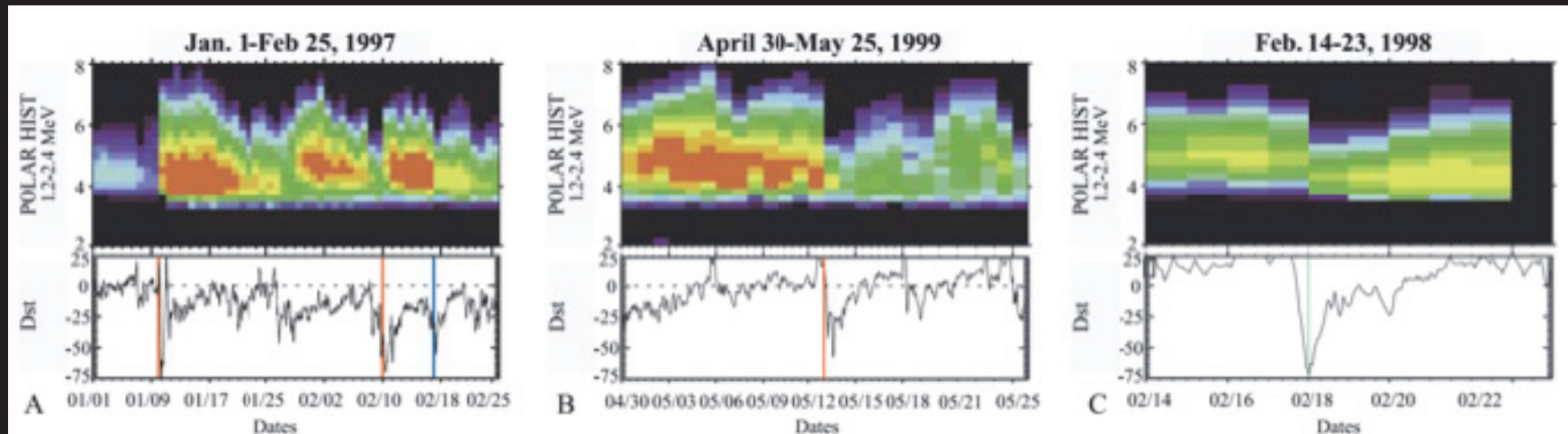
# Growing Role of Space Weather



# What's the Big Mystery?

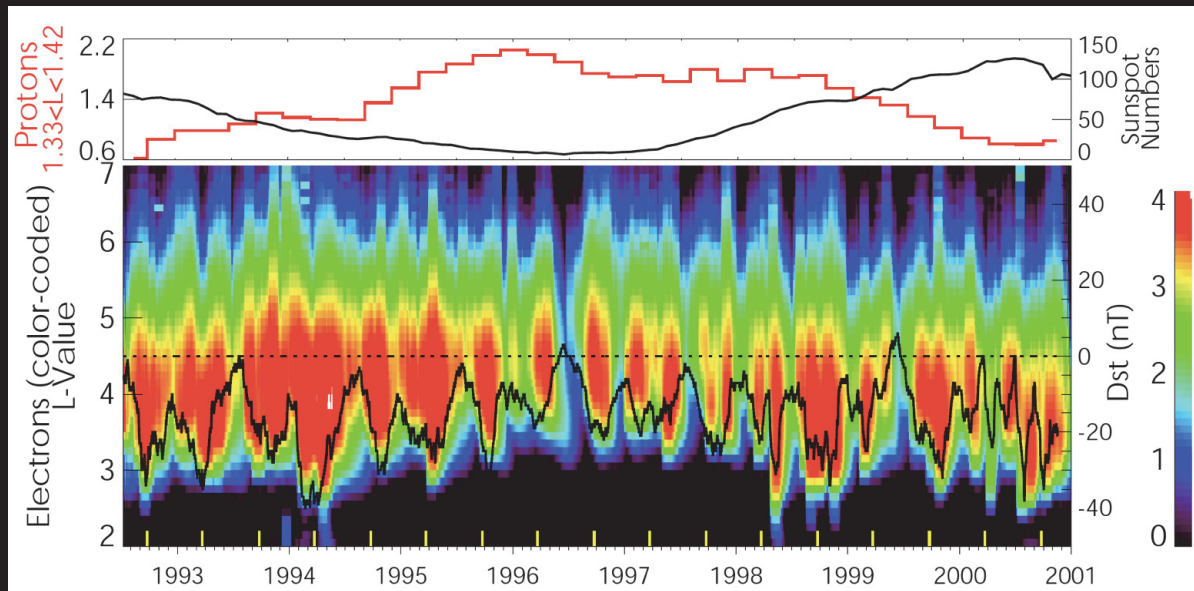
Some geomagnetic storms can:

- (1) Cause dramatic radiation belt enhancement;
- (2) Deplete radiation belt fluxes;
- (3) Cause no substantial effect of flux distributions;

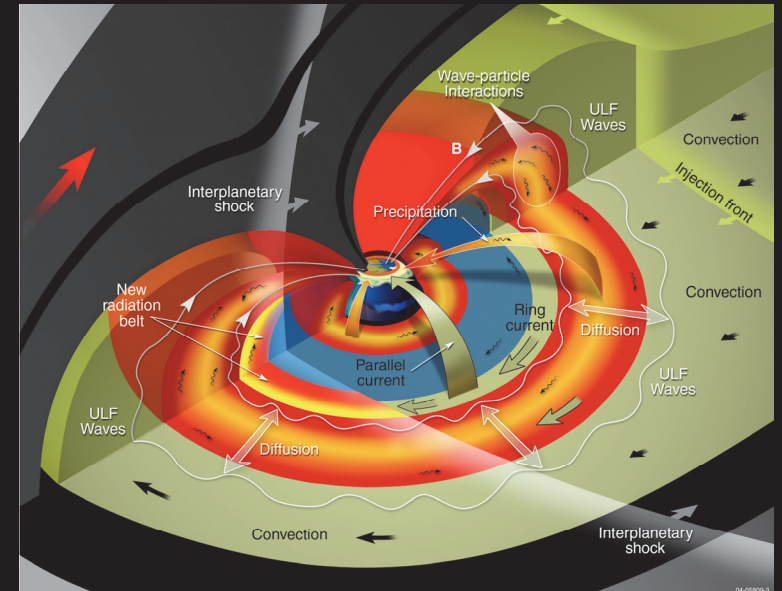


[Reeves et al., 2003]

