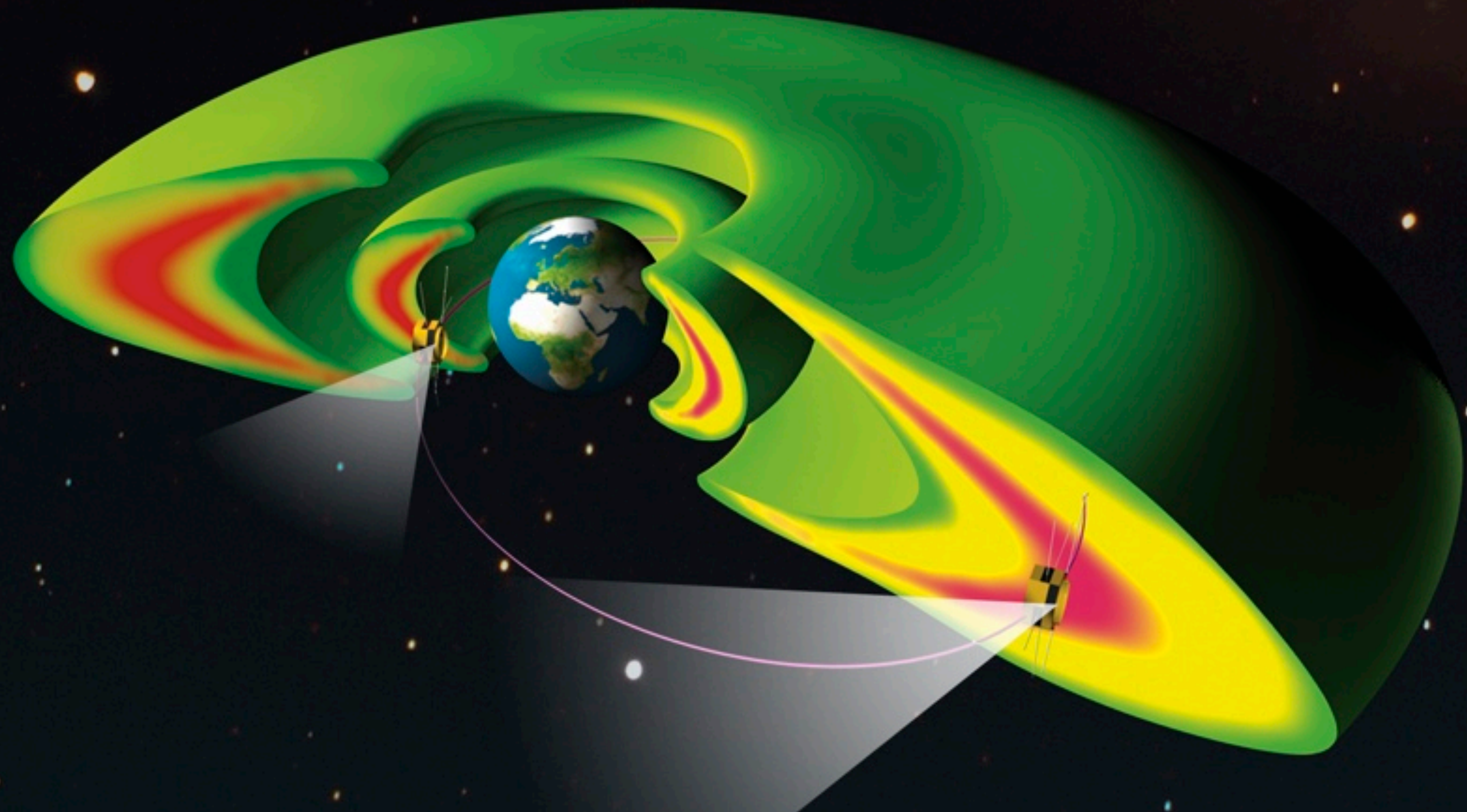
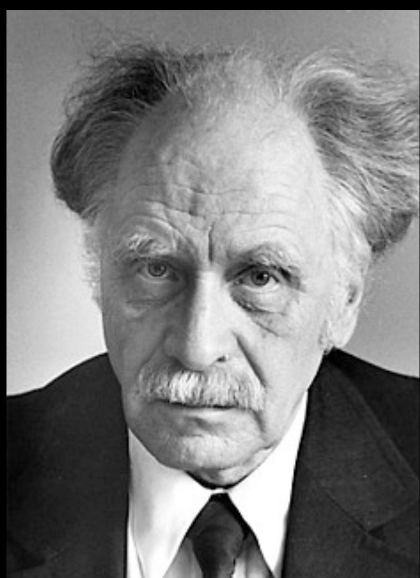
RBSP Mission: Understanding Particle Acceleration and Electrodynamics of the Inner Magnetosphere

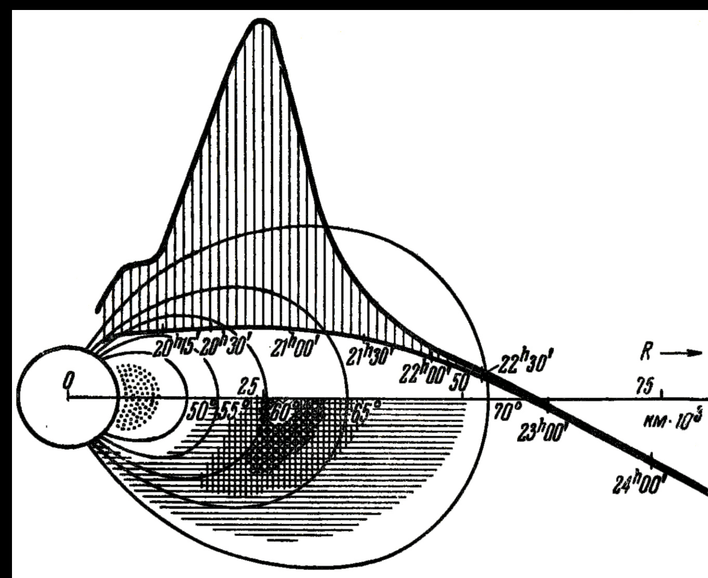


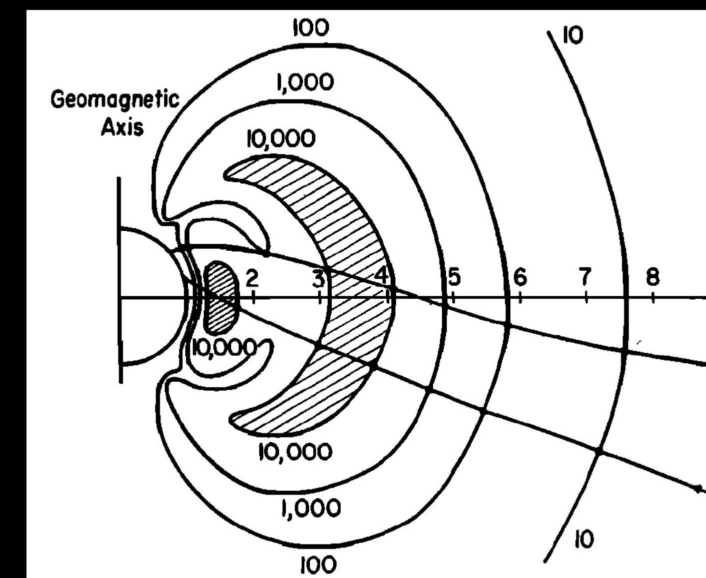
A. Y. Ukhorskiy, B. Mauk, N. Fox
JHU/APL

“My God, space is radioactive!”

Ernie Ray, 1958





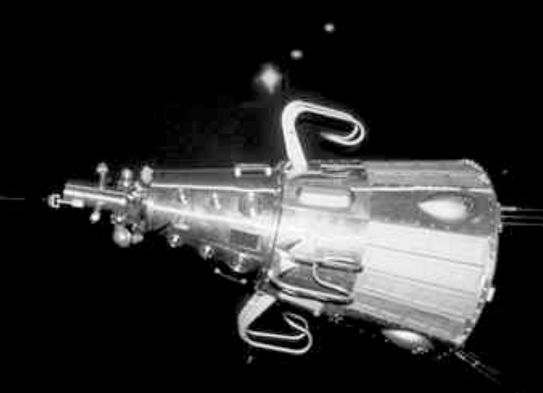


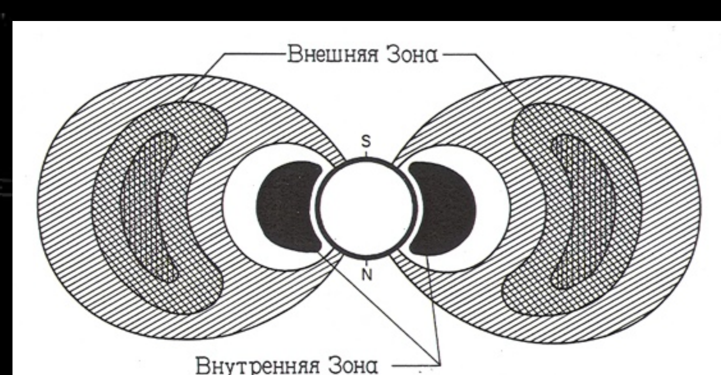
Спутник II, III

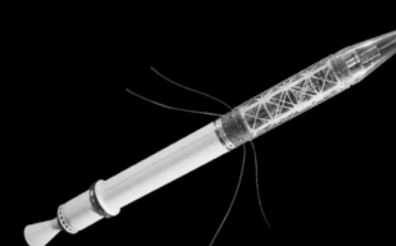
[Vernov et al., 1959]

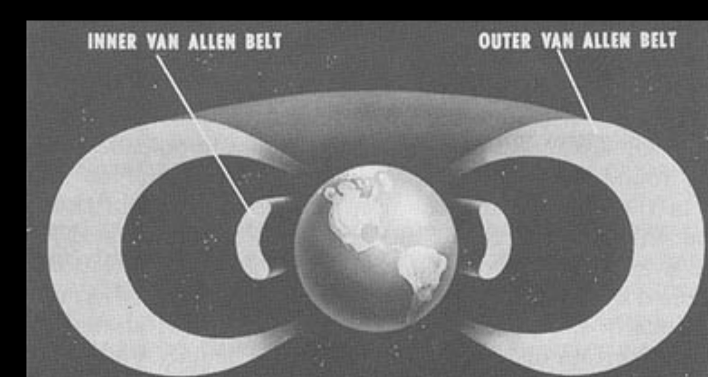
Explorer 1

[Van Allen, 1959]









Dynamic Evolution of the Belts

SAMPEX 2002 Daily Averaged >1 MeV Fluxes

Inner belt

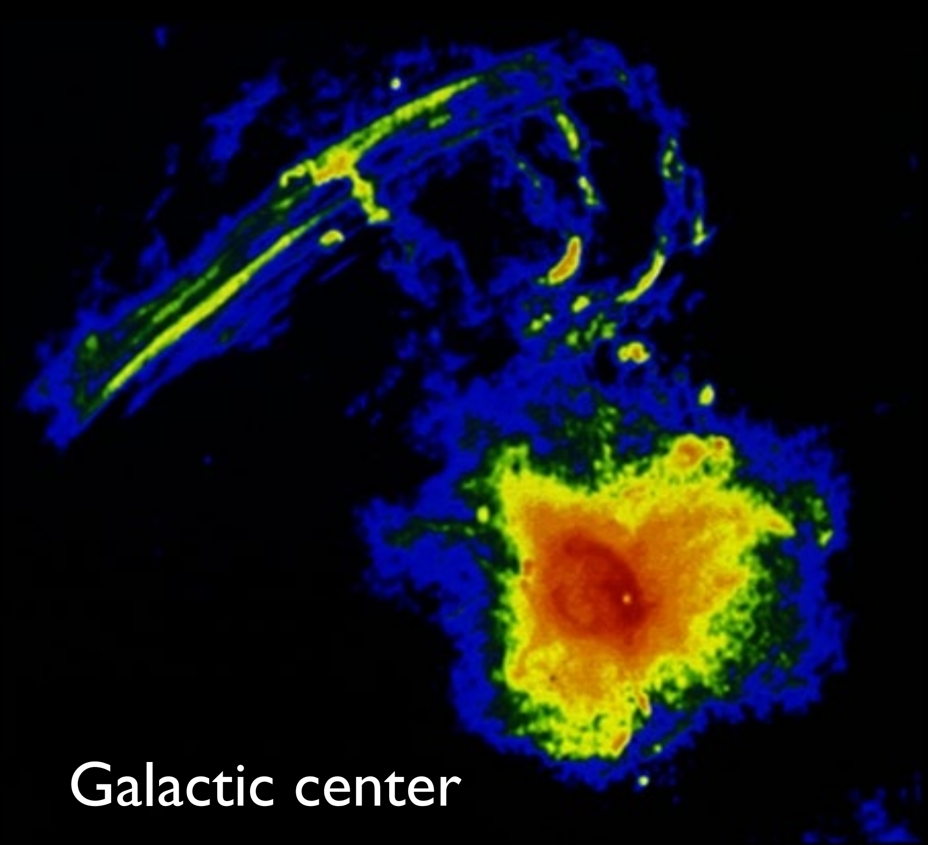
- ≲ 2.5 R_E
- electrons: ≳0.5 - 10s MeV
- protons: ≳1 MeV - 1GeV

