The Living With a Star Radiation Belt Storm Probes Mission:

Resolving fundamental physical processes that have practical consequences.

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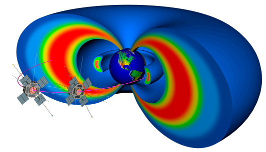
The Radiation Belt Storm Probes

- NASA will launch two identical probes into the radiation belts to provide unprecedented insight into the physical dynamics of near-Earth space.
- The radiation belts are now part of our technology infrastructure.
  - If we can understand the belts, we can improve our mission planning, and spacecraft operation and system design
- Data collected by the probes will help researchers develop and improve various models for the radiation belts that can be used by:
  - engineers to design radiation-hardened spacecraft
  - forecasters to predict space weather phenomena and alert astronauts and spacecraft operators to potential hazards
  - spacecraft operators for anomaly resolution

The Radiation Belt Storm Probes' Mission Objective is important and its Impacts are broad

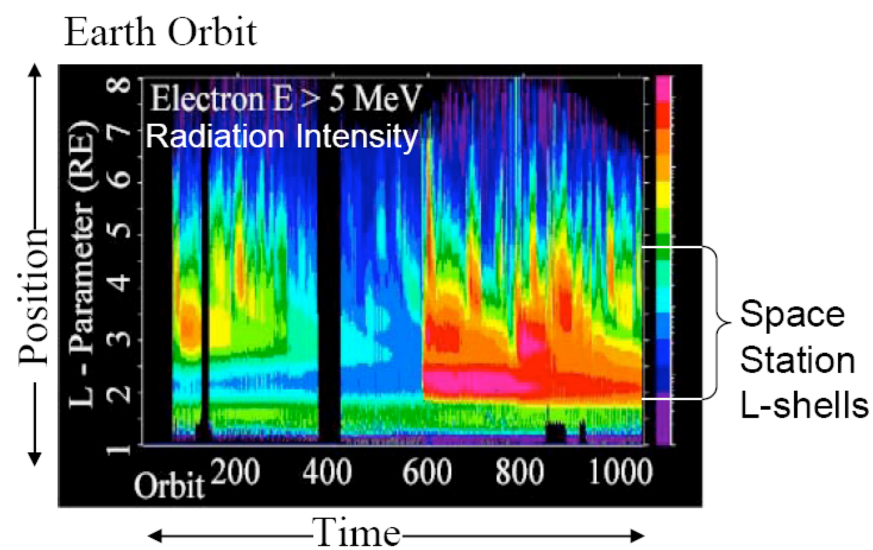


- <u>Objective</u>:

  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.

- <u>Impacts</u>:

1. Understand fundamental radiation processes operating throughout the universe.
2. Understand Earth's radiation belts and related regions that pose hazards to human and robotic explorers.



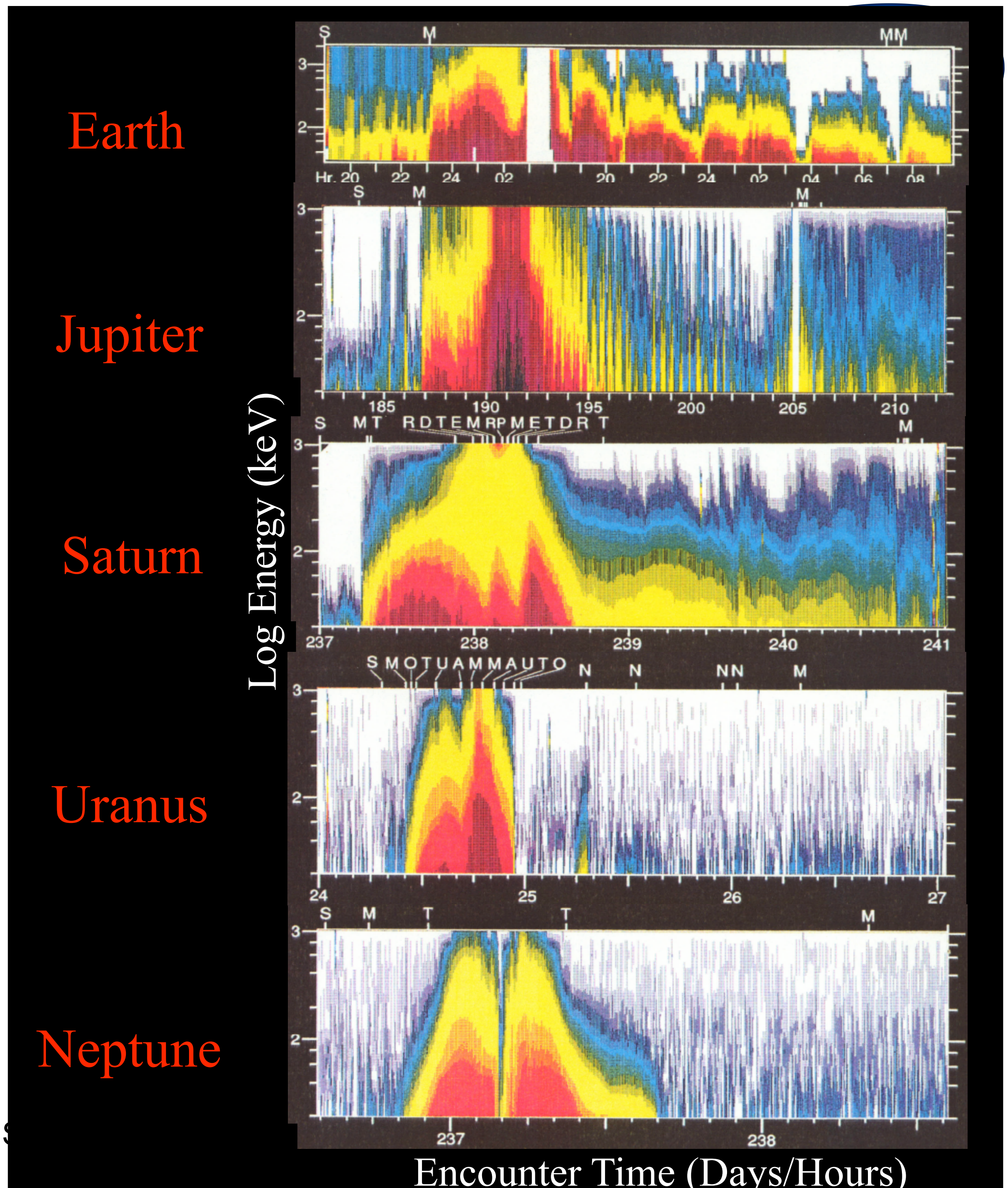
Intensities of Earth's dynamic radiation belts