# Challenge: Understanding Complex Dynamical System



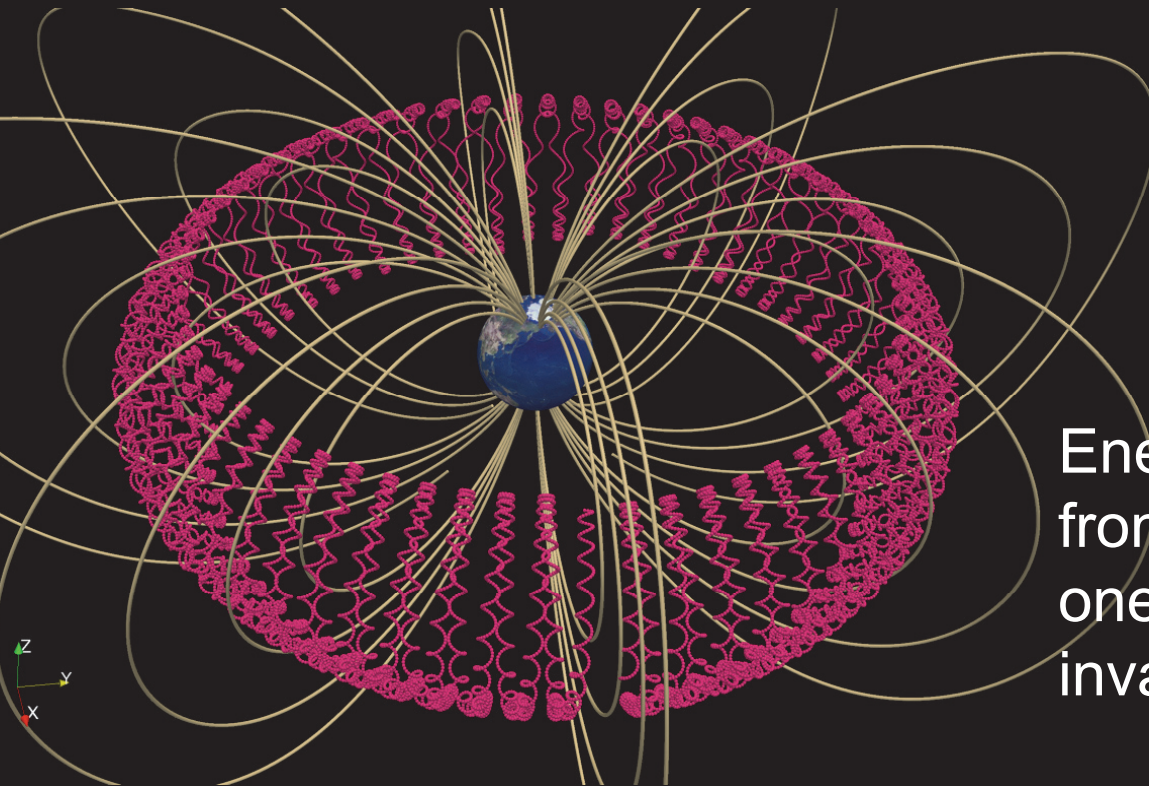
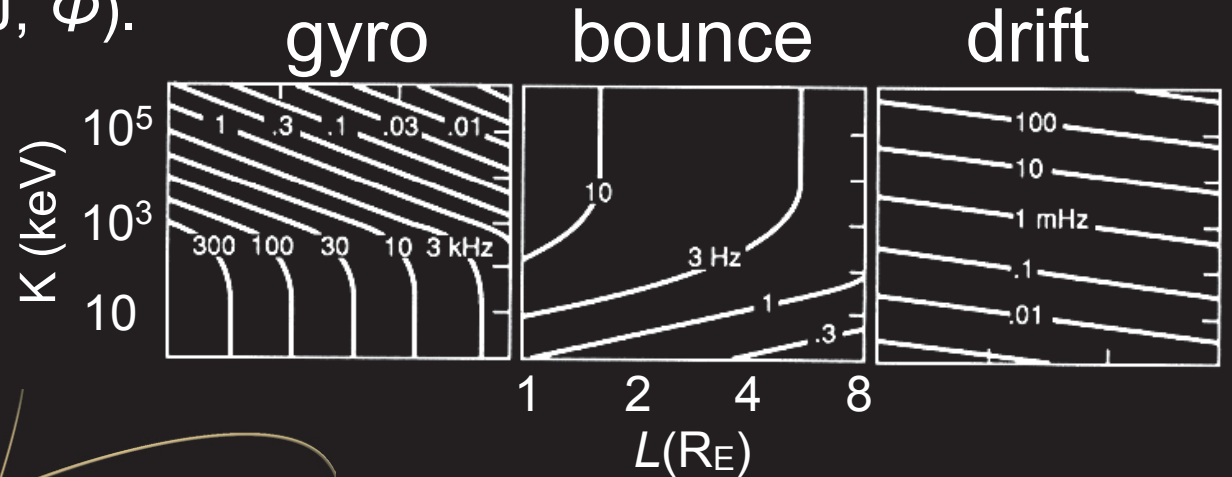
[Li et al., 2001]



Creation and variation of radiation populations are produced by a complicated interplay of multiple processes. A broad range of coordinated measurements is needed to sort them out. How processes interact with each other under varying conditions to generate real space environments is unknown. Profound mysteries remain because existing observations are insufficient to resolve the system science.

# Electron Motion in the Belt

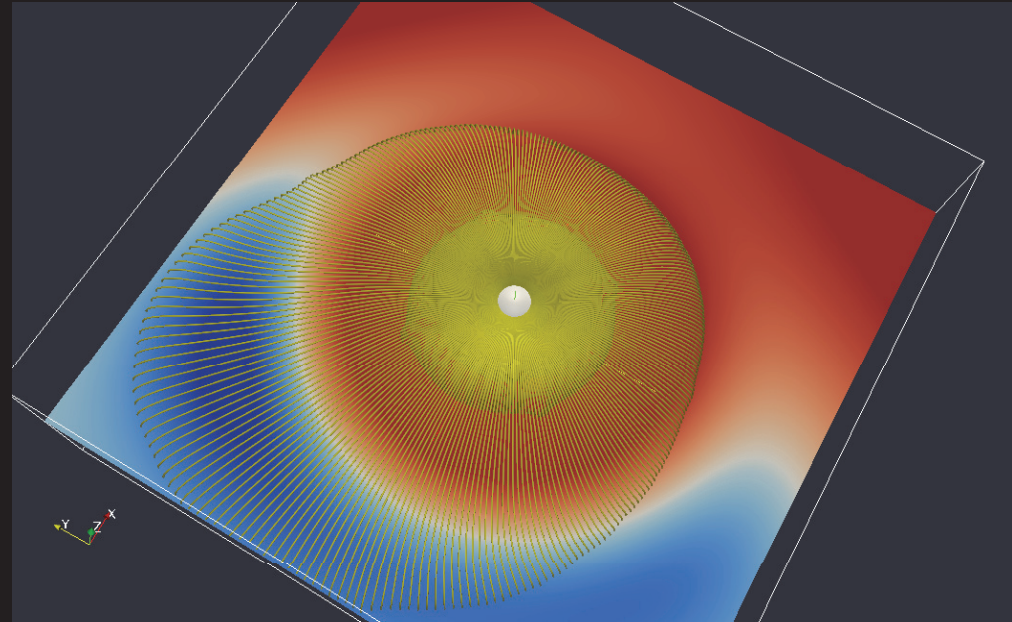
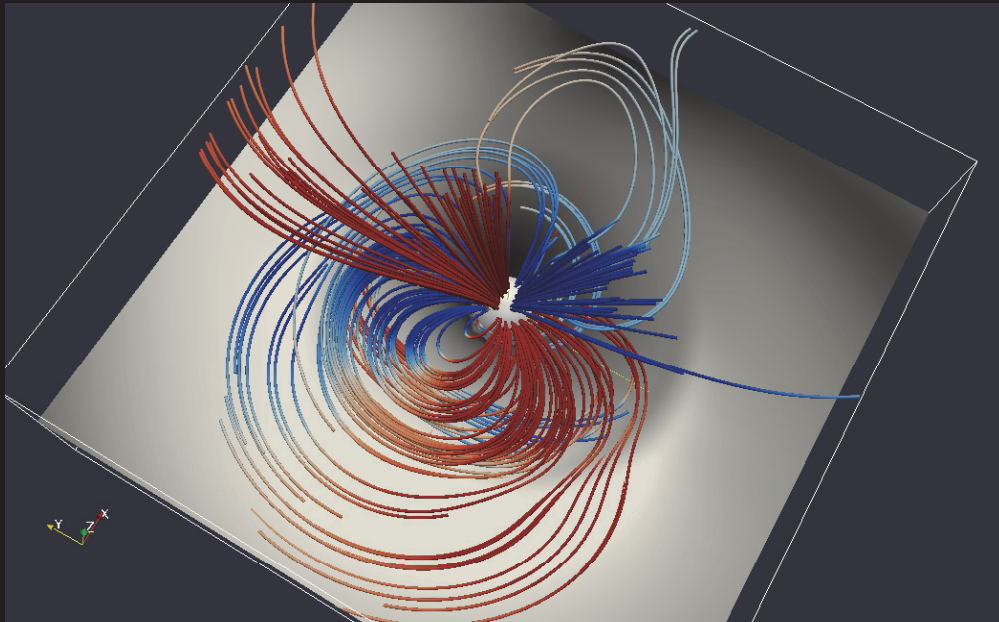
Electrons trapped in the Earth's magnetic field exhibit three quasi-periodic associated with adiabatic invariants ( $\mu$ ,  $J$ ,  $\Phi$ ).



Energization and loss of electrons from the belt requires violation of one or more of the adiabatic invariants.