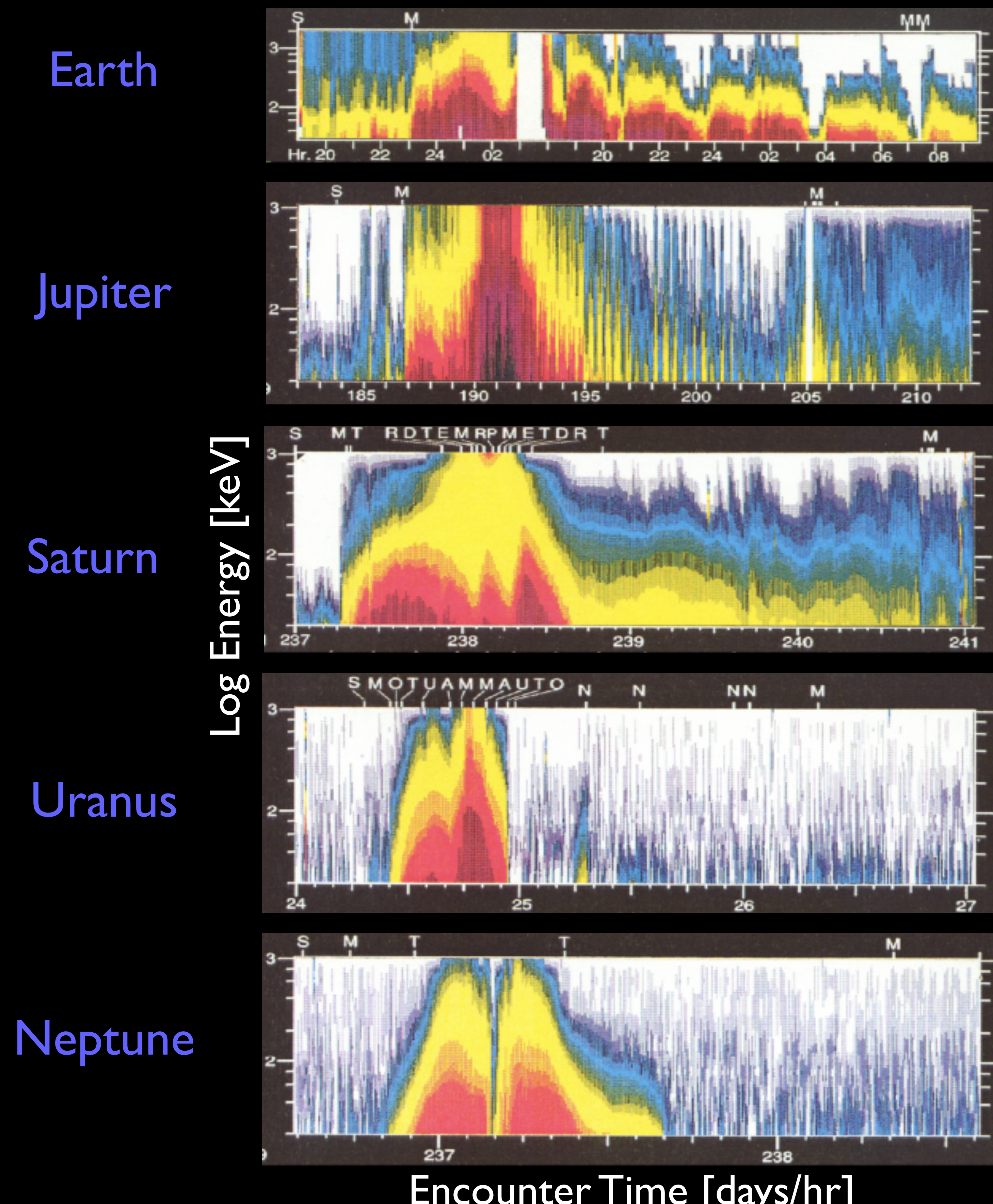
Outer belt

- ≳ 2.5 R_E
- electrons: ≳ 0.5 MeV

Particle Acceleration in Space

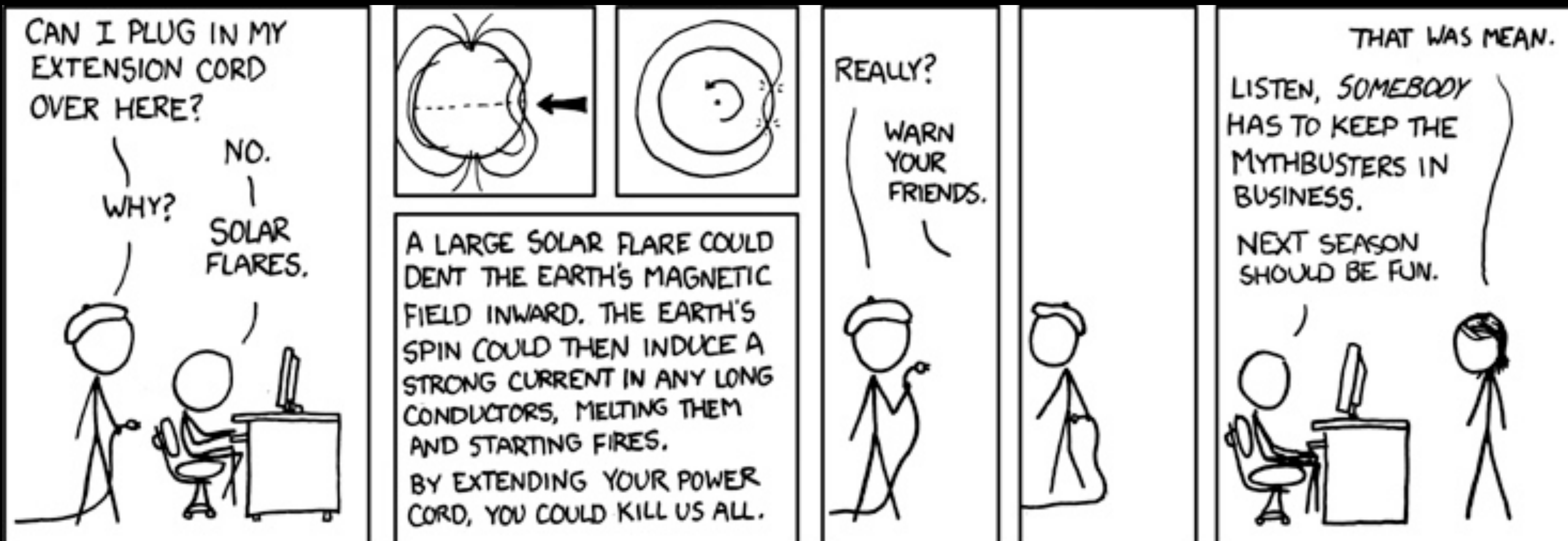
ISEE and Voyager results suggest that radiation belts exist at all strongly magnetized planets





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

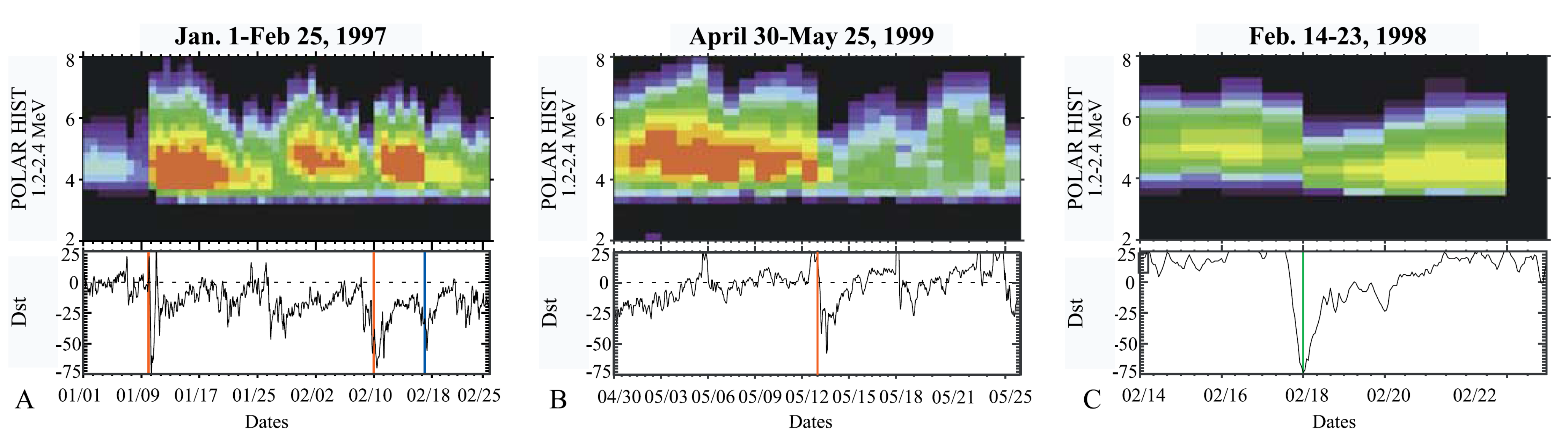
Growing Role of Space Weather



[www.xkcd.com/509]

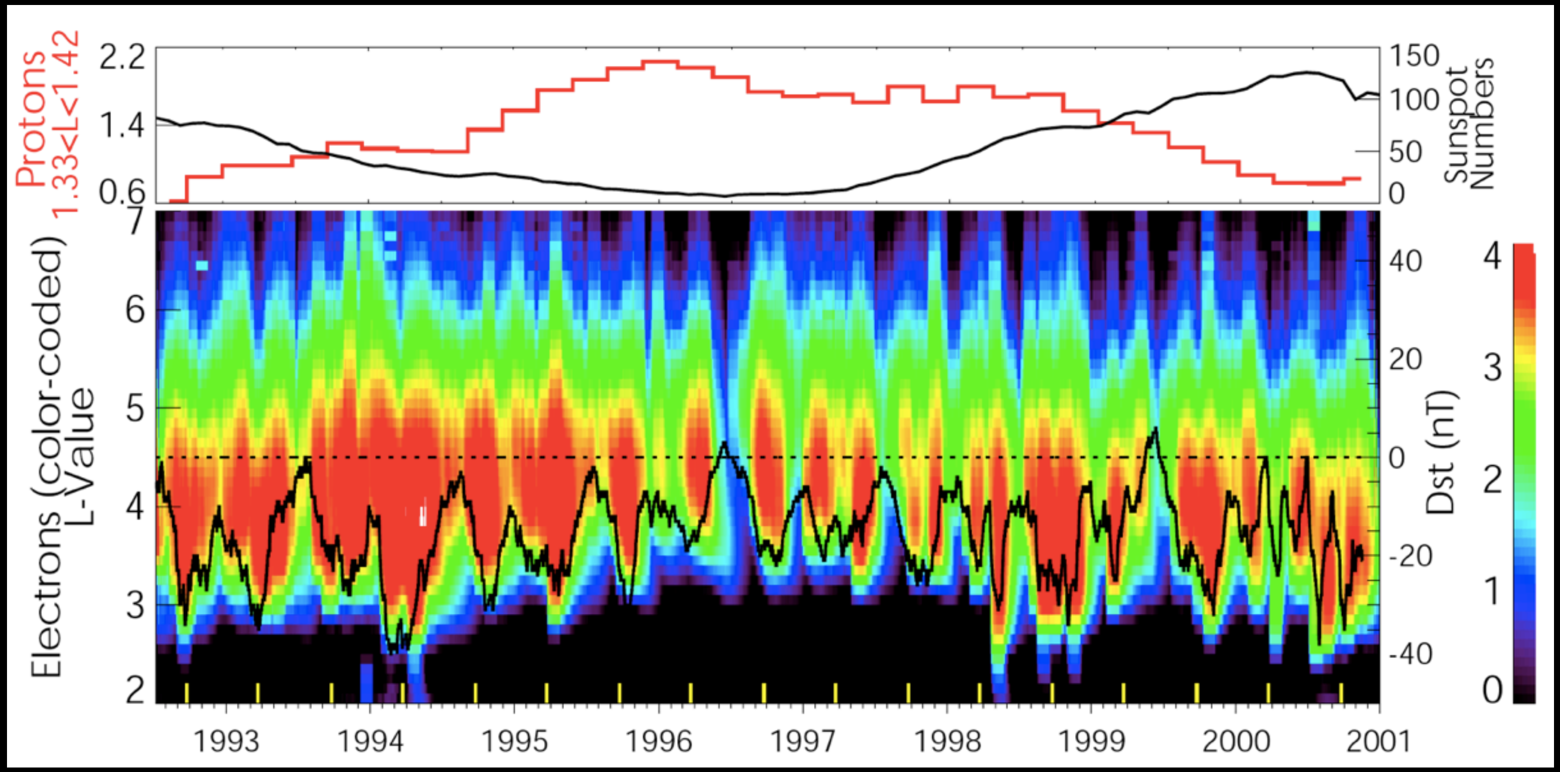
What's the Big Mystery?