Planetary Radiation Belts are a Universal Phenomenon

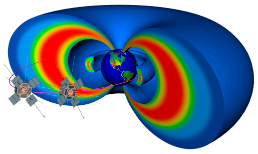
Results from recent NASA missions have shown clear evidence that radiation belts exist at all strongly magnetized planets throughout our solar system

Radiation Electron Intensities

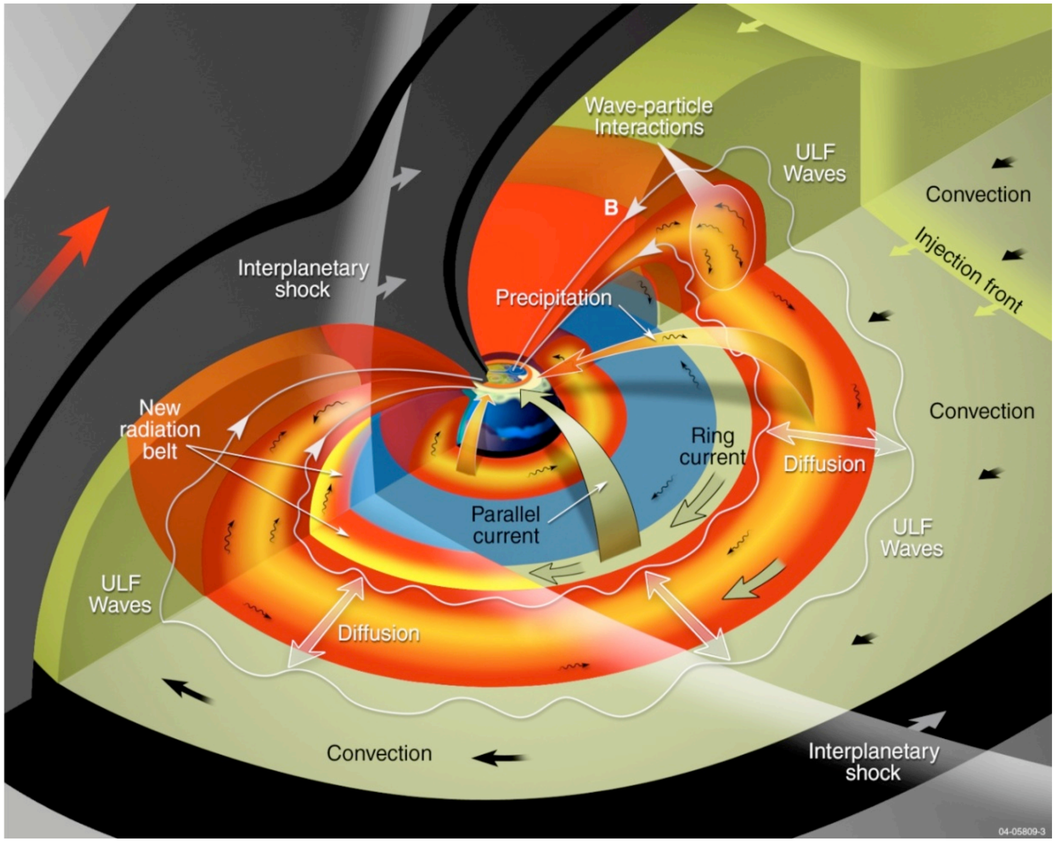
NASA's ISEE Mission
+
NASA's Voyager Mission



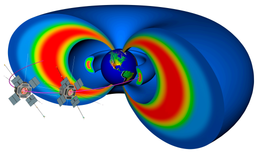
We have learned much about Earth's radiation belts in the last 50+ years but substantial & important mysteries remain



1. Why do the radiation belts respond so differently to different storm events?
2. Do magnetic topology change losses contribute to variable responses to storms?
3. Can radial transport be reasonably described & quantified as a diffusion process?
4. Why do observed global electric field patterns behave so differently than expected?
5. Do quasi-linear wave-particle interactions explain dramatic particle acceleration and loss?
6. What causes particle "microbursts"; do they require strongly non-linear wave interactions?
7. What are the relative roles of acceleration and loss in sculpting particle distributions?
8. Do dynamic injections create the conditions that explain the strongest particle accelerations?