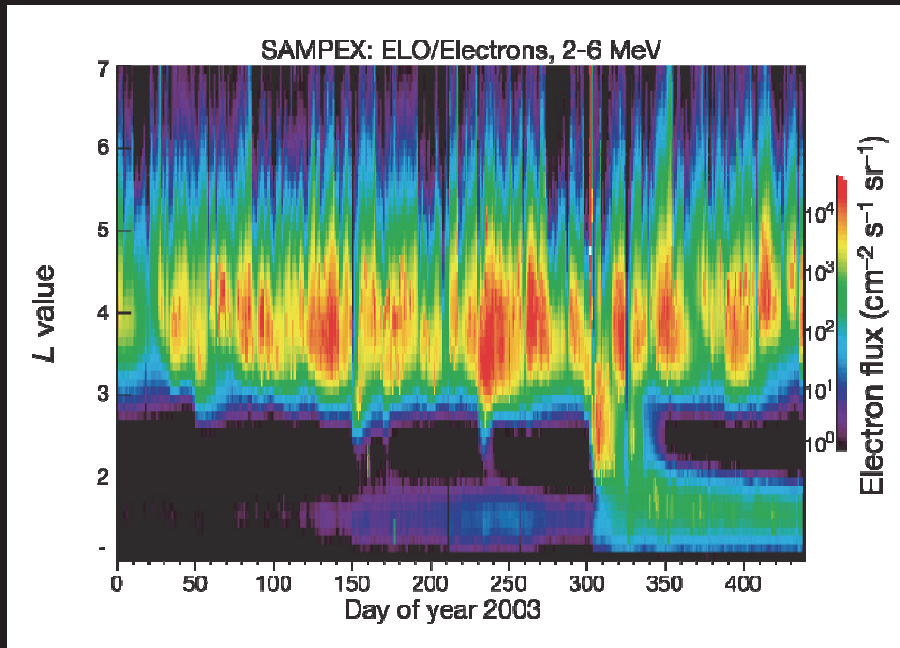
# Storm-Time Electrodynamics



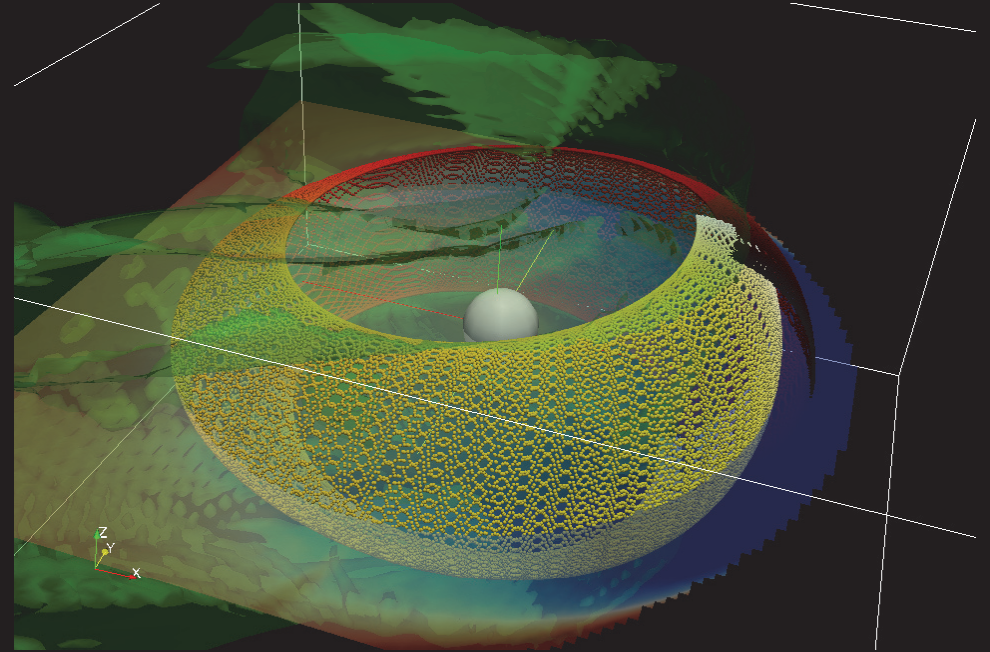
Evolution of hot plasma pressure in the inner magnetosphere drives global current system which produces large distortions in the inner magnetospheric fields.



# Global Mechanisms



[Baker et al., 2005]



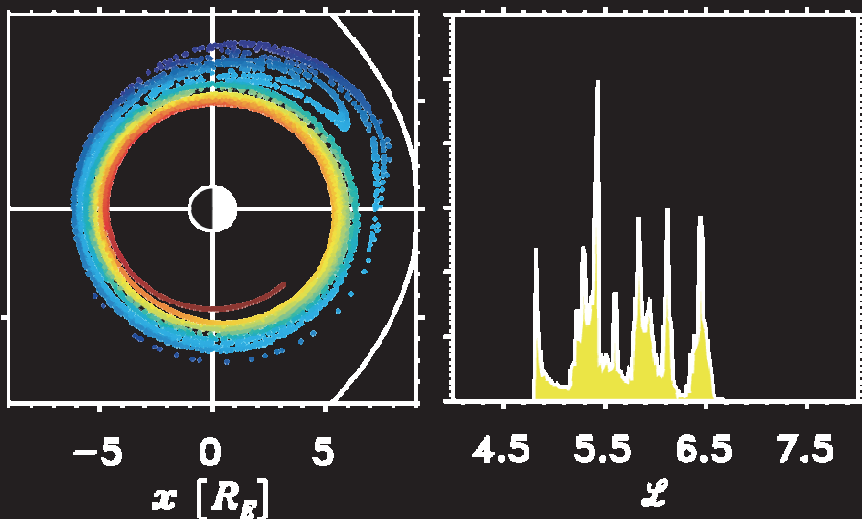
The observed large-scale variability of electron fluxes across the belt implies the existence of global mechanisms active over broad spacial regions of the inner magnetosphere. Global mechanisms drive radial transport of electrons across their drift shells by violating their third adiabatic invariant ( $\Phi$ ).

# Non-Diffusive Radial Transport

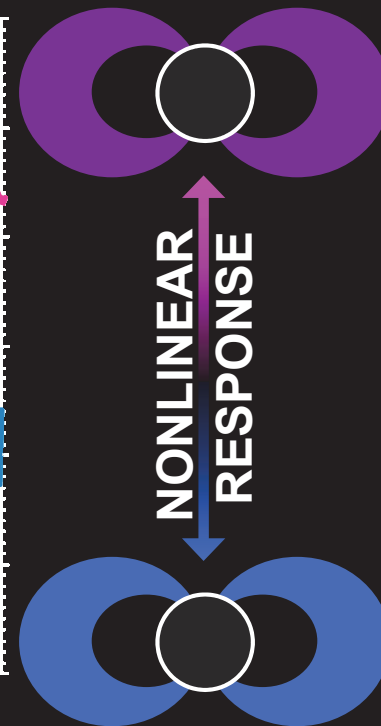
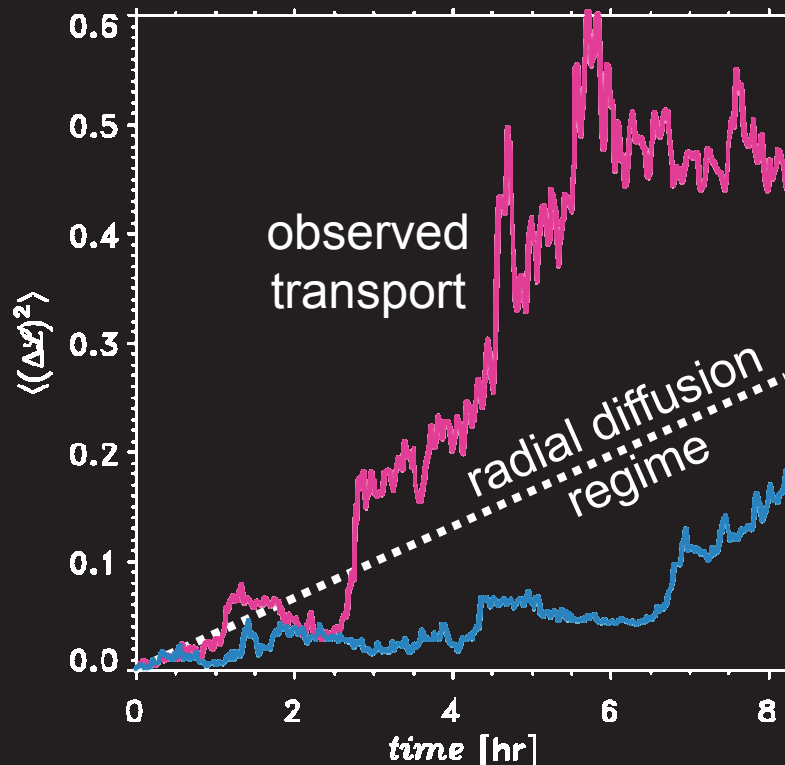
## ULF Wave Driver

QuickTime™ and a  
GIF decompressor  
are needed to see this picture.