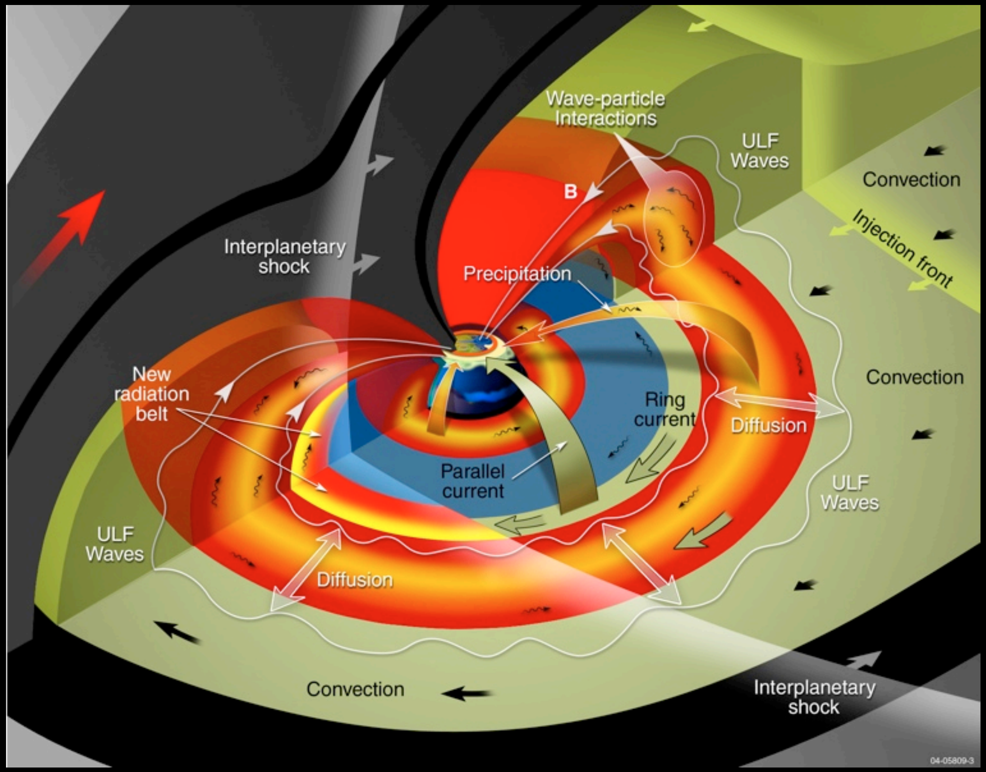
Some geomagnetic storms can:
(1) Cause dramatic radiation belt enhancement;
(2) Deplete radiation belt fluxes;
(3) Cause no substantial effect of flux distributions;



[Reeves et al., 2003]

Challenge: Understanding Complex Dynamical System



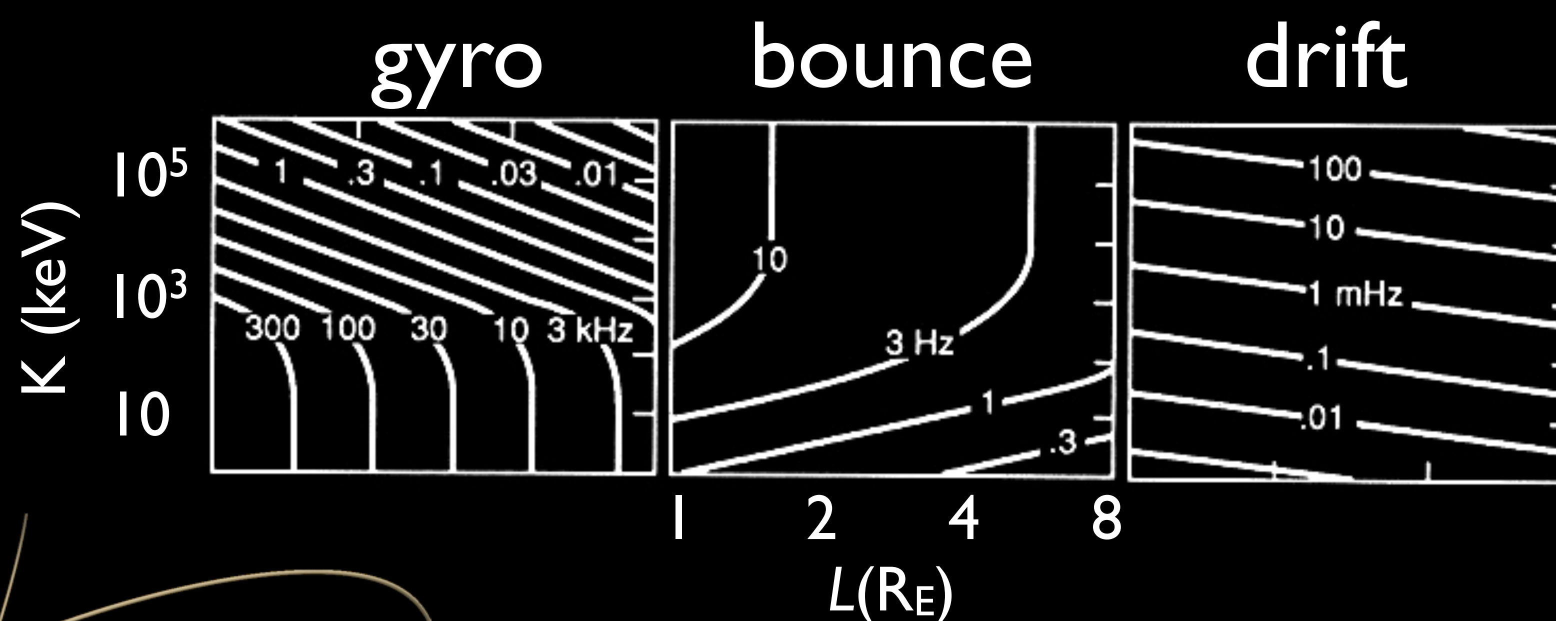


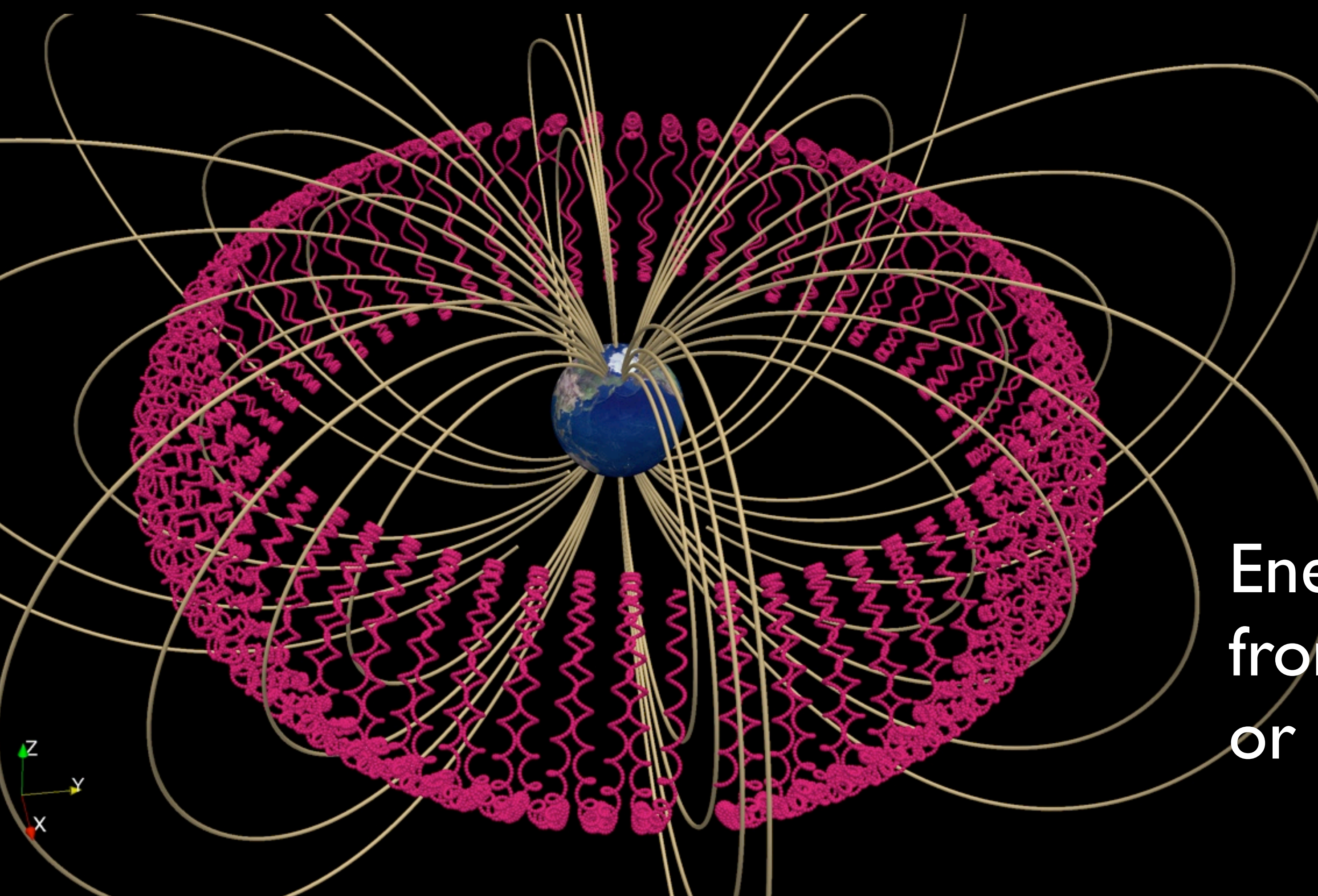
[Li et al., 2001]

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

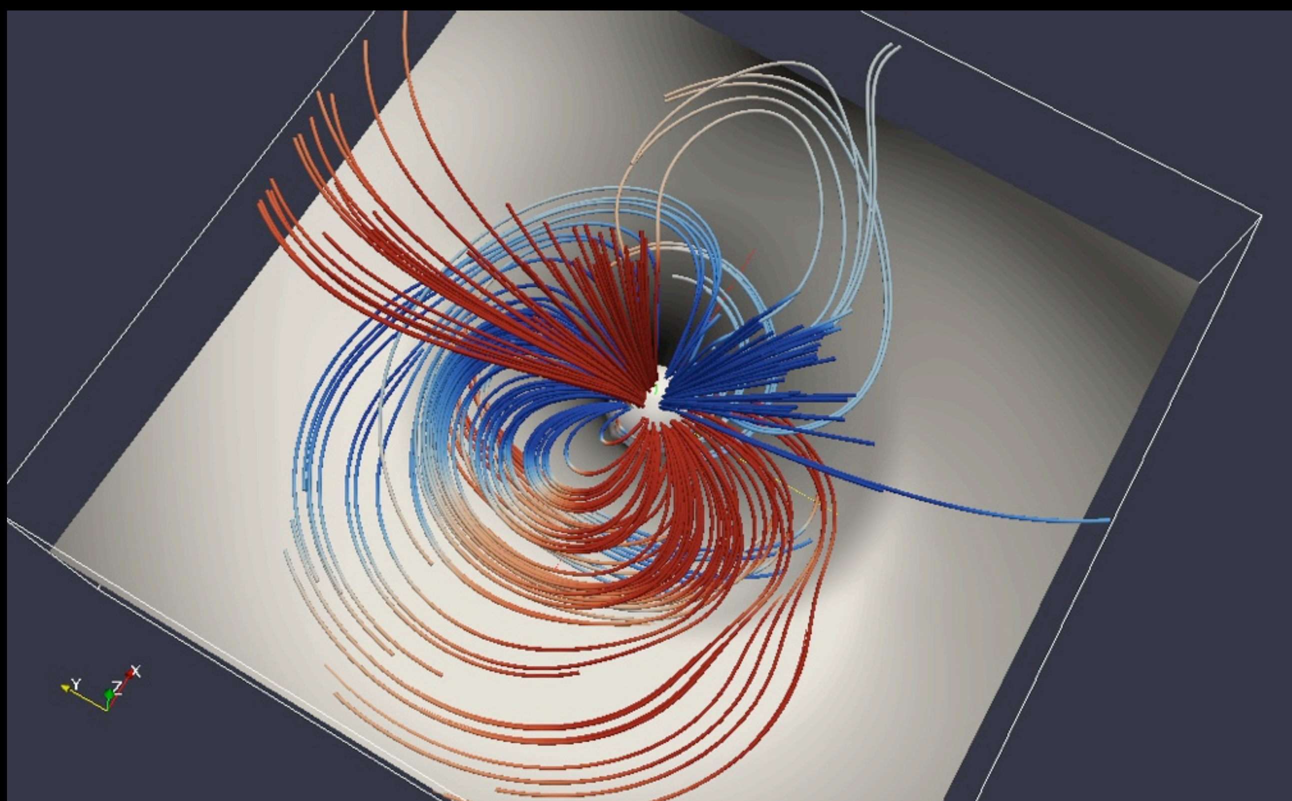
Electrons trapped in the Earth's magnetic field exhibit three quasi-periodic associated with adiabatic invariants (μ, J, Φ).