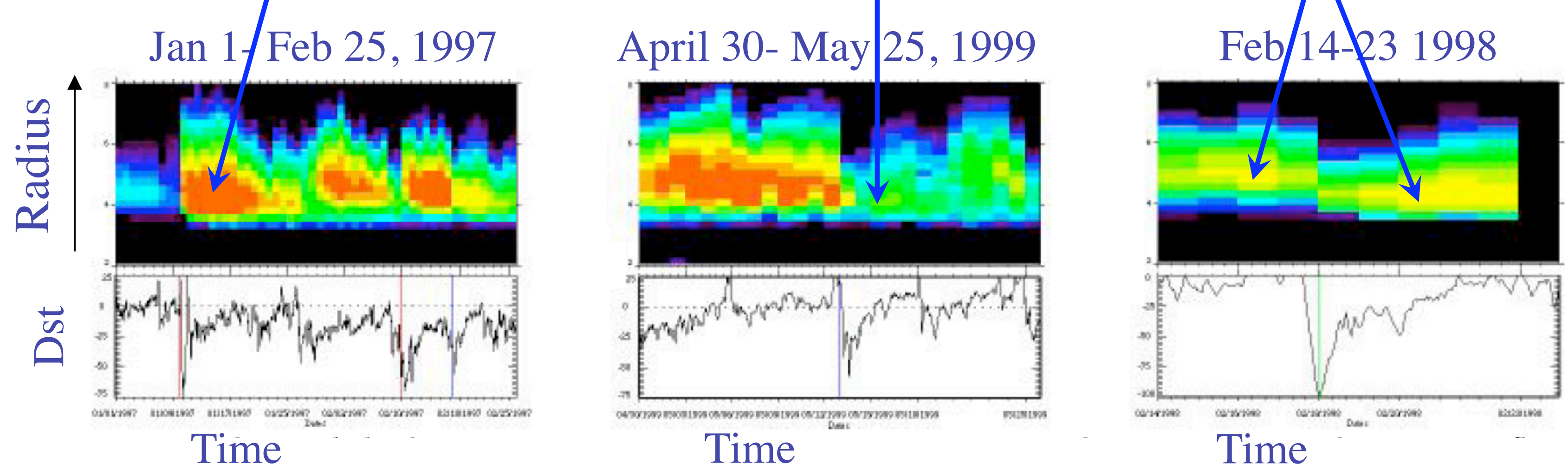


Why do the radiation belts respond so differently to different dynamic storm events?



Response of radiation belt electrons to geomagnetic storms (measured by Dst) cannot yet be predicted. Some Magnetic Storms:

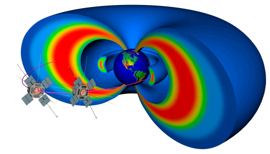
Cause dramatic radiation belt enhancements | Cause dramatic radiation Belt suppression | Cause no dramatic effects on Radiation Belts



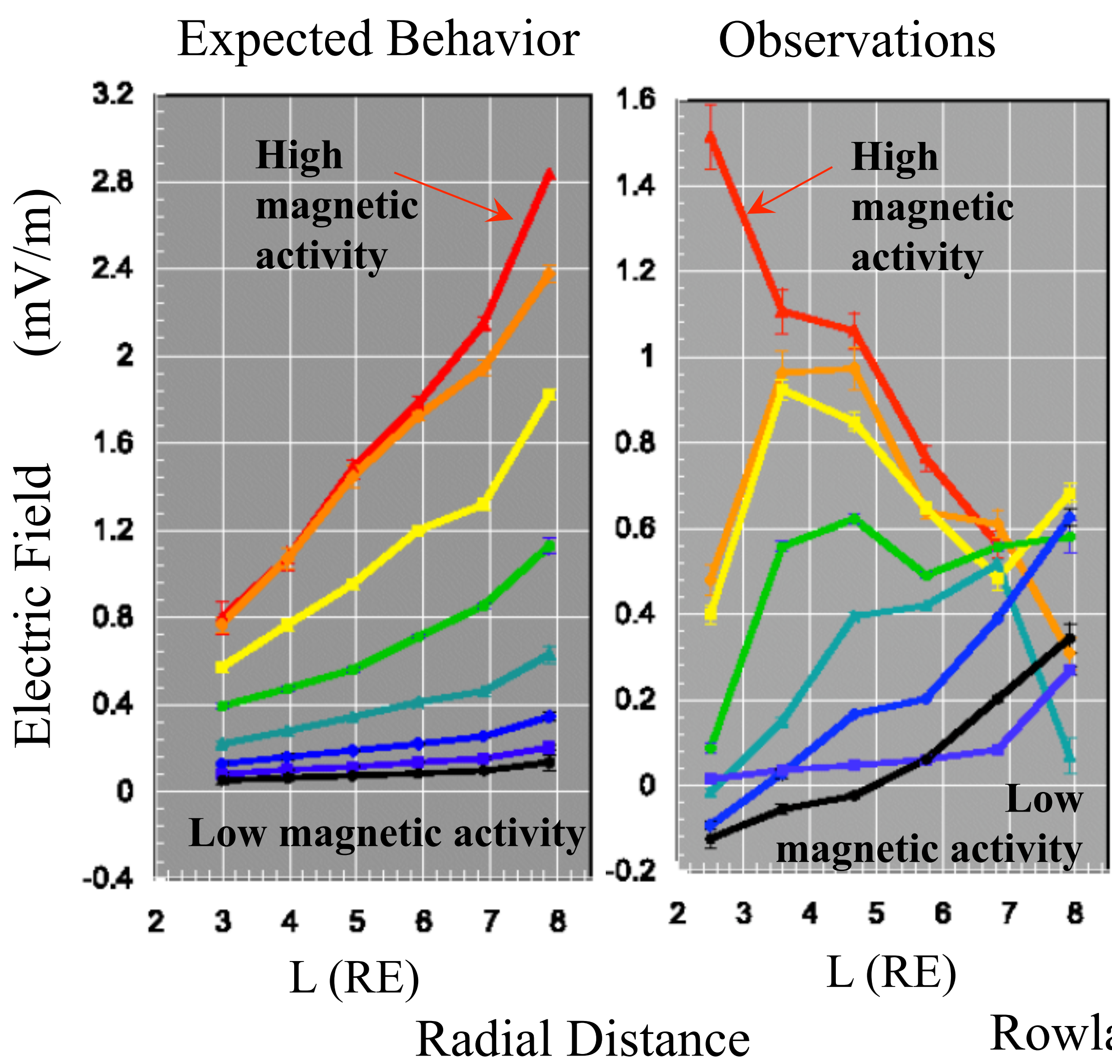
1.2-2.4 MeV electrons

Reeves et al., 2003.