## Filamentation of PSD

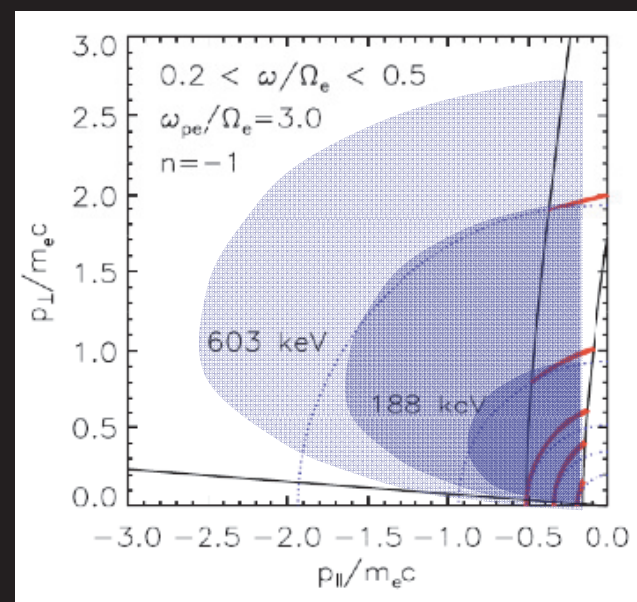
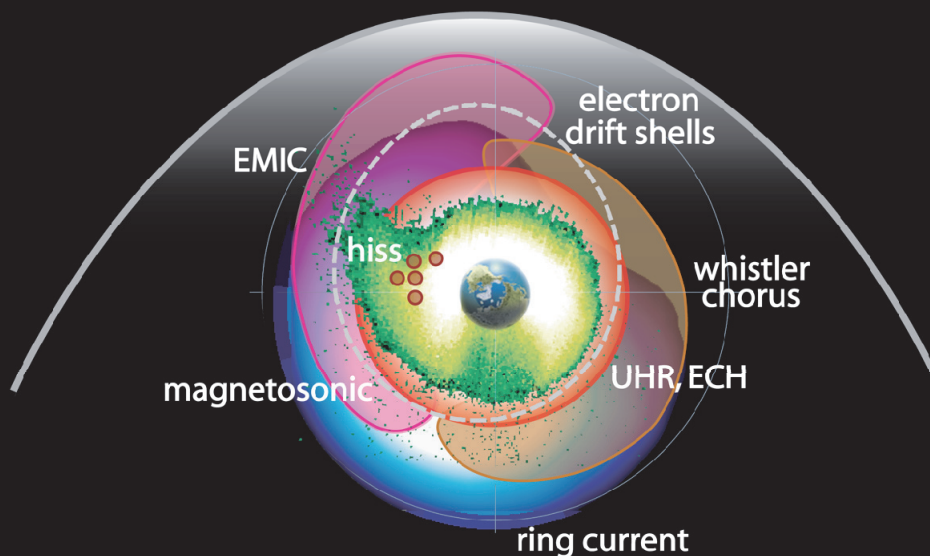


## Non-diffusive Transport



Radial transport in the outer belt can exhibit large deviations from radial diffusion, which may account of the observed nonlinear response of electron fluxes to geomagnetic activity: even similar storms can produce vastly different radiation levels across the belt.

# Local Mechanisms



[Thorne et al., 2005]

Local mechanisms break the first invariant of radiation belt electrons. Resonant wave-particle interactions of electrons with EMIC and whistler waves can produce both acceleration and loss of particles from the belt.

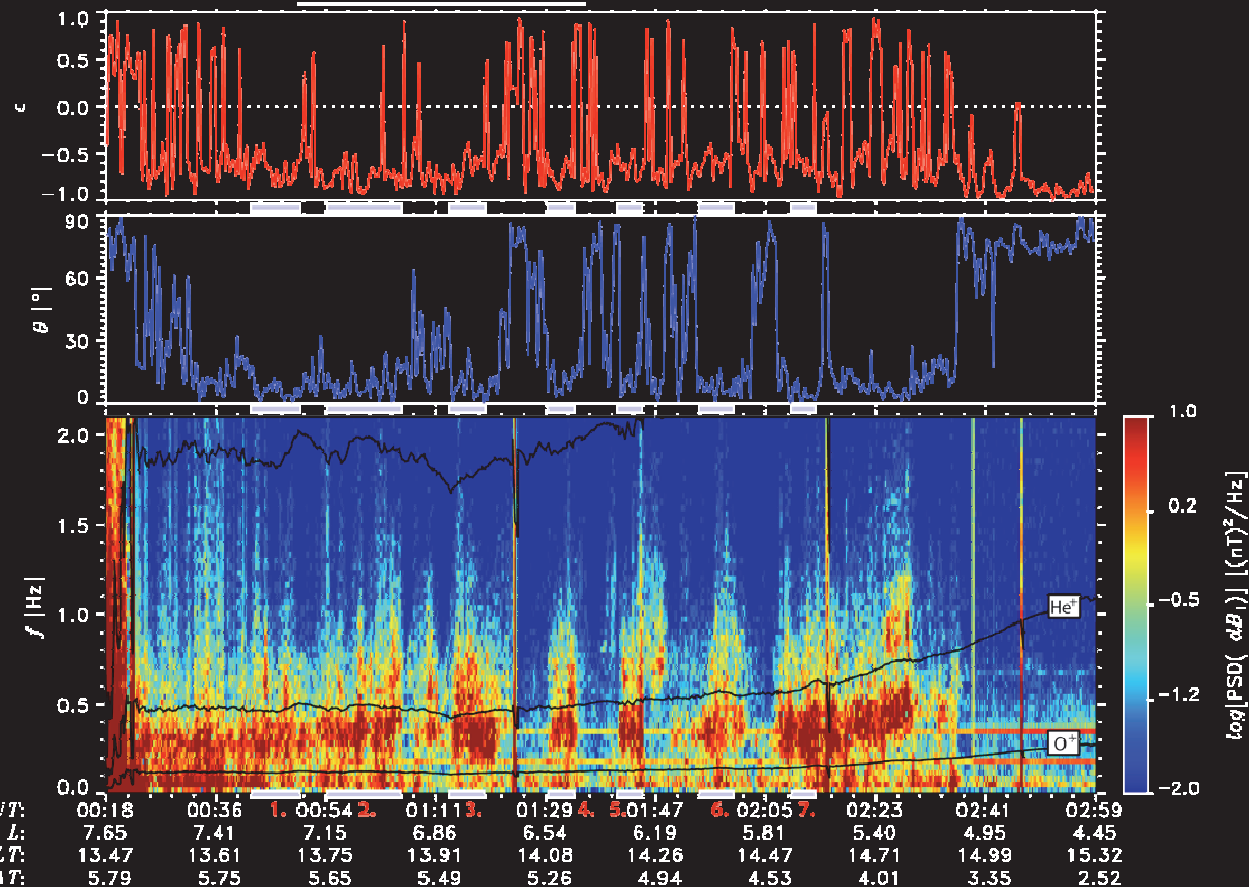
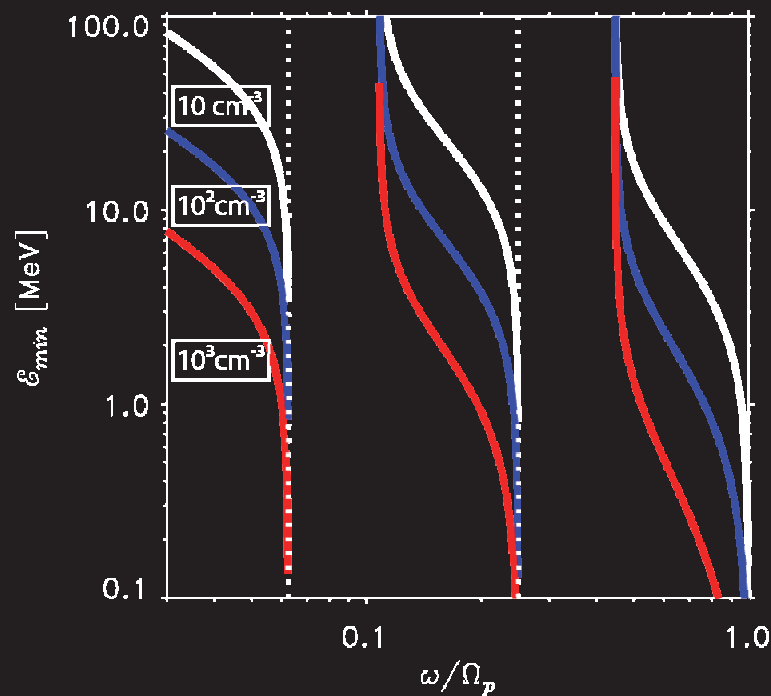
# EMIC Waves

$$\omega - k_{\parallel} v_{\parallel} = \frac{\Omega_e}{\gamma}$$

Minimum Energy      Resonance

EMIC Waves @ AMPTE/CCE

$$\mathcal{E}_{min} \simeq \frac{B^2}{8\pi N_i} \frac{m_i}{m_e} \frac{\delta\omega}{\Omega_i}$$



Global impact of EMIC waves on losses across the outer radiation belt depends on spatial extent of EMIC wave activity in the inner magnetospheric regions.