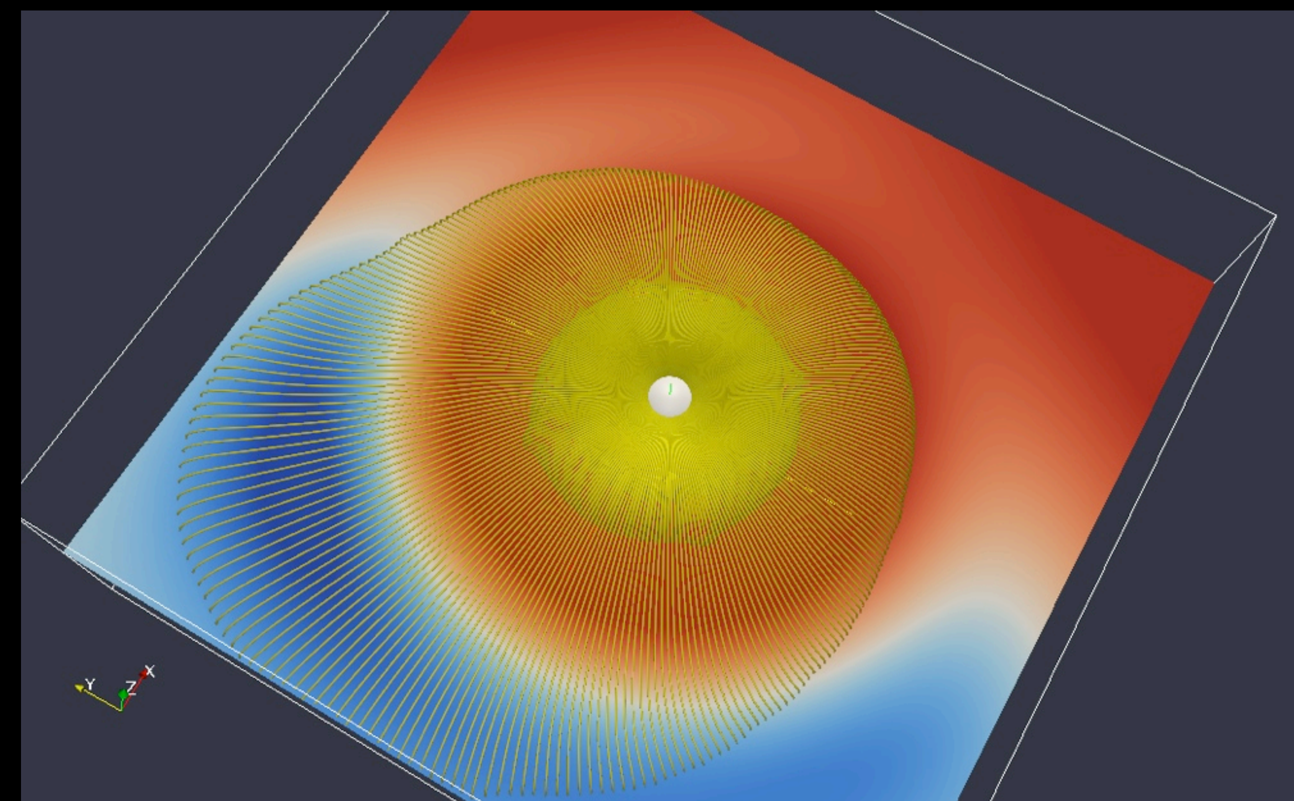




Energization and loss of electrons from the belt requires violation of one or more of the adiabatic invariants.

Storm-Time Electrodynamics



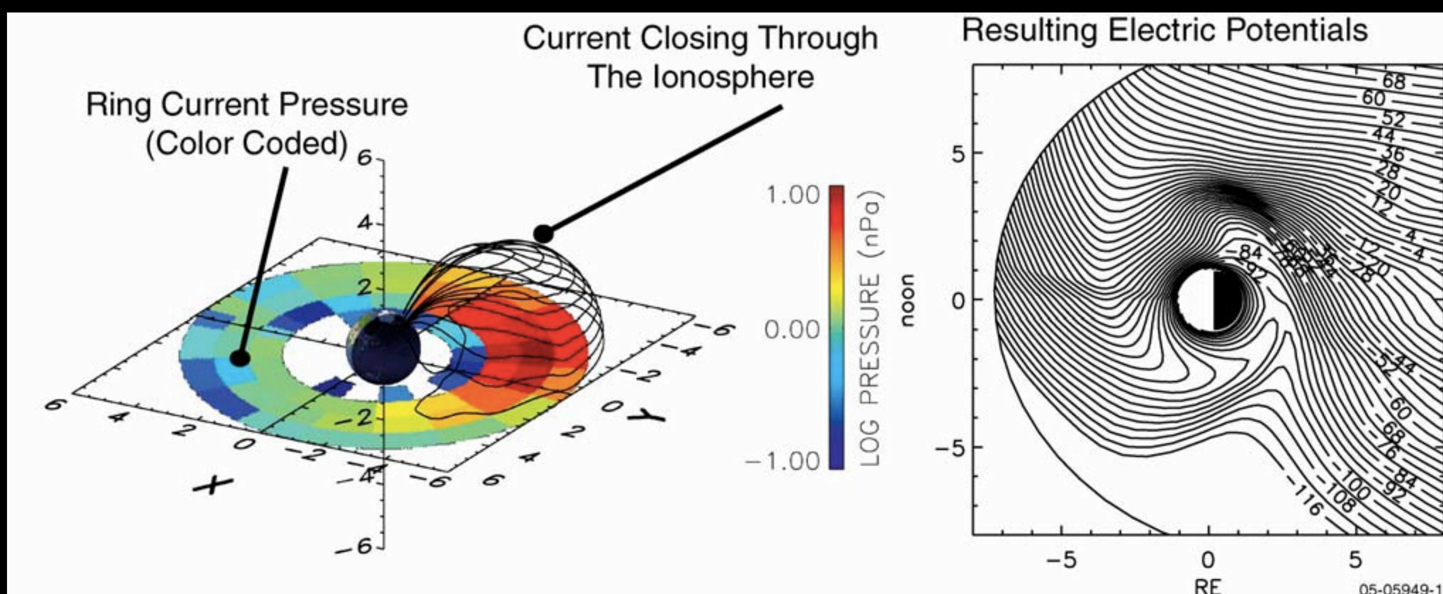


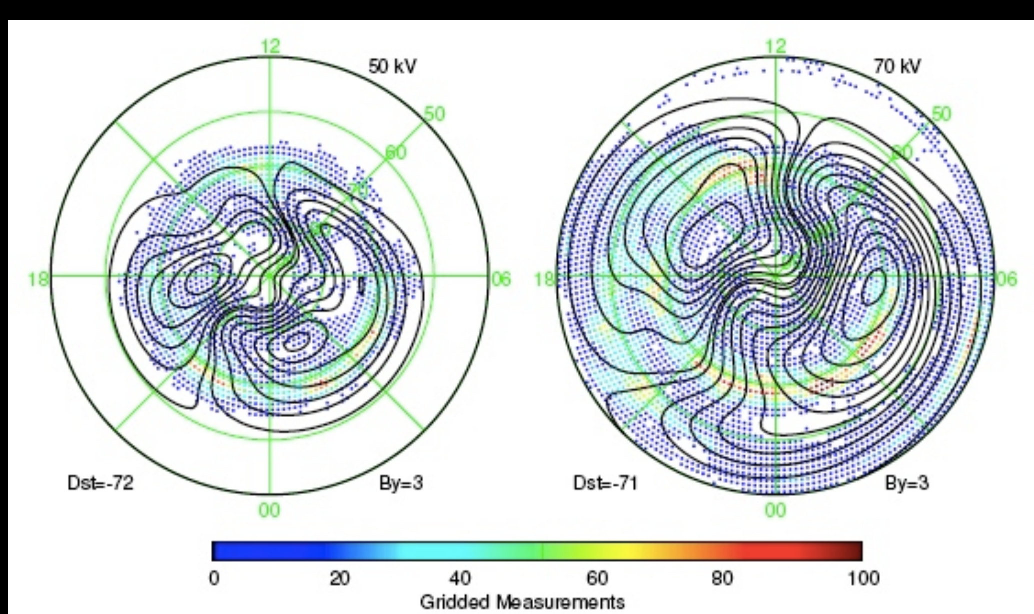
Evolution of hot plasma pressure in the inner magnetosphere drives global current system which produces large distortions in the inner magnetospheric fields.

What are the Mechanisms of RC & Seed Population Energization and Transport?

$$\mathbf{E} = -\nabla\varphi - \frac{1}{c}\frac{\partial \mathbf{A}}{\partial t}$$

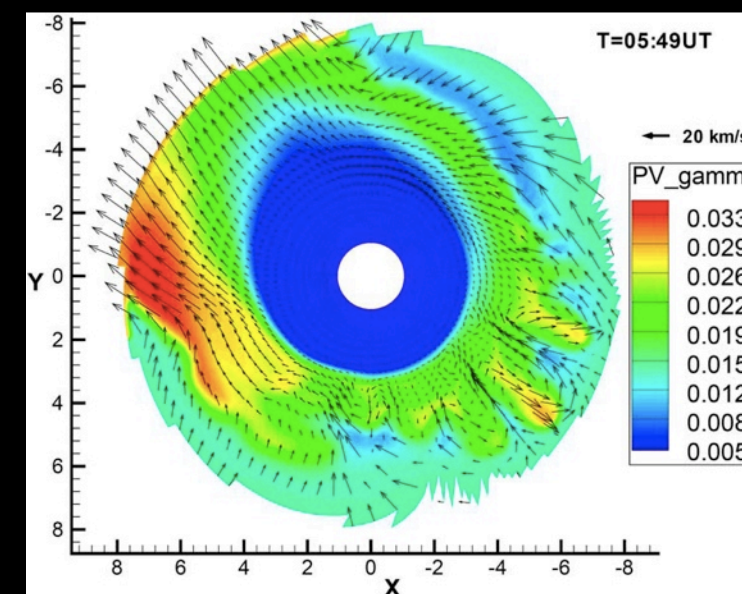
Steady-state convection



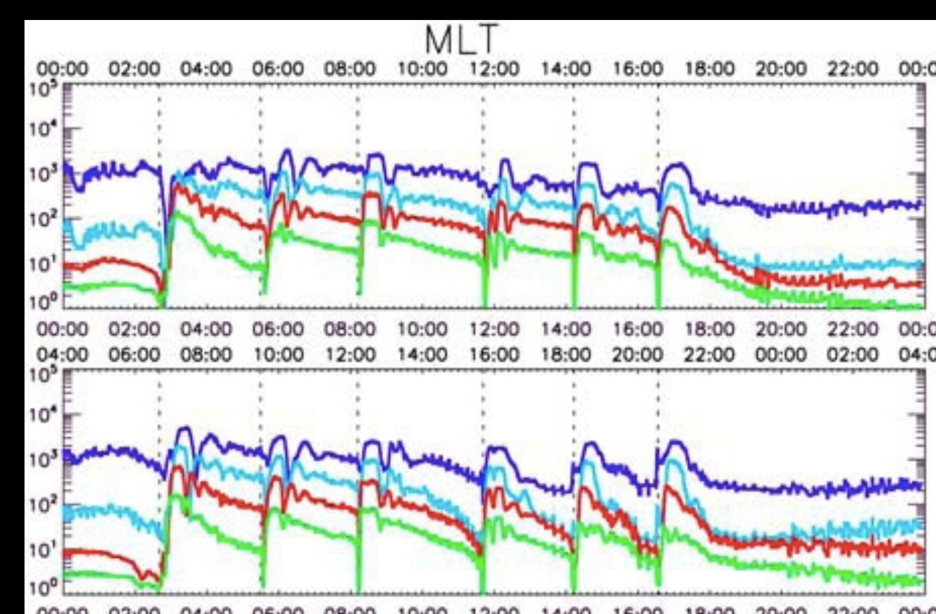


[Grocott and Yeoman, 2006]