We do not understand the fundamental physics: the response of acceleration and loss mechanisms to solar-induced geomagnetic storms



Why do observed global electric field patterns behave so differently than expected?



Rowland & Wygant, 1998

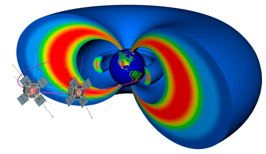
<u>Text book thinking is shown to be wrong:</u>

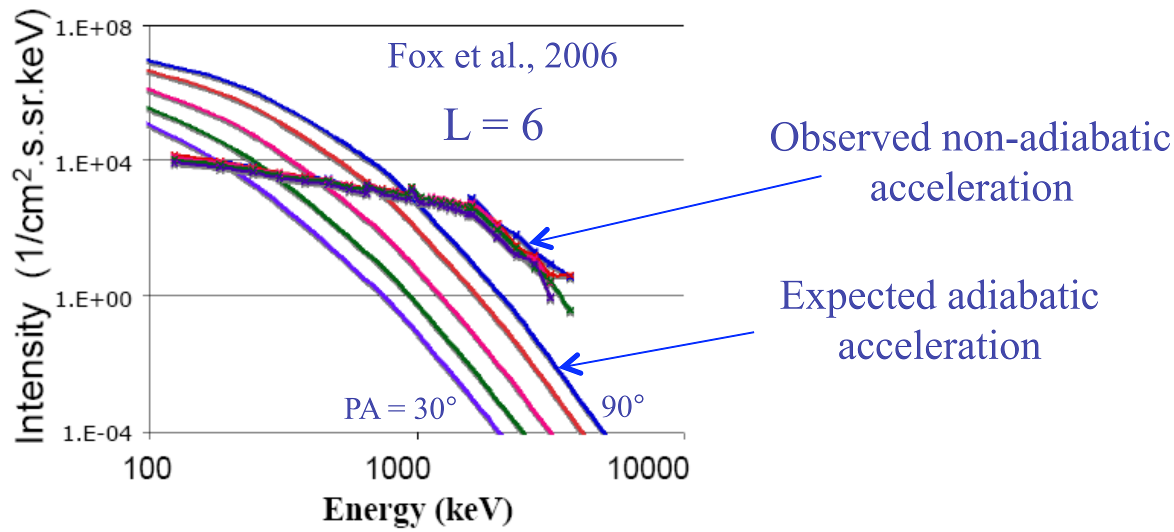
These electric fields control the configuration of plasmas that control the radiation belts

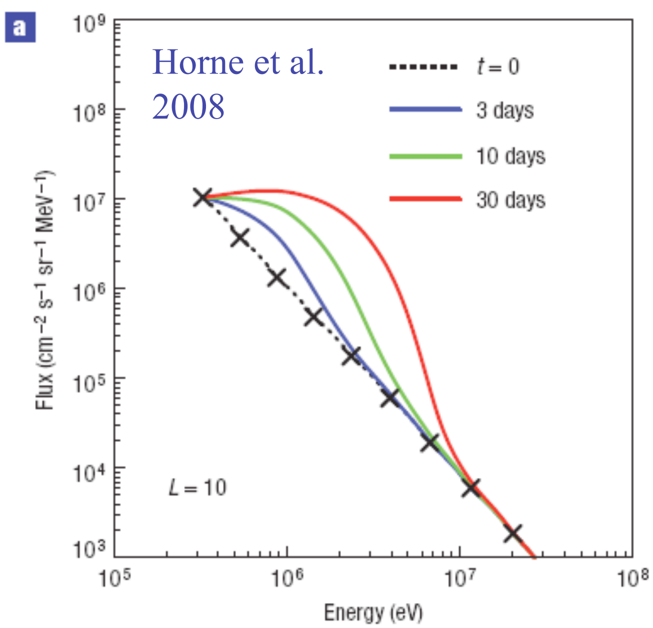
These CRRES observations showing "backward" behavior shocked the space science community and stimulated much controversy

Integrated measurements are needed to resolve this mystery

Do quasi-linear wave interactions explain dramatic particle acceleration and loss?

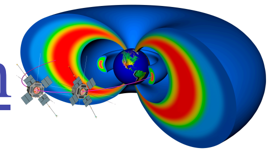




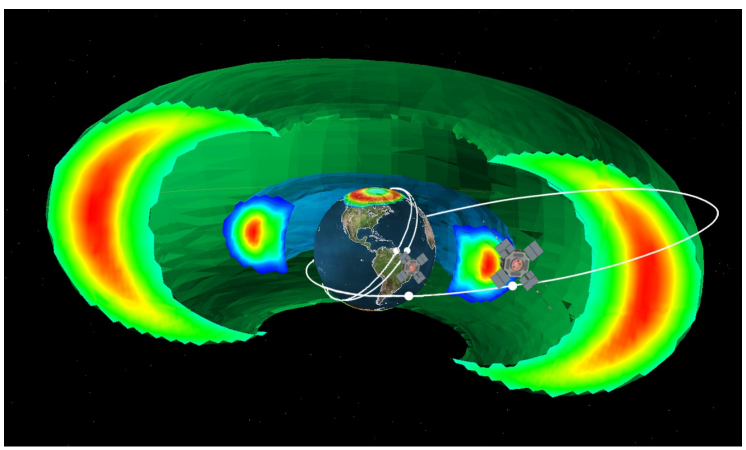


- We have observed that there is a need for non-adiabatic processes
- Example of a quasi-linear calculation of energization.
  - Does this suffice to explain the difference in the observed and expected ?