# RBSP Orbit:

EQUATORIAL ORBIT, COMPLETE MLT COVERAGE

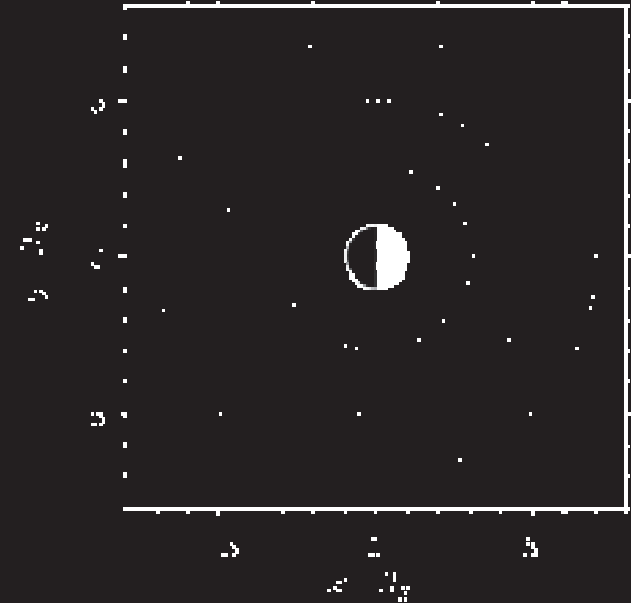
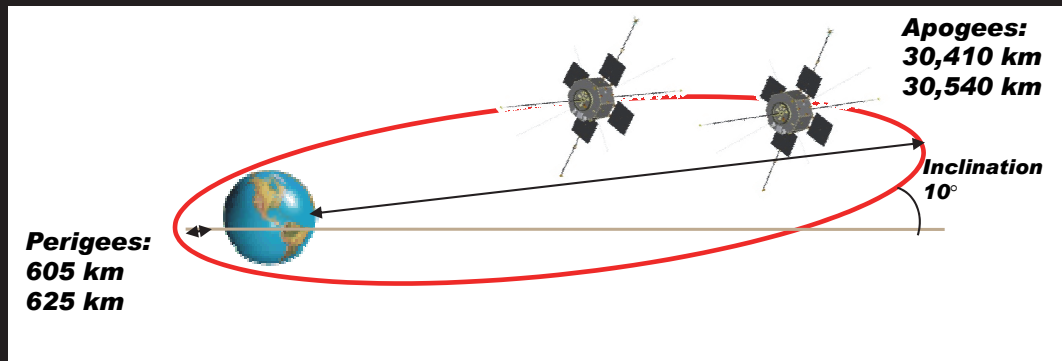
## 2 Observatories

Spin Stabilized ~5 RPM

Spin-Axis  $15^{\circ}$ - $27^{\circ}$  off Sun

Attitude Maneuvers Every 21 days

Operational Design Life of 2 years



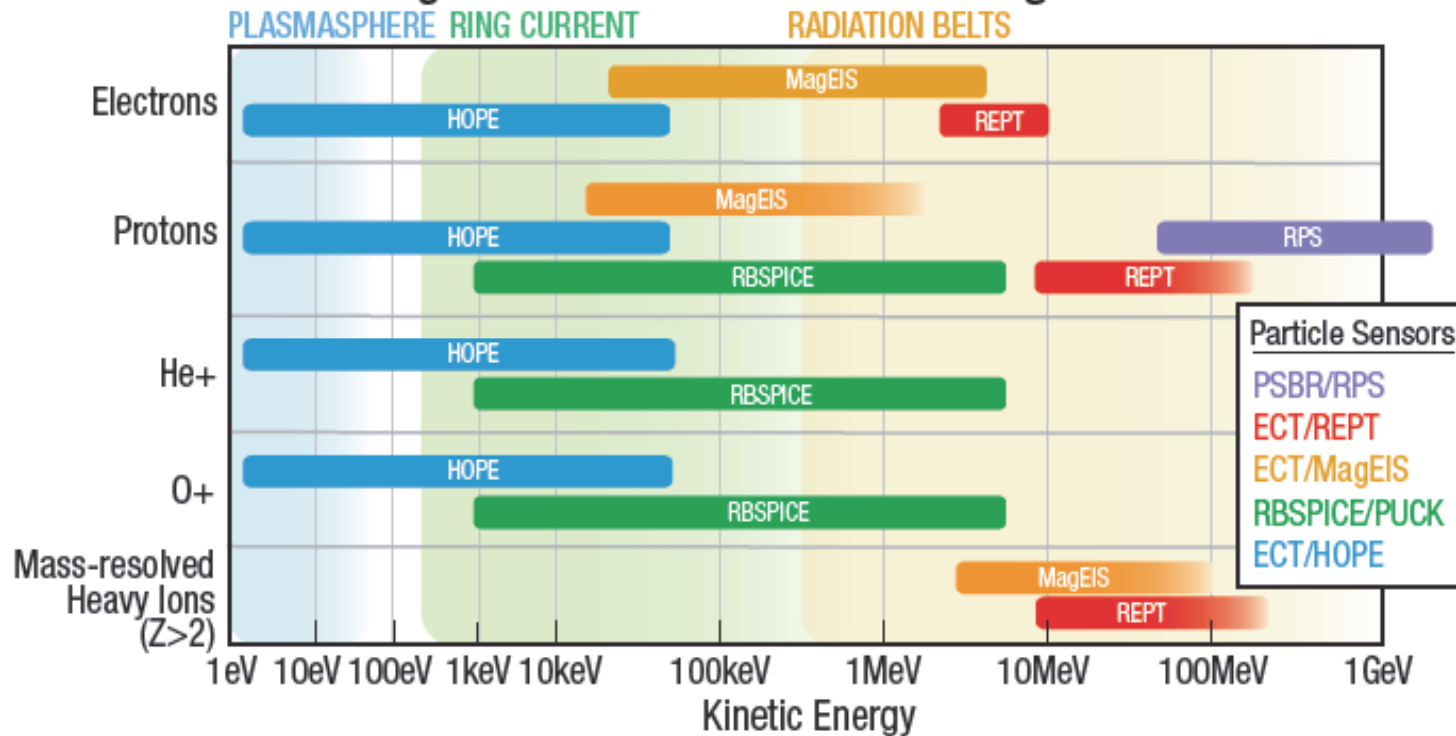
Differing apogees allow for simultaneous measurements to be taken over the full range of observatory separation distances several times over the course of the mission. Design allows one observatory to lap the other every ~75 days.

# RBSP Science Team

Science Teams	Science Investigation	Instruments/Suites
<b>Dr. Harlan Spence, PI</b> Boston University,	Measure near-Earth space radiation belt particles to determine the physical processes that produce enhancements and loss	<i>ECT</i> : Energetic Particle, Composition and Thermal Plasma Suite
<b>Dr. Craig Kletzing, PI</b> University of Iowa,	Understand plasma waves that energize charged particles to very high energies; measure distortions to Earth's magnetic field that control the structure of the radiation belts	<i>EMFISIS</i> : Electric and Magnetic Field Instrument Suite and Integrated Science Suite
<b>Dr. John Wygant, PI</b> University of Minnesota,	Study electric fields that energize charged particles and modify inner magnetosphere	<i>EFW</i> : Electric Field and Waves Instrument
<b>Dr. Louis Lanzerotti, PI</b> New Jersey Institute of Technology	Understand the creation of the "storm time ring current" and the role of the ring current in the creation of radiation-belt populations	<i>RBSPICE</i> : Radiation Belt Storm Probes Ion Composition Experiment
<b>Dr. David Byers, PI</b> National Reconnaissance Office	Specification models of the high-energy particles in the inner-most Van Allen radiation belt	<i>RPS</i> : Relativistic Proton Spectrometer