Impulsive transport

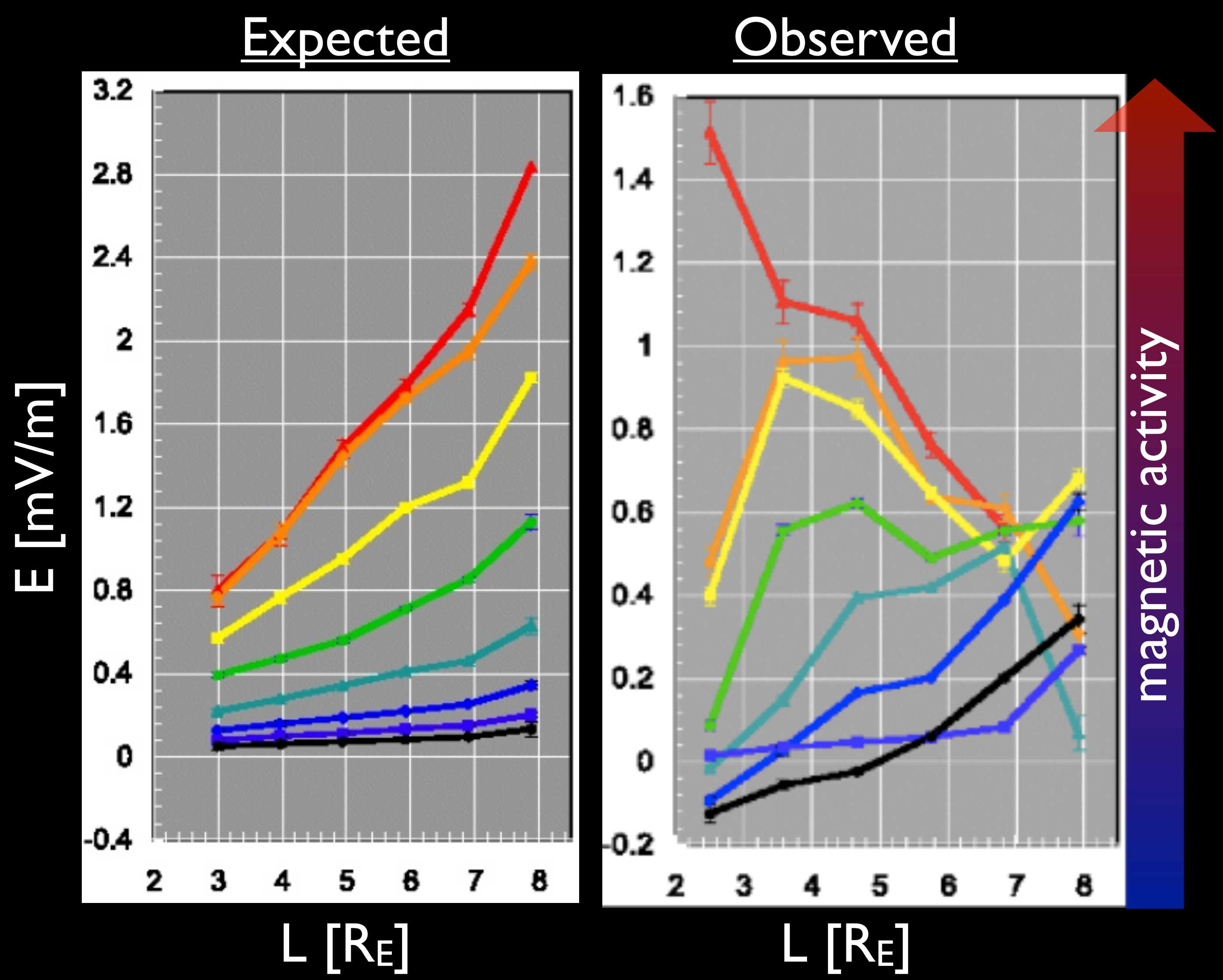


[Yang et al., 2008]



[Yang et al., 2008]

How do Global Electric Fields Behave During Storms?



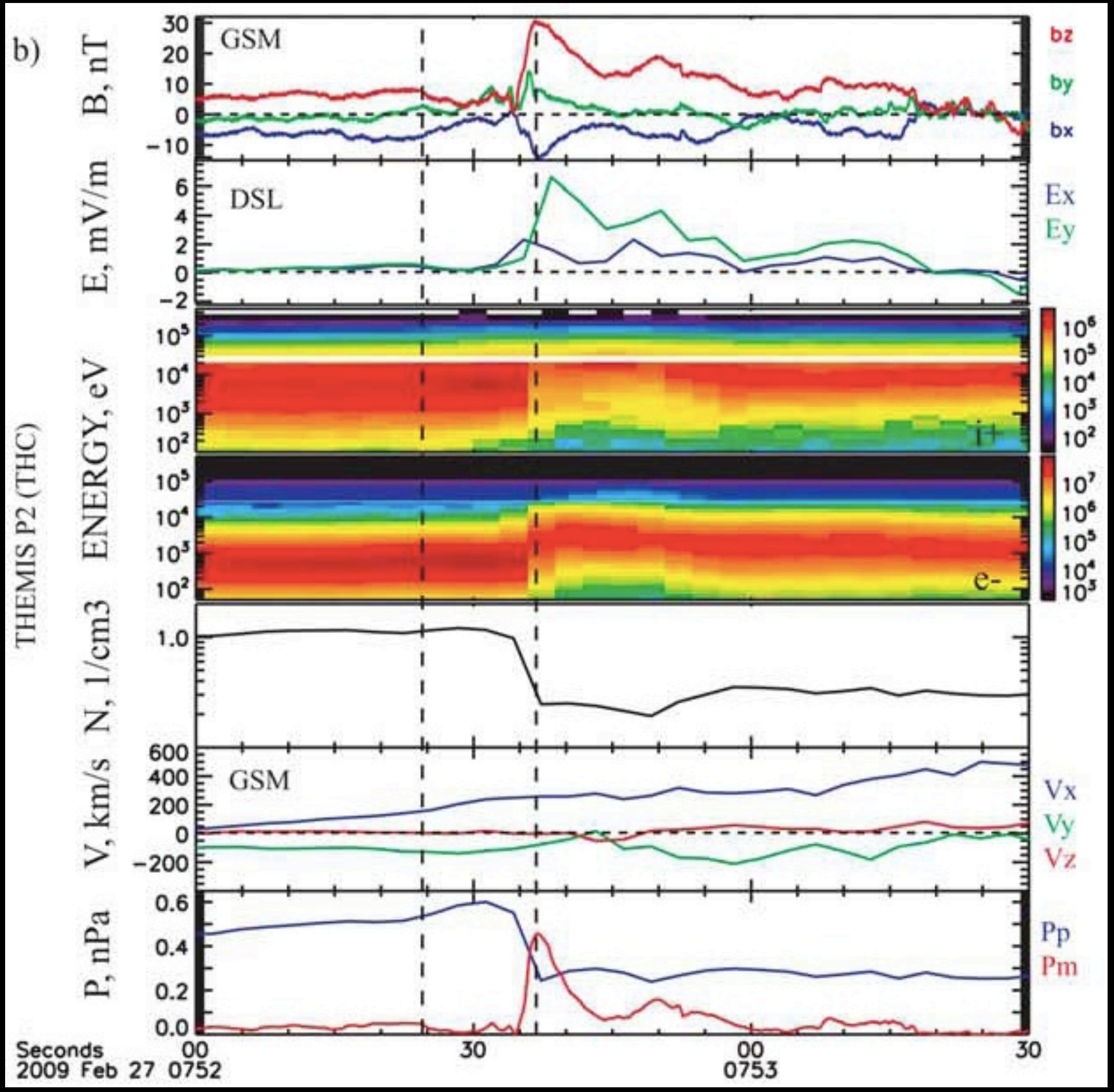
[Rowland and Wygant, 1989]

Distribution of global electric fields during large geomagnetic activity measured at CRRES contradicts the well accepted concept of “shielding” which may have important implications to global convection, ring current energization, and seed population control.

What Drives Impulsive Transport?

Quantify injection events based on their observational signatures, use two-point measurements to separate spatial and temporal variability.

[Runov et al., 2009]



Bz front

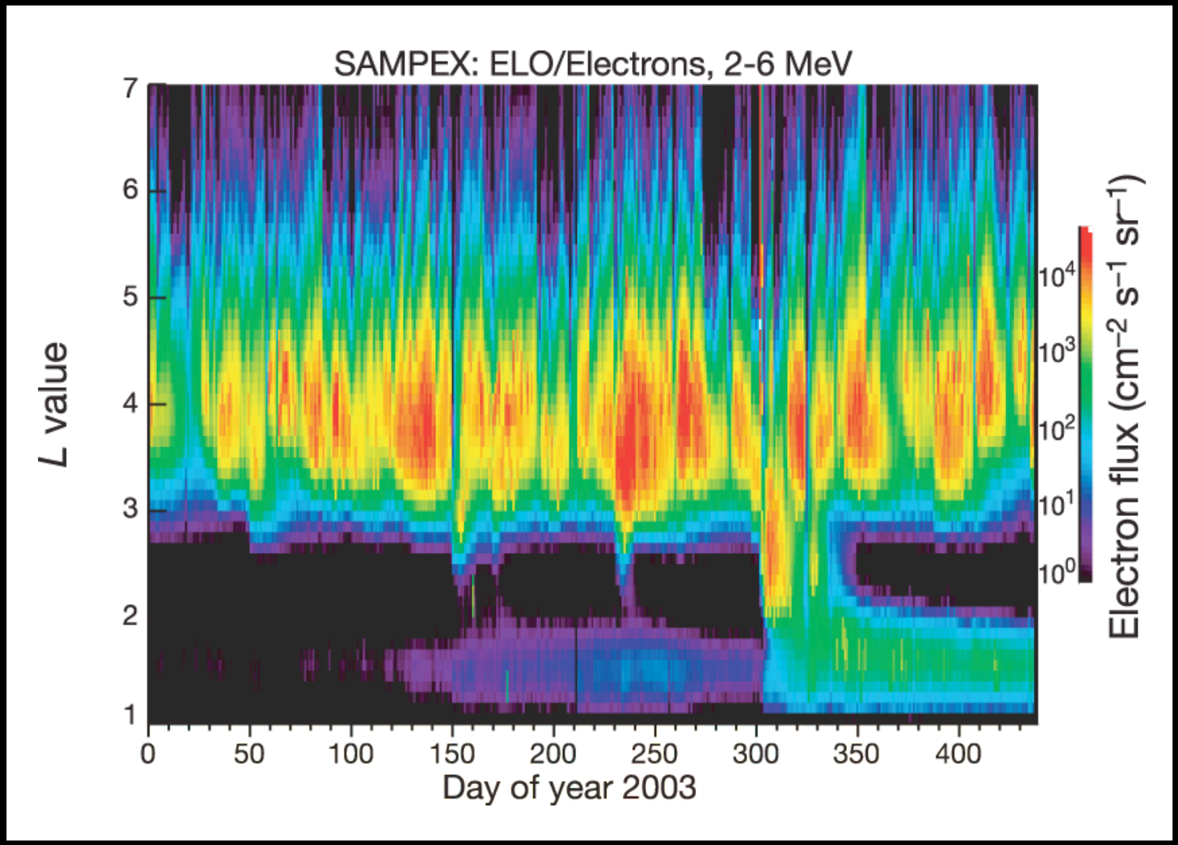
Electric field increase

Hardening of
the spectra

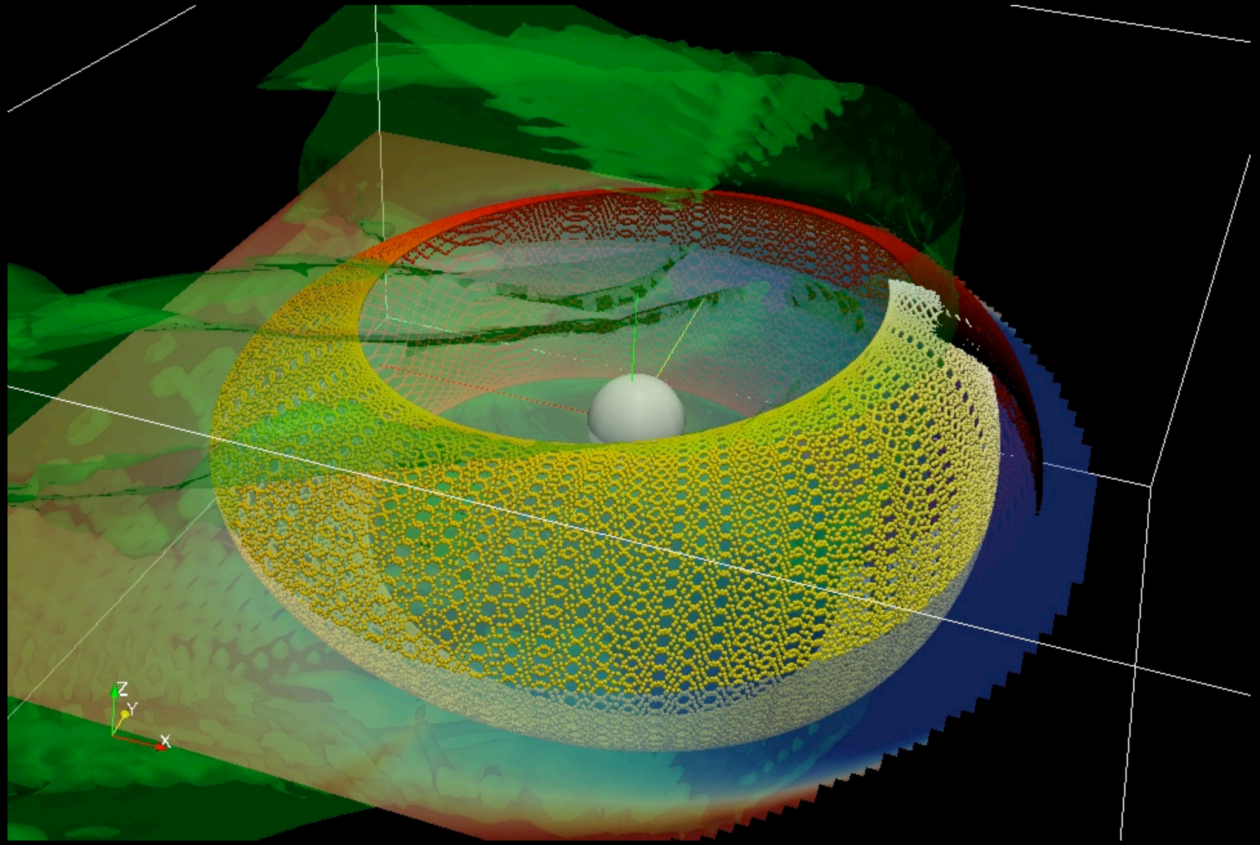
Density depletion

- How deep can injection propagate into the inner magnetosphere?
- Are the events distributed continuously by size and magnitude?
- Can we identify their solar wind/geomagnetic control parameters?
- Are the events at RBSP different from the events in the outer magnetosphere ($x<-10R_E$)?