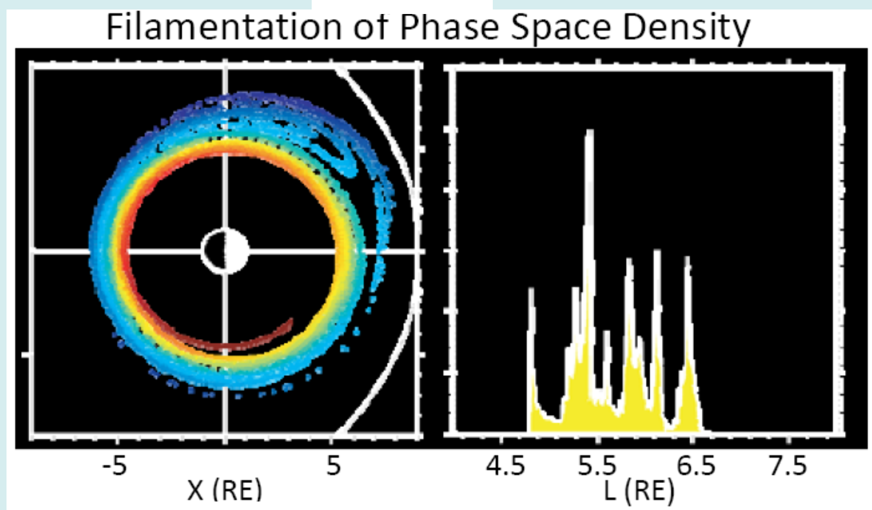
To solve these (and other) mysteries, a new approach is needed: multipoint sampling is critical to answering radiation belt questions



- Simultaneous, multipoint sampling at various spatial scales resolves the space-time structuring
- e.g. simulation showing space-time structuring – need to be able to determine the relative importance of spatial and temporal effects

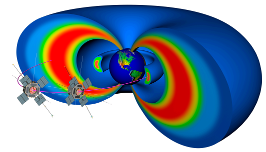


Space-time structuring (filamentation) of particle phase space density radial profiles reveal the nature of the radial transport of radiation particles.

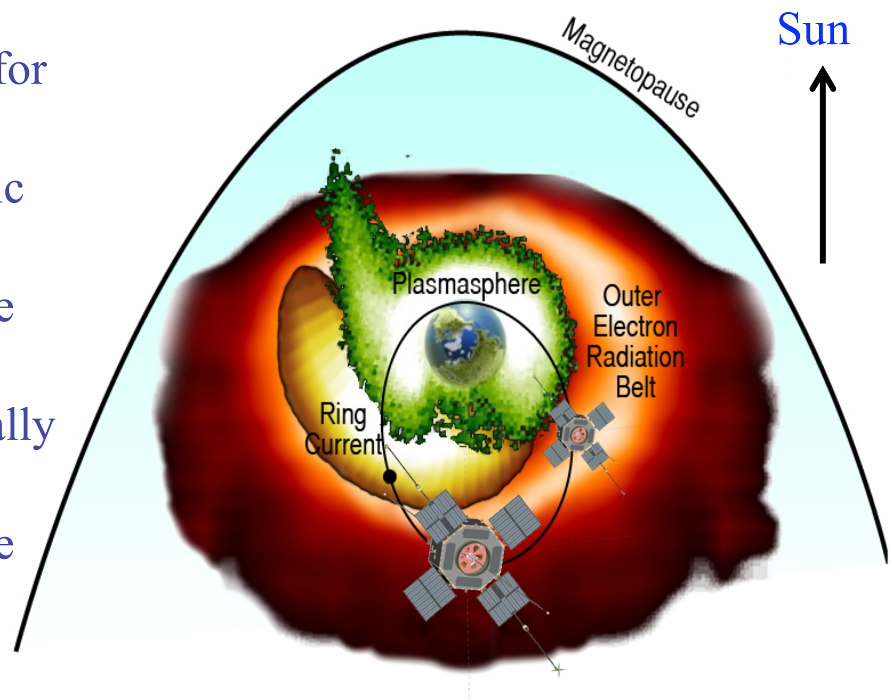


Courtesy A. Ukhorskiy

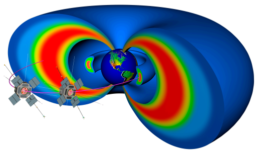
Multiple spacecraft must target key radiation belt regions with variable spacing



- The RBSP Mission design is optimized to achieve mission objectives
- 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.
- 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



RBSP Comprehensive Measurements are provided by several experienced teams



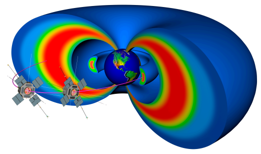
NASA Funded Investigations:

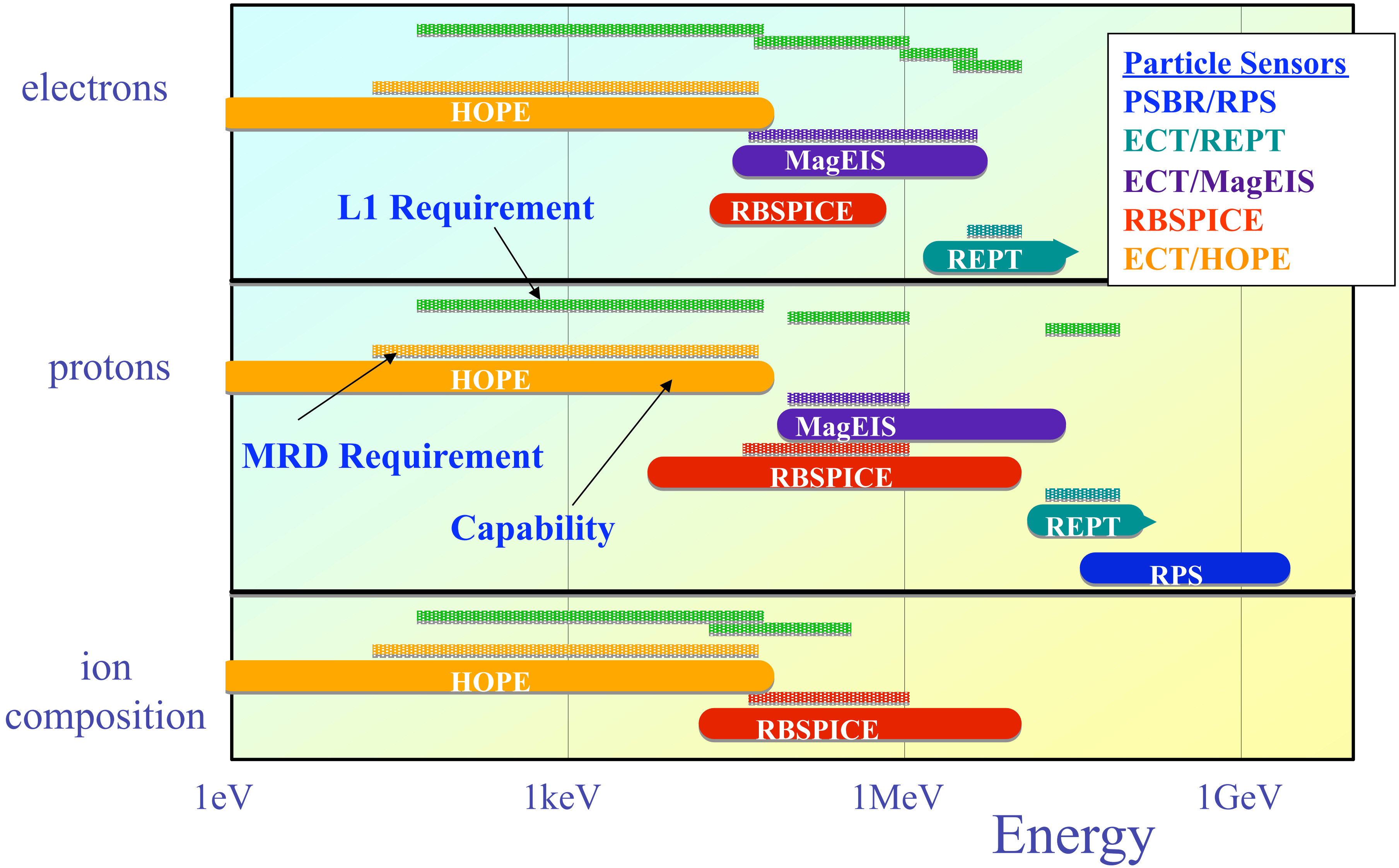
- **Energetic Particle, Composition, and Thermal Plasma (ECT) Instrument Suite**
  - PI: Dr. Harlan Spence, University of New Hampshire
  - Key partners: LANL, SwRI, Aerospace, LASP
- **Electric and Magnetic Field Instrument Suite and Integrated Science (EMFISIS)**
  - PI: Dr. Craig Kletzing, University of Iowa
  - Key partners: NASA/GSFC, University of New Hampshire
- **Electric Field and Waves Instrument (EFW)**
  - PI: Dr. John Wygant, University of Minnesota
  - Key partners: University of California, Berkeley, LASP
- **Radiation Belt Storm Probes Ion Composition Experiment (RBSPICE)**
  - PI: Dr. Louis Lanzerotti, New Jersey Institute of Technology
  - Key partners: APL, Fundamental Technologies

Non-NASA Funded (GFE):

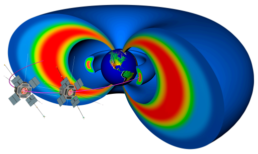
- **Proton Spectrometer Belt Research (PSBR) - Relativistic Proton Spectrometer (RPS)**
  - PSBR PI: Dr. David Byers, National Reconnaissance Office (NRO)
  - RPS PI: Dr. Joseph Mazur, Aerospace Corp.