# Coverage for Electron and Ion Pitch Angle Distributions



**Energetic Particle, Composition, and Thermal Plasma (ECT) Suite:**

**HOPE:** Helium Oxygen Proton Electron top-hat analyzer and coincidence detector

**MagEIS:** Magnetic Electron Ion Spectrometer

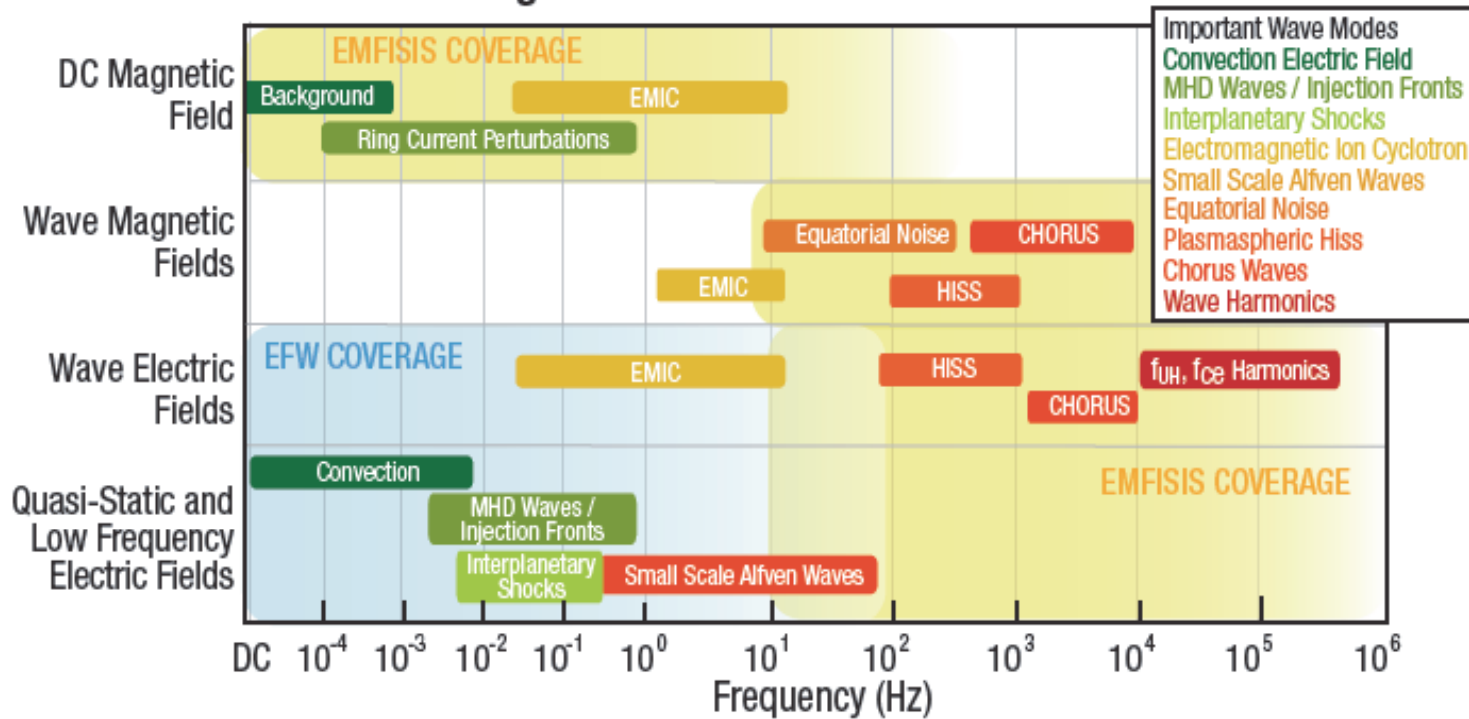
**REPT:** Relativistic Electron Proton Telescope

**Radiation Belt Storm Probes Ion Composition Experiment (RBSPICE):**  
**PUCK:** Ring current ion composition, energy, and pitch-angle sensor

**Proton Spectrometer Belt Research (PSBR):**

**RPS:** Relativistic Proton Spectrometer

# Coverage for Fields and Waves Measurements



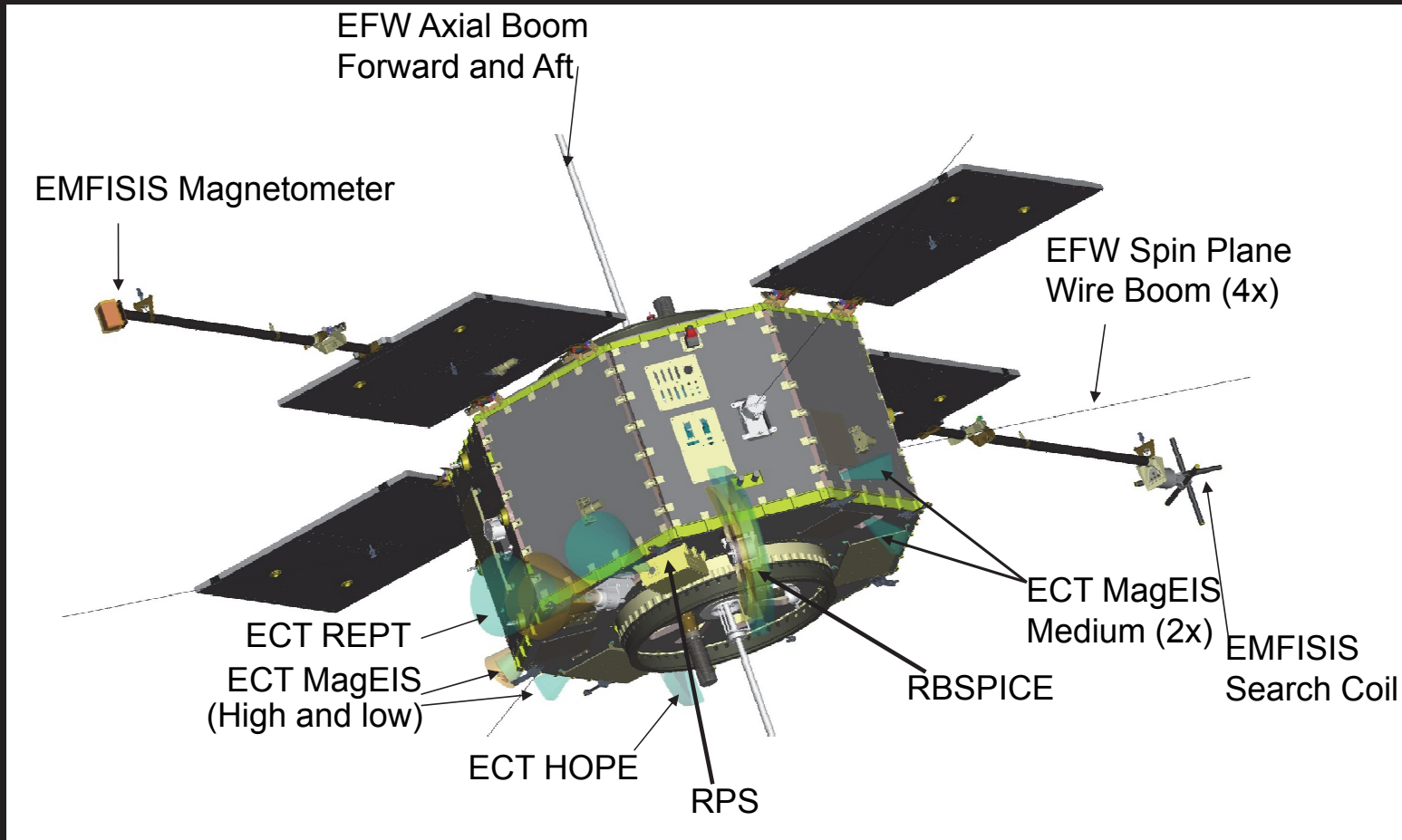
**Electric and Magnetic Field Instrument Suite and Integrated Science (EMFISIS) Suite:**