Global Mechanisms



[Baker et al., 2005]

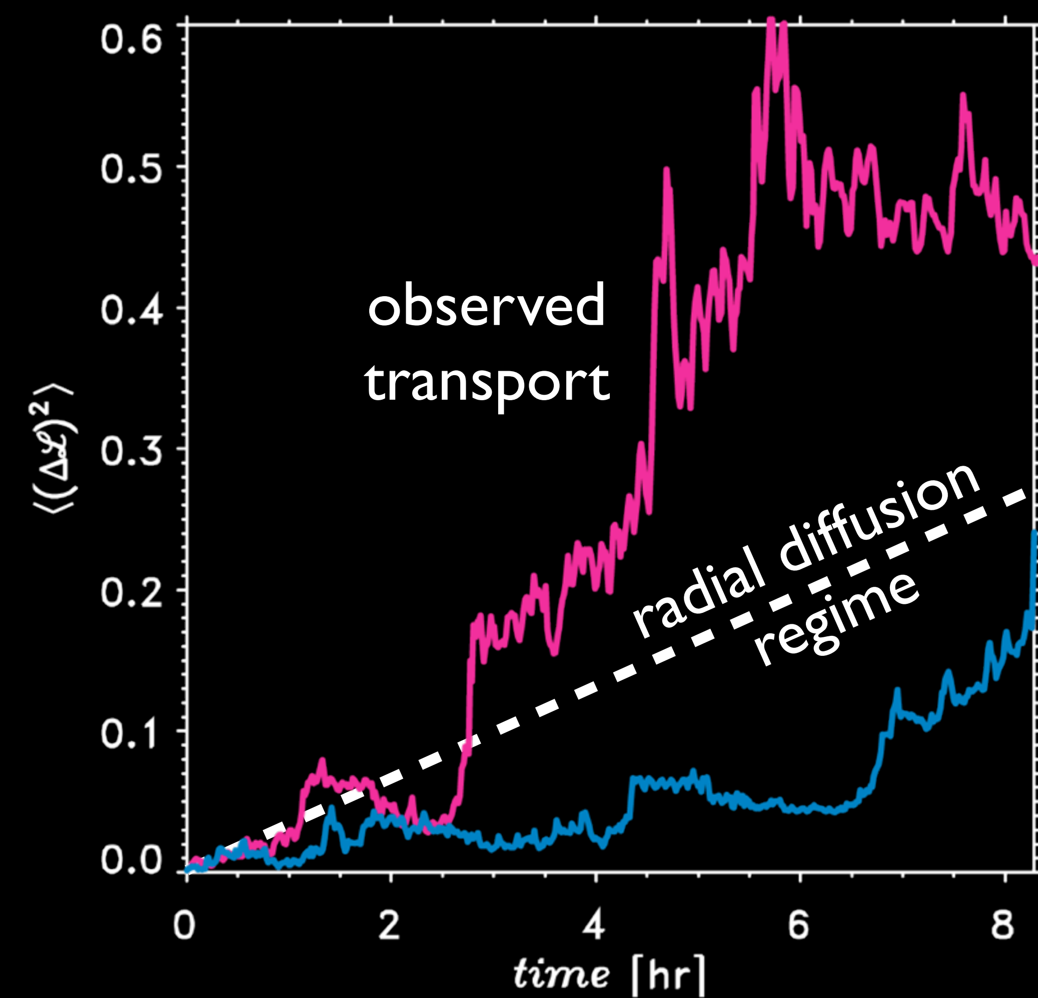


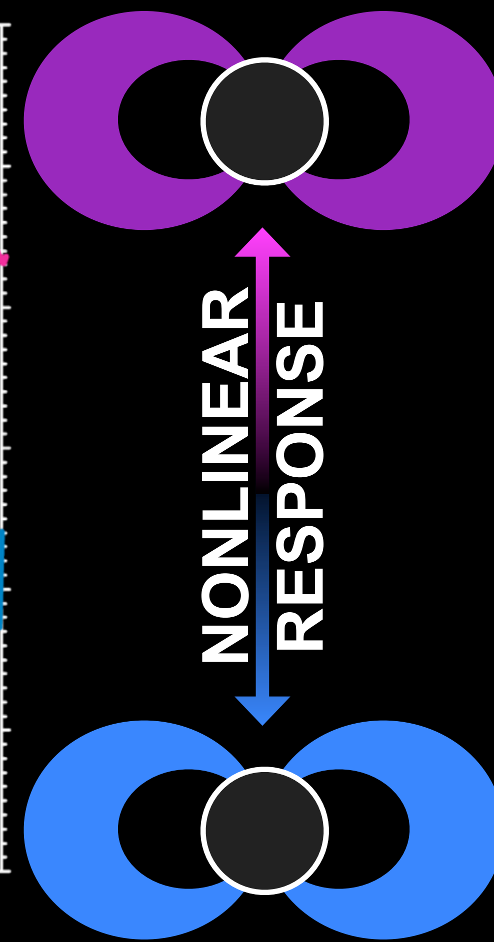
The observed large-scale variability of electron fluxes across the belt implies the existence of global mechanisms active over broad spacial regions of the inner magnetosphere. Global mechanisms drive radial transport of electrons across their drift shells by violating their third adiabatic invariant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

Non-Diffusive Radial Transport

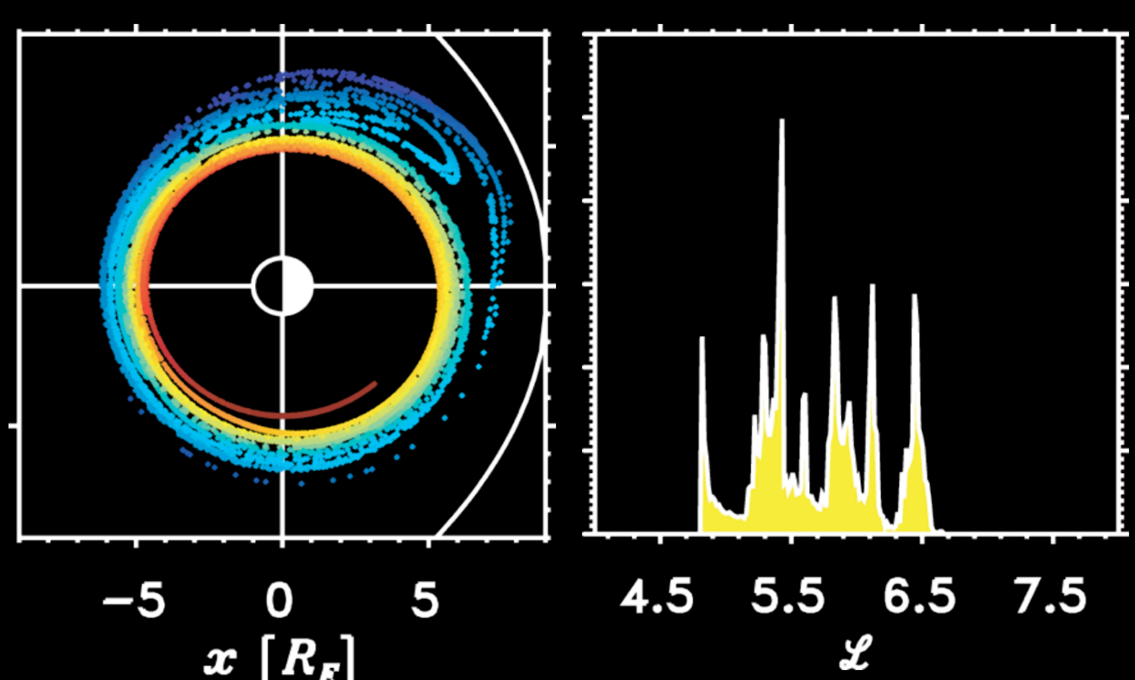
ULF Wave Driver

Non-diffusive Transport



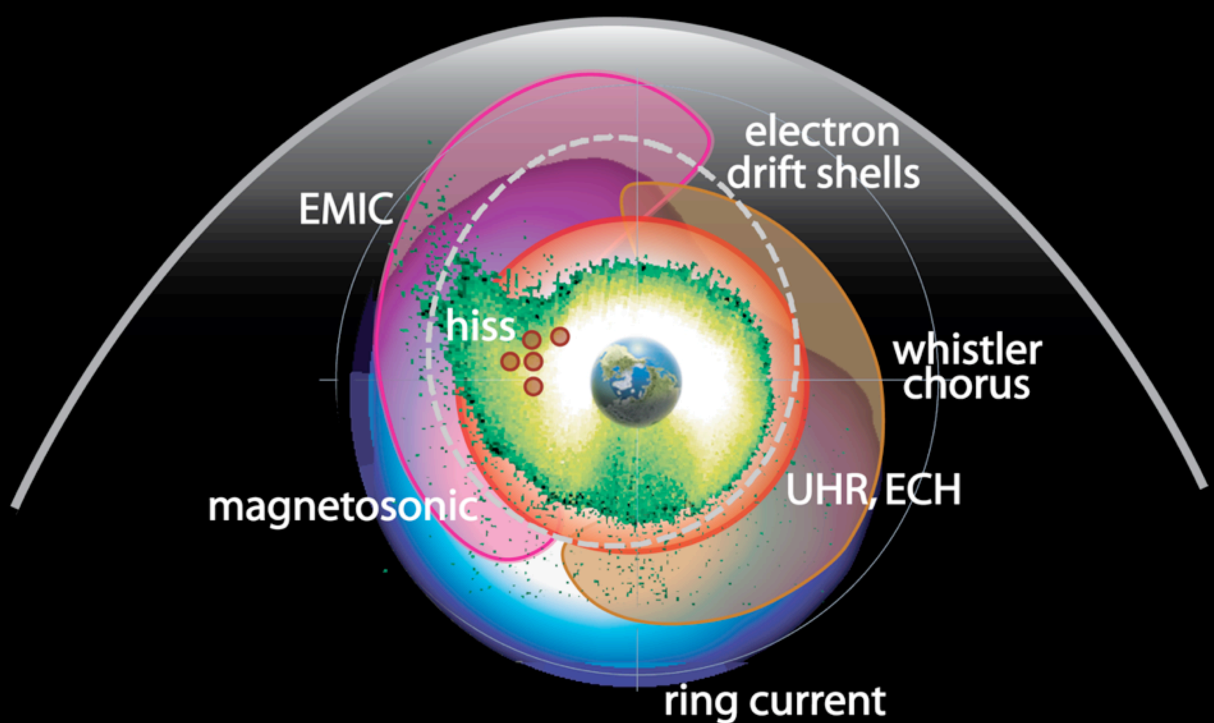


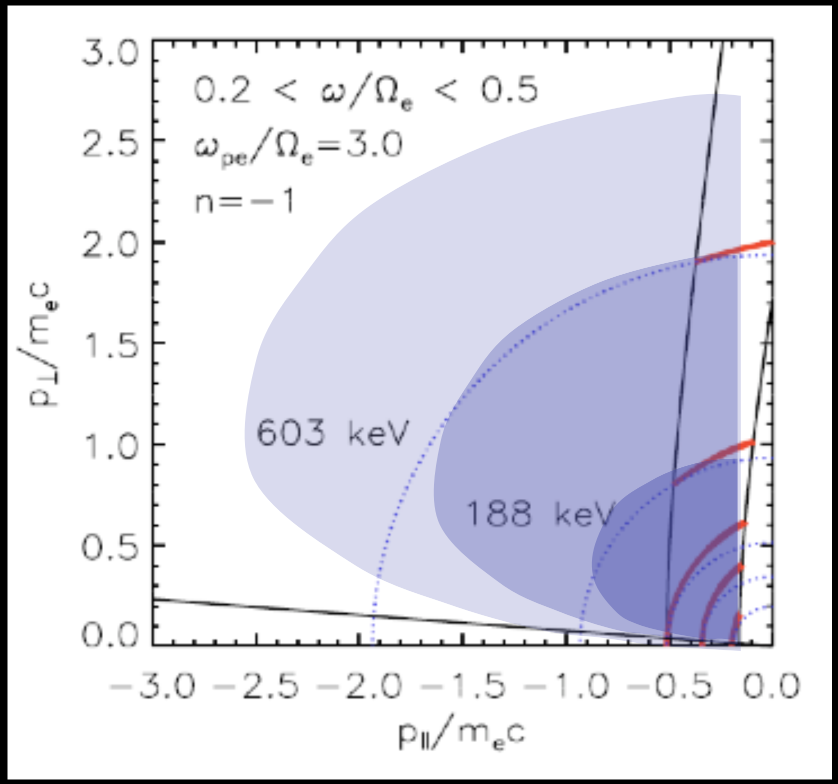
Filamentation of PSD



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]