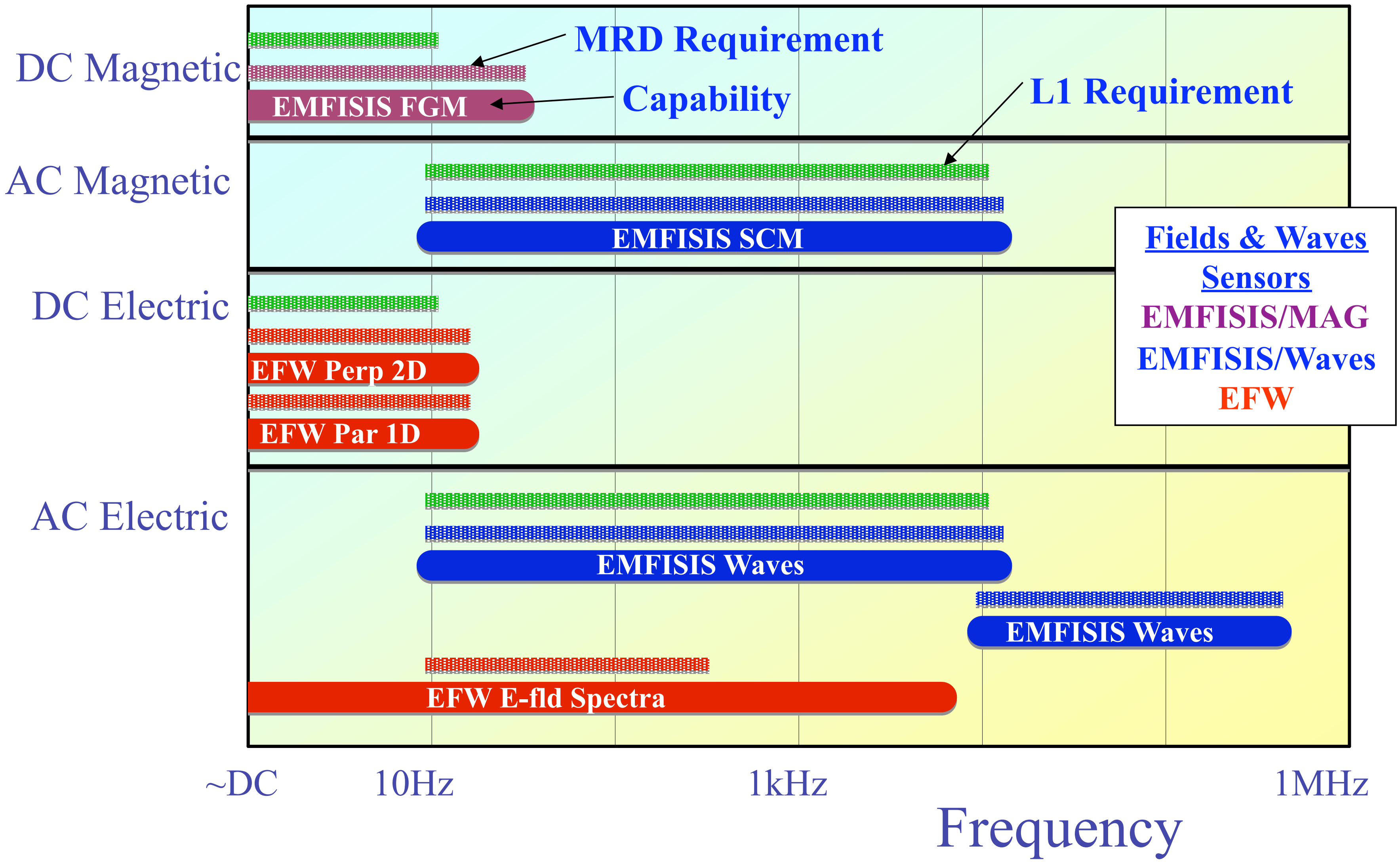
RBSP has unusually comprehensive particle instrument measurement capabilities



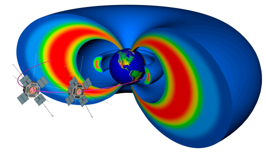


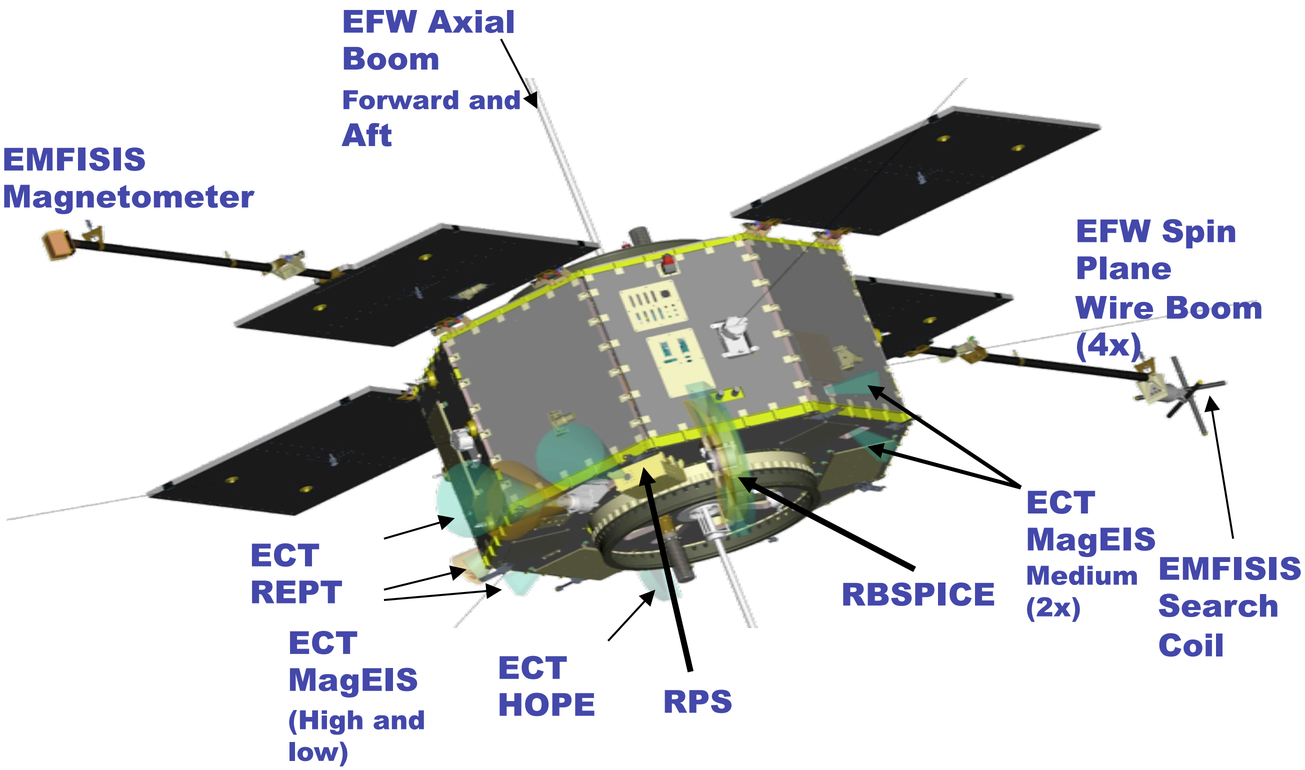
RBSP has unusually comprehensive fields instrument measurement capabilities





RBSP is mature: The mission passed its Critical Design Review December 2009, and will launch in 2012