**MAG:** Triaxial fluxgate Magnetometer

**WAVES:** Triaxial Search Coil and Waveform Receivers

**Electric Field and Waves Instrument (EFW):**  
Spin Plane Double Probes  
Axial Stacer Booms

# RBSP Observatory (2x) Operational Configuration



Stack Mass Estimate: 1190 kg  
Orbit Average Power Load: 269 W

# RBSP Status

Launch: August 15, 2012

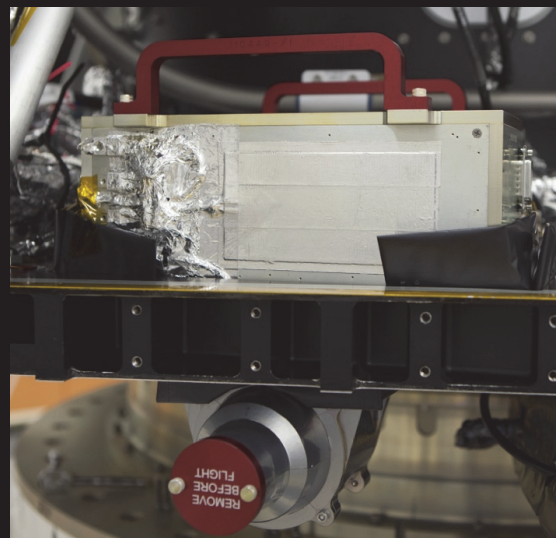


## RBSPICE



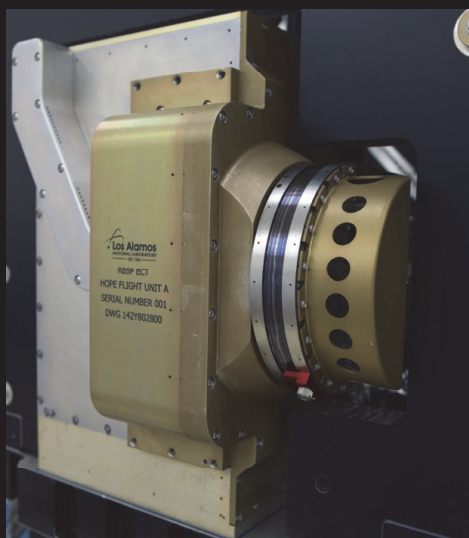
e, H, He, O: 1 keV-2 MeV

## REPT



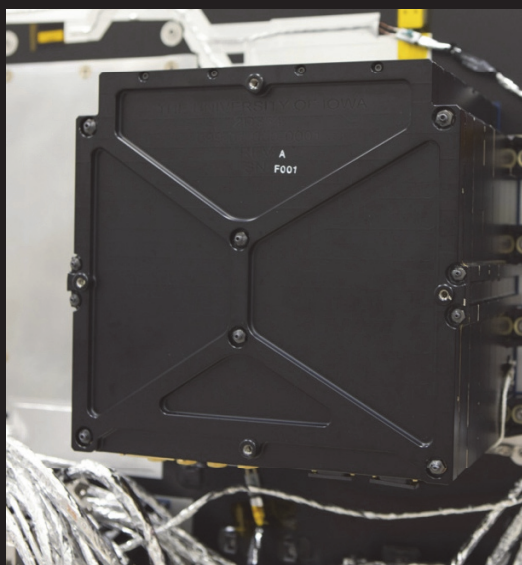
e: 2-10 MeV, H: 10-100 MeV

## HOPE



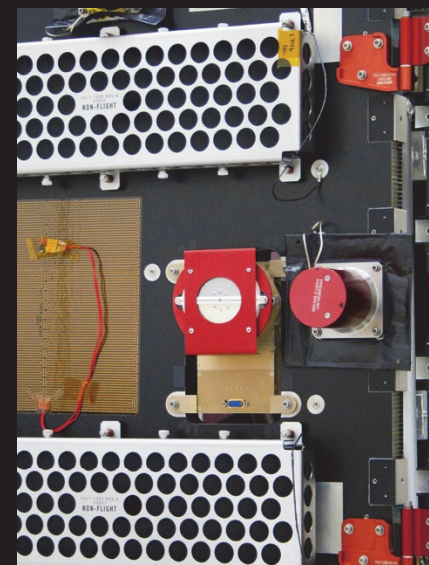
e, H, He, O: 1 eV-50 keV

## EMFISIS



B, E (>10 Hz)

## EFW

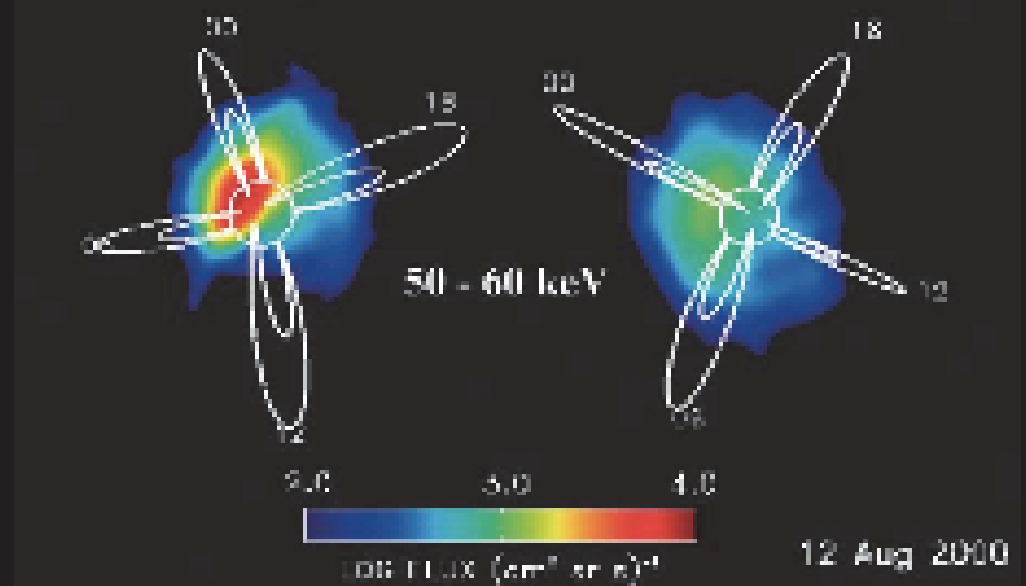
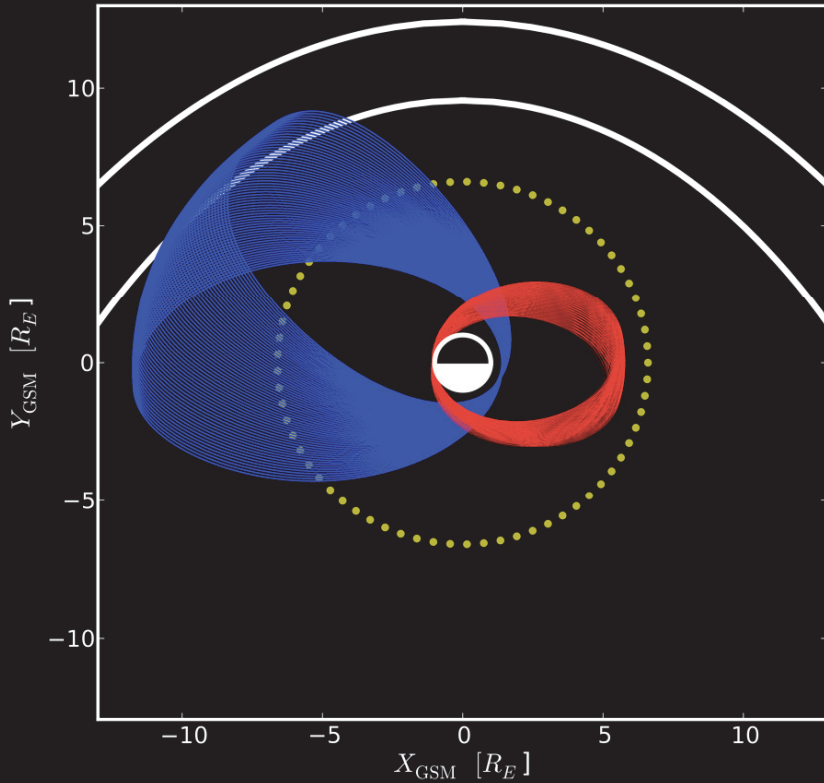


E (<100 Hz)

QuickTime™ and a  
H.264 decompressor  
are needed to see this picture.