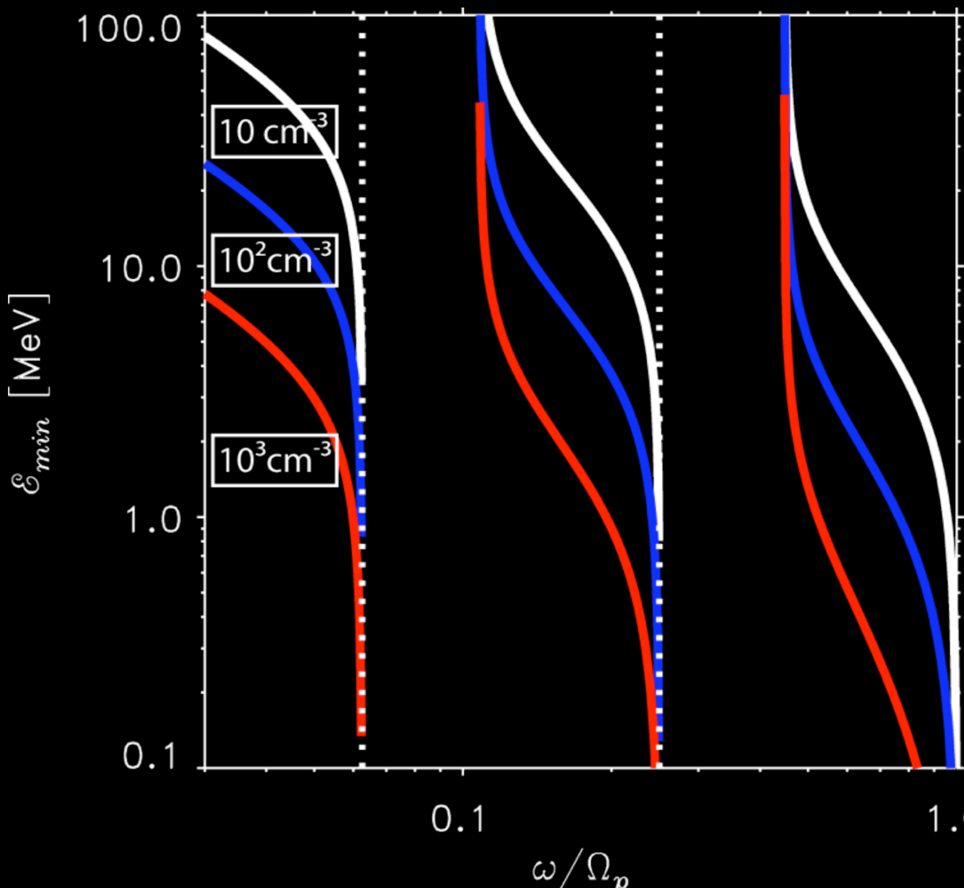
Local mechanisms break the first invariant of radiation belt electrons. Resonant wave-particle interactions of electrons with EMIC and whistler waves can produce both acceleration and loss of particles from the belt.

EMIC Waves

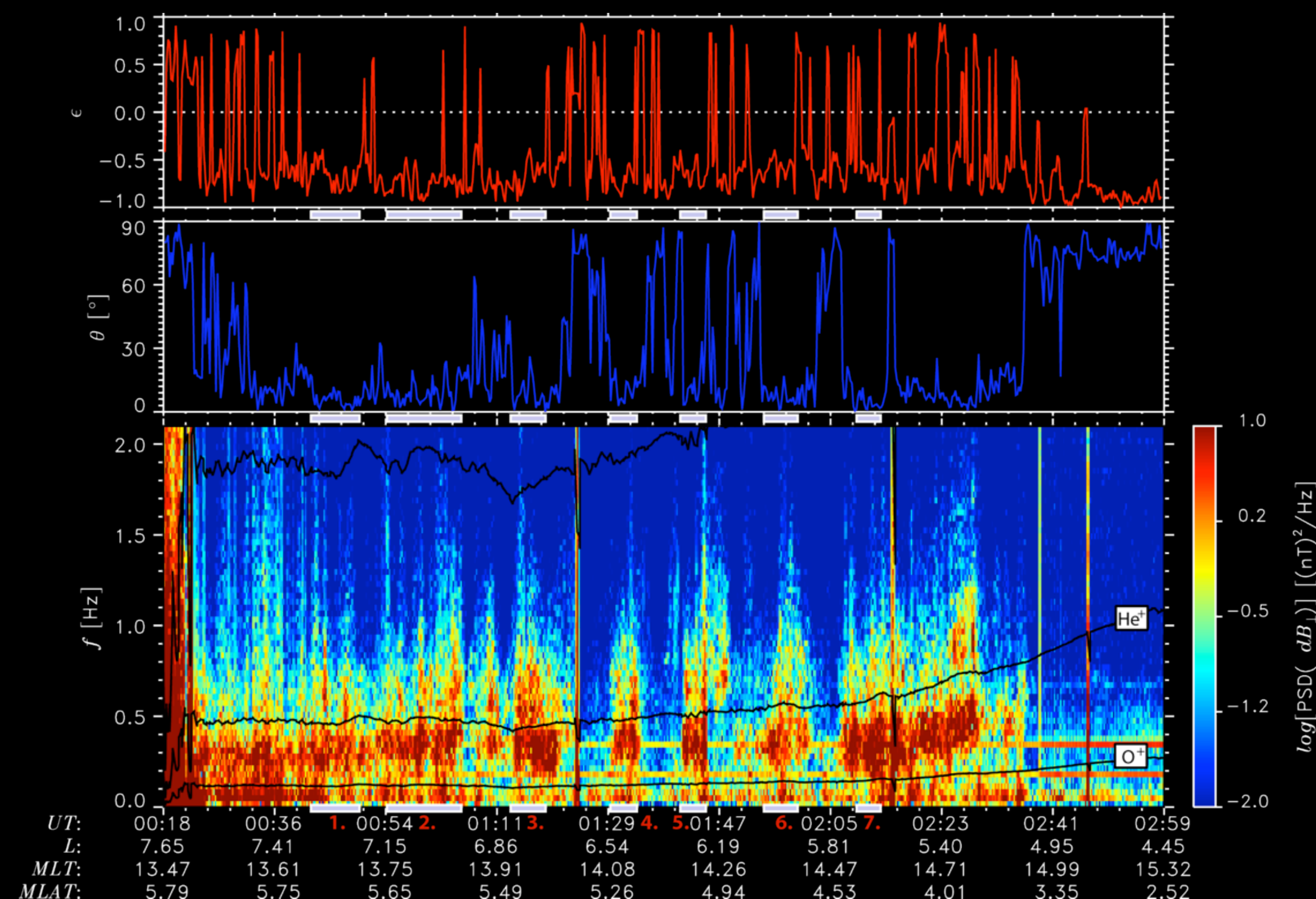
$$\omega - k_{\parallel} v_{\parallel} = \frac{\Omega_e}{\gamma}$$

Minimum Resonance Energy

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



EMIC Waves @ AMPTE/CCE



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.

SuperDARN-RBSP Joint Science Campaigns

1. Global Electric Fields - Transport and Acceleration of plasma from the tail to the inner magnetosphere.

2. ULF Waves (mHz) - Radial transport of electrons across the outer belt.

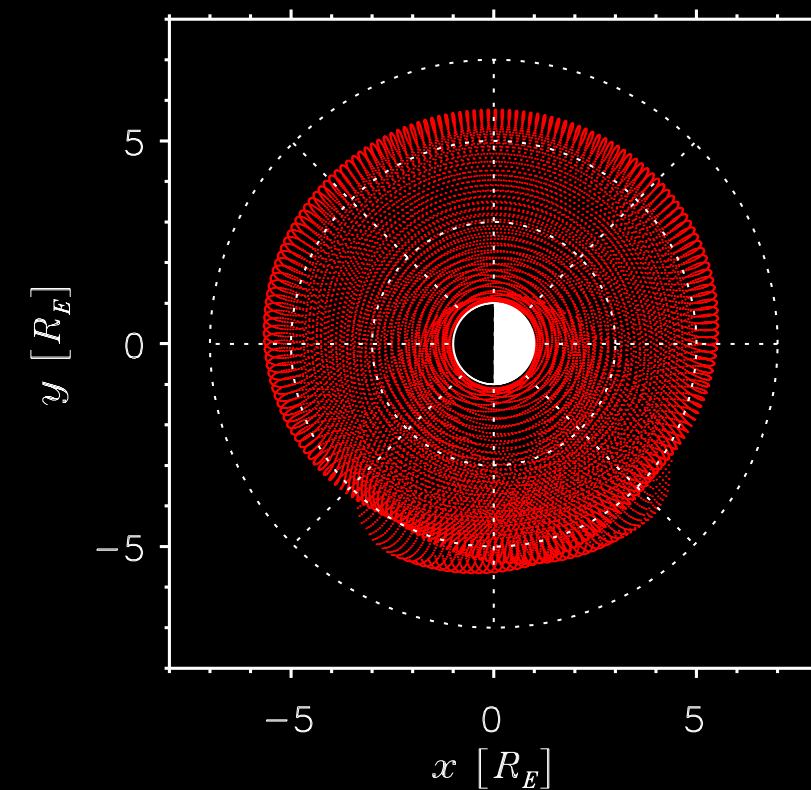
3. EMIC Waves ($\lesssim$ Hz) - Local loss of electrons from the outer belt.

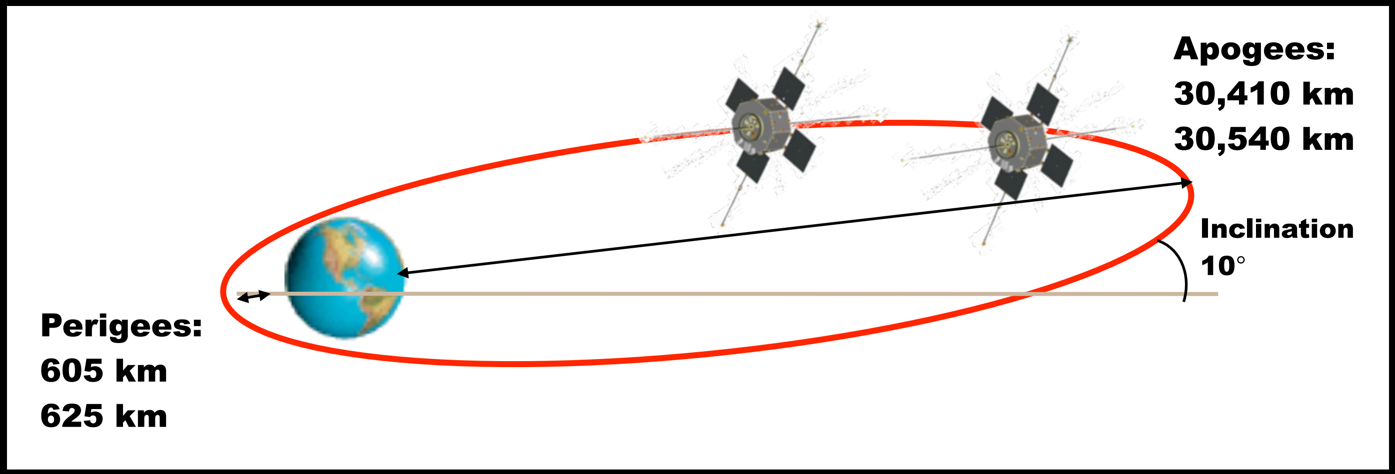
RBSP Orbit:

EQUATORIAL ORBIT, COMPLETE MLT COVERAGE

<u>2 Observatories</u>

- Spin Stabilized ~5 RPM
- Spin-Axis 15°-27° off Sun
- Attitude Maneuvers Every 21 days
- Operational Design Life of 2 years



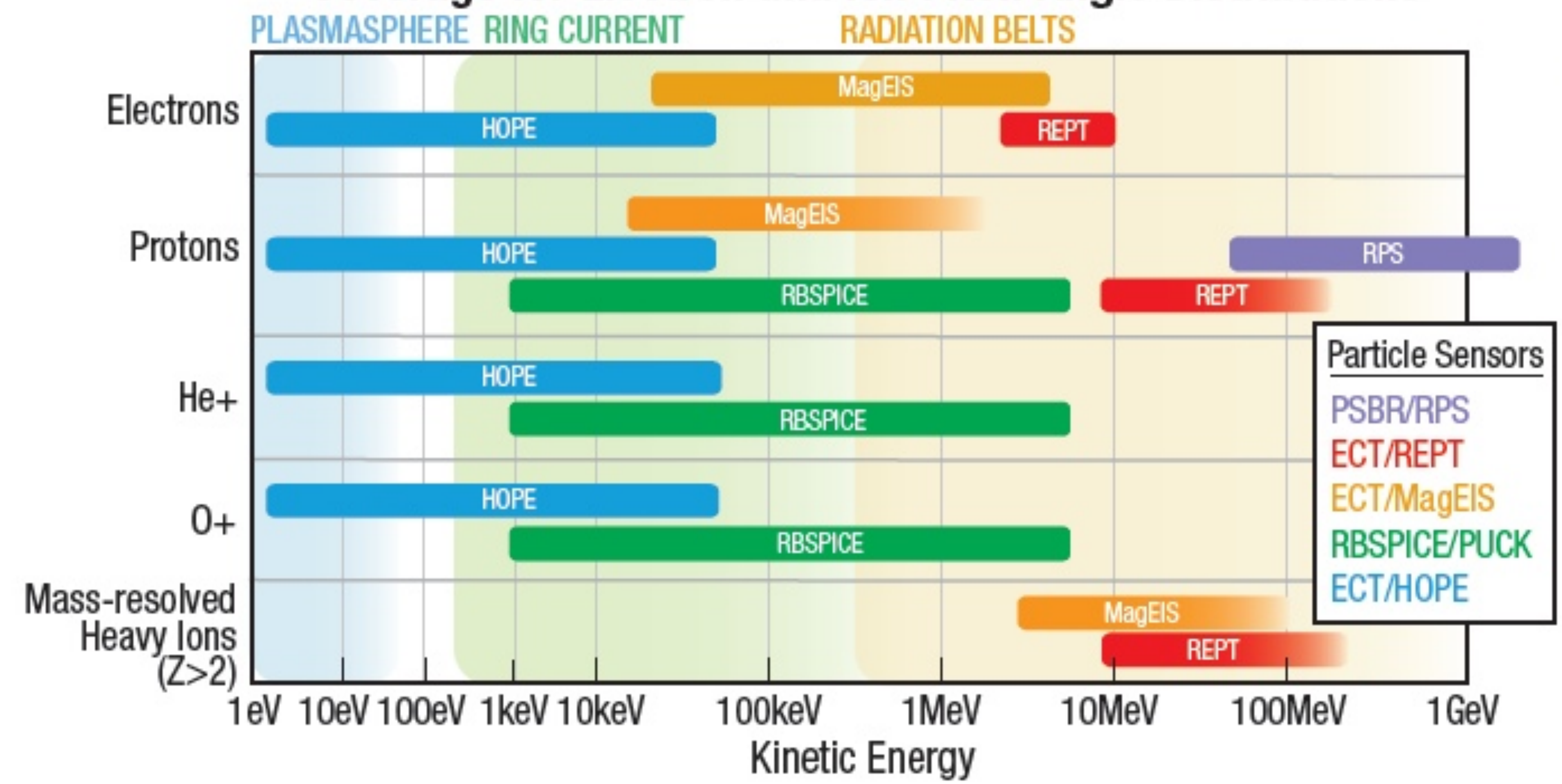


Differing apogees allow for simultaneous measurements to be taken over the full range of observatory separation distances several times over the course of the mission. Design allows one observatory to lap the other every ~75 days.

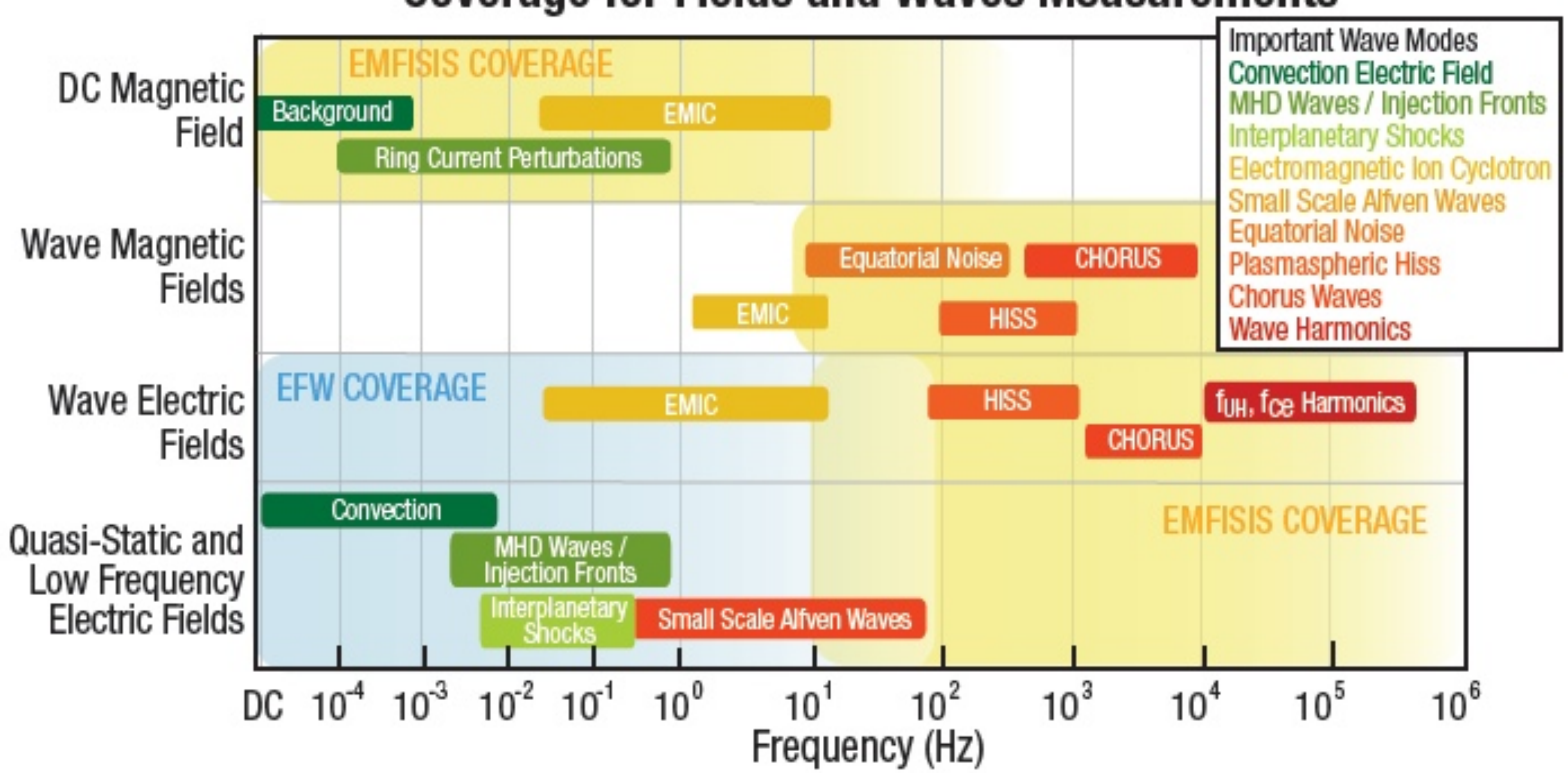
RBSP Science Team

Science Teams	Science Investigation	Instruments/Suites
Dr. Harlan Spence, PI Boston University,	Measure near-Earth space radiation belt particles to determine the physical processes that produce enhancements and loss	***ECT***: **E**nergetic Particle, **C**omposition and **T**hermal Plasma Suite
Dr. Craig Kletzing, PI 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	***EMFISIS***: **E**lectric and **M**agnetic **F**ield **I**nstrument **S**uite and **I**ntegrated **S**cience Suite
Dr. John Wygant, PI University of Minnesota,	Study electric fields that energize charged particles and modify inner magnetosphere	***EFW***: **E**lectric **F**ield and **W**aves Instrument
Dr. Louis Lanzerotti, PI 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	***RBSPICE***: **R**adiation **B**elt **S**torm **P**robes **I**on **C**omposition **E**xperiment
Dr. David Byers, PI National Reconnaissance Office	Specification models of the high-energy particles in the inner-most Van Allen radiation belt	***RPS***: **R**elativistic **P**roton **S**pectrometer

Coverage for Electron and Ion Pitch Angle Distributions



Coverage for Fields and Waves Measurements



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

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

MAG: Triaxial fluxgate Magneto-meter

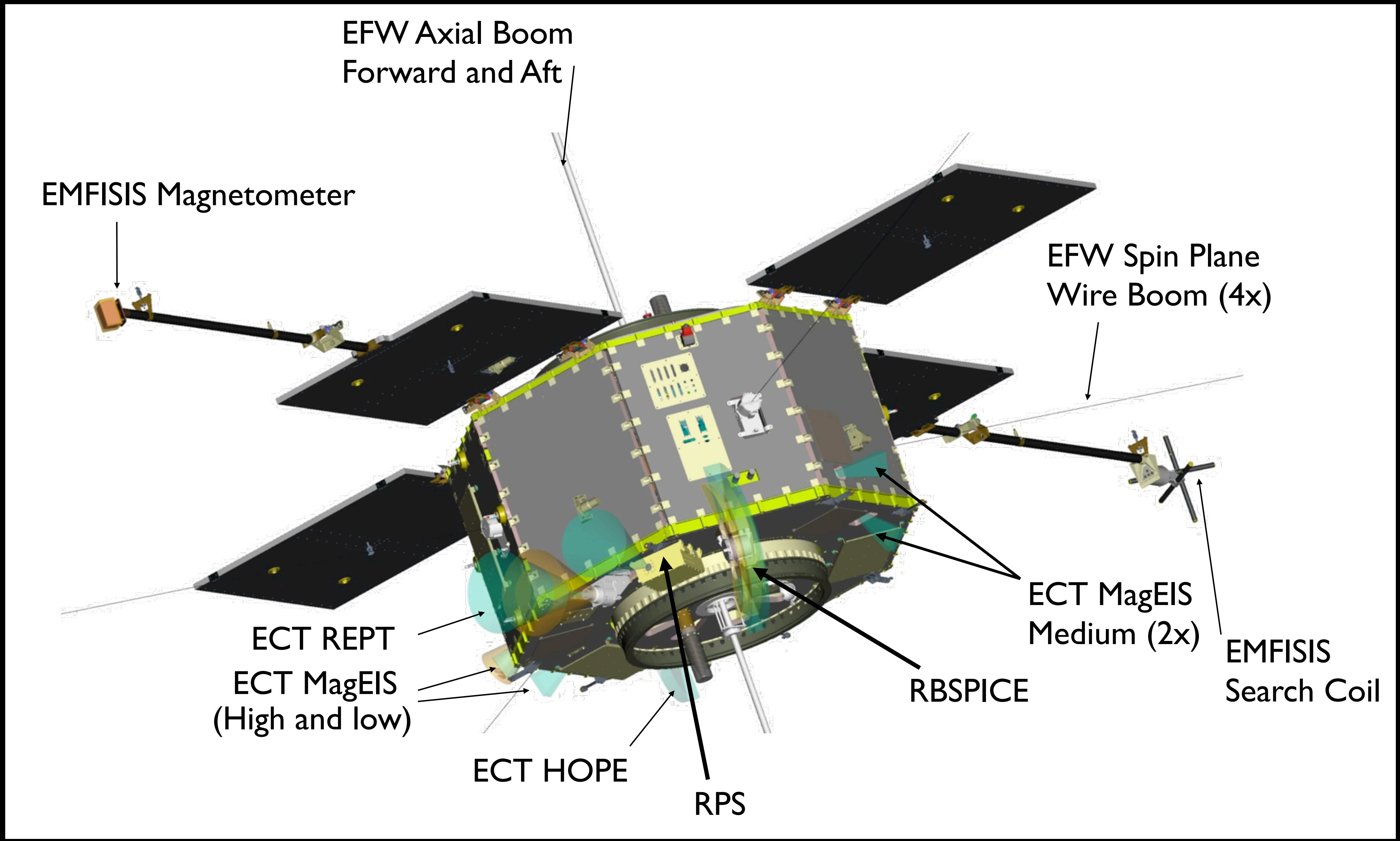
WAVES: Triaxial Search Coil and Waveform Receivers

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