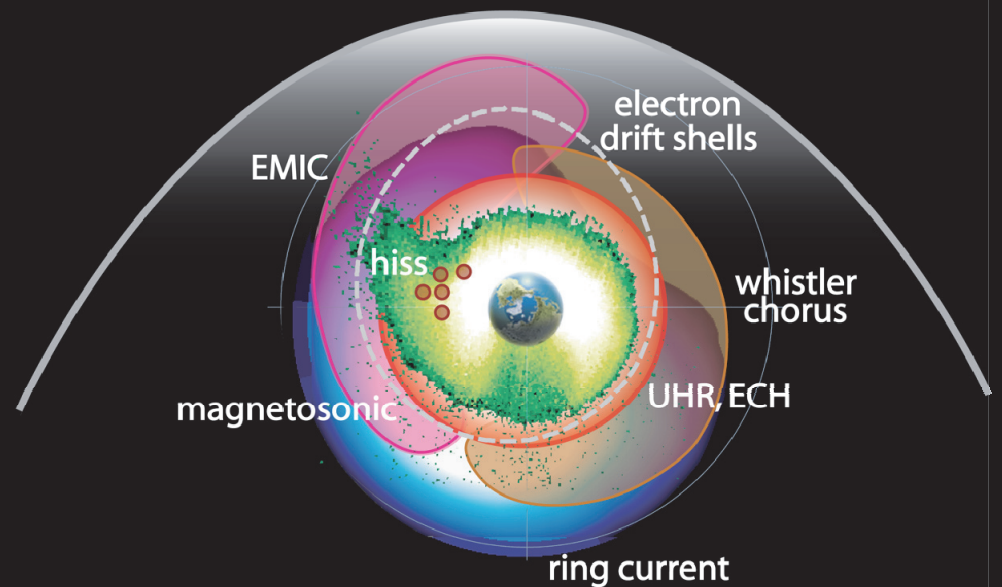
# Dawn-Dusk Campaign

October-November 2012

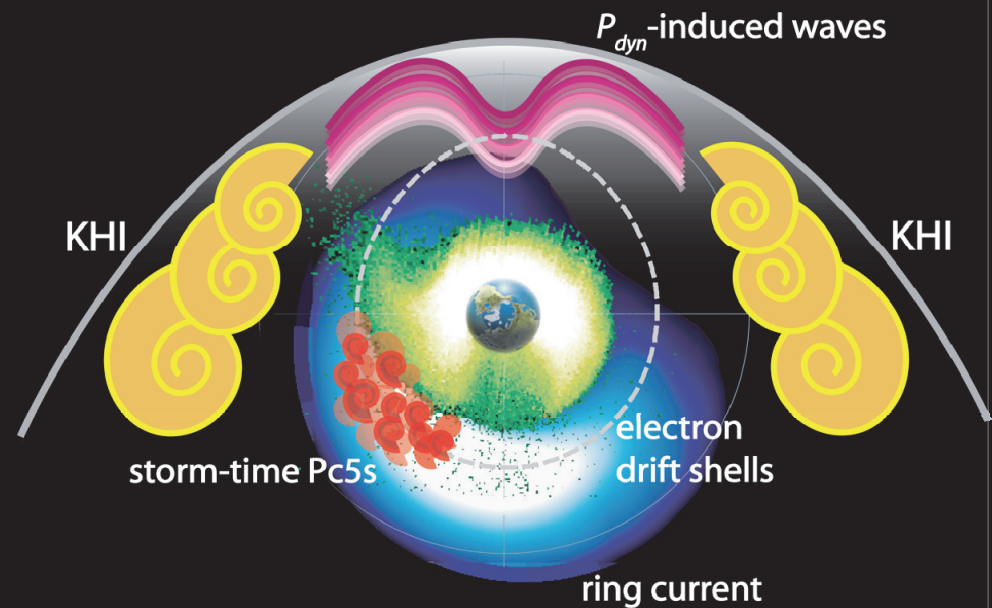
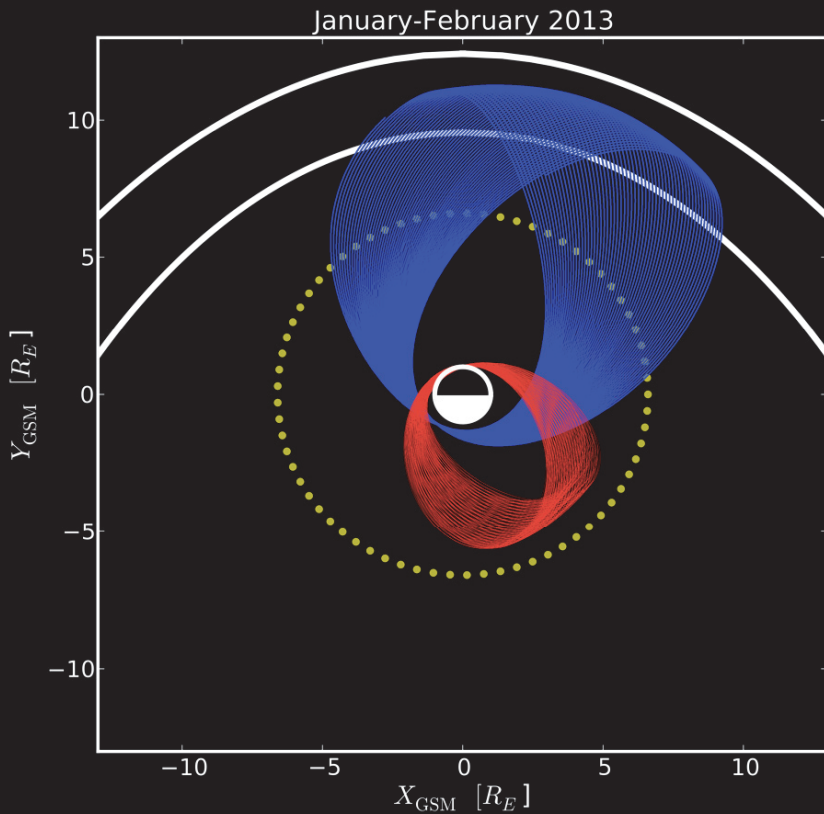


What are the relative roles of various local wave-particle interaction mechanisms in RB acceleration and loss?

How does the MLT distribution of hot plasma change at different phases of geomagnetic storms?



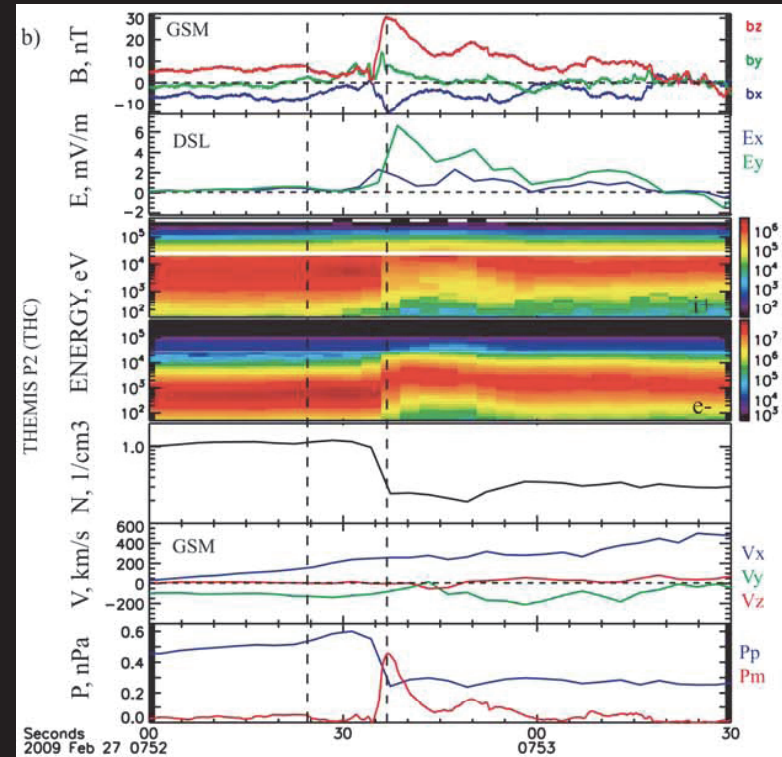
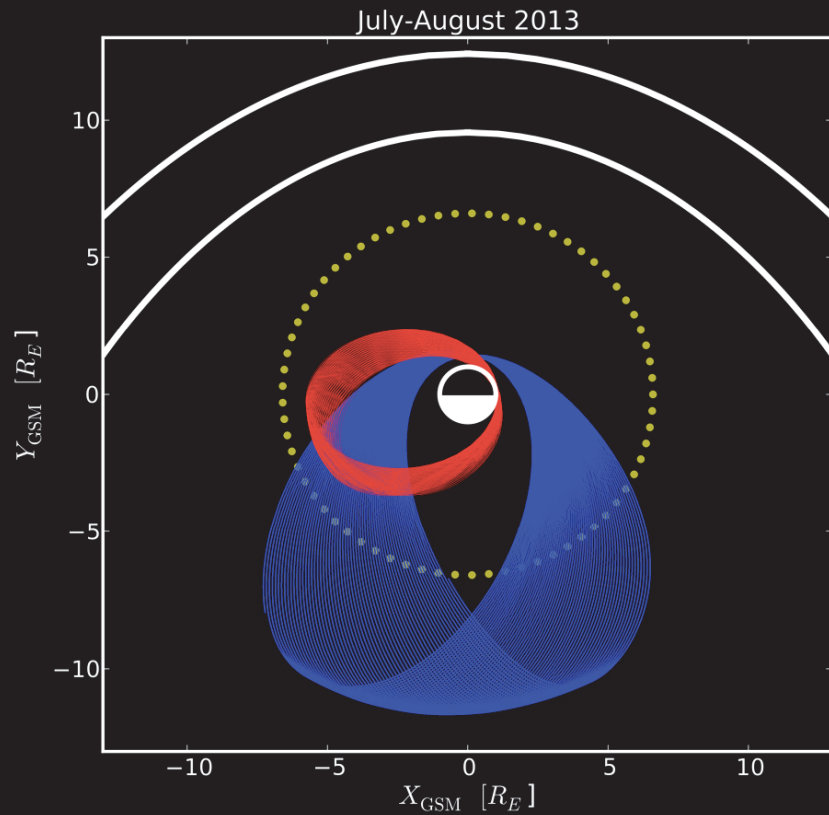
# Dayside-Nightside Campaign



What role dayside ULF waves play in transport and energization of radiation belt particles?

What is the relative role of the magnetopause losses in producing dropouts of radiation levels across the outer radiation belt?

# Dusk-Nightside Campaign



[Runov et al., 2009]

How far can ion injection events propagate into the inner magnetosphere and how do their properties change?