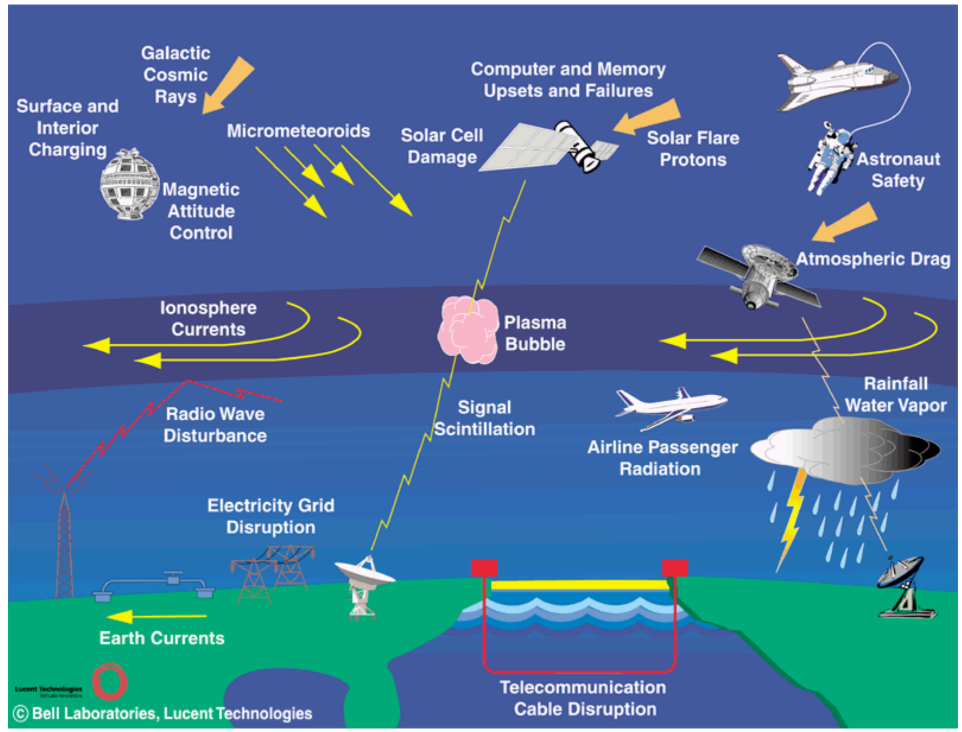


The structure has been built and has just undergone vibration testing

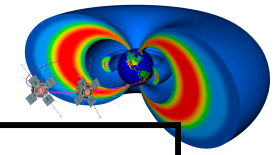
RBSP Space Weather Broadcast

- In addition to providing unique datasets that enable understanding of fundamental physics and improvement to modeling and forecasting efforts, the RBSP mission will have a real-time downlink of space weather data

- These data are a subset of the complete science dataset deemed to be the most useful to the user community

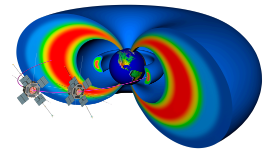


RBSP Real time data set

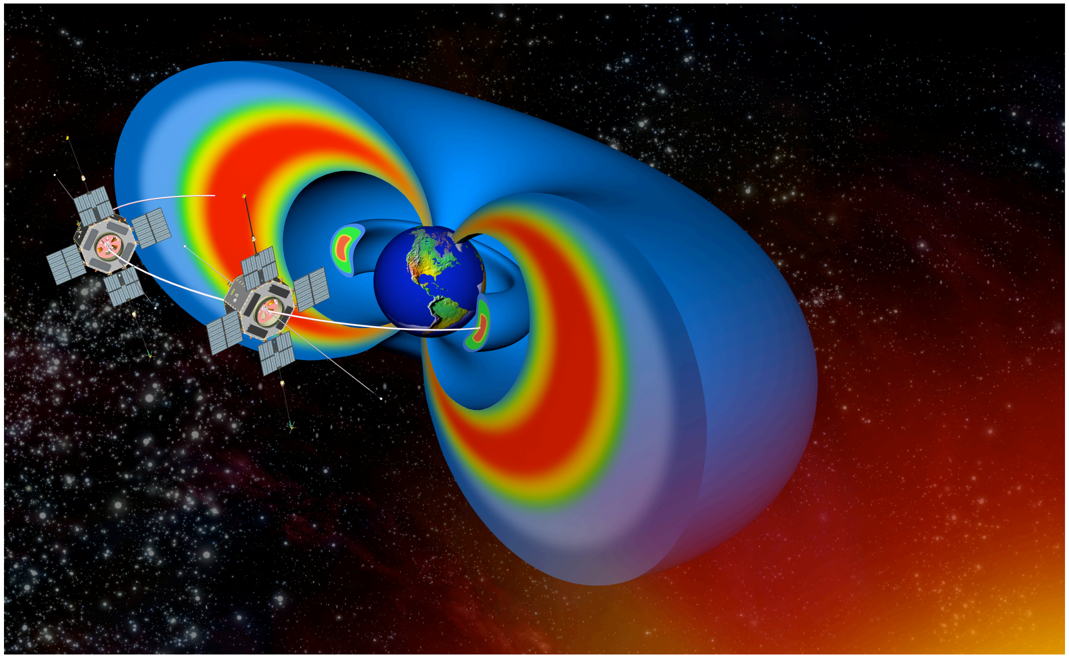


Measurement	Instrument	Details
Vector magnetic field	EMFISIS/MAG	3 components
Vector electric field	EFW	2D spin plane vector sample
VLF Wave power	EMFISIS/WAVES	3 electric field spectra every 12 secs; 3 magnetic field spectra every 12 secs
Spacecraft potential	EFW	Once/spin
Energetic electrons	ECT/HOPE	25 eV, 300 eV, 10 keV, 40 KeV
	ECT/MagEIS	30 keV, 60 keV, 100 keV, 300 keV, 600 keV, 1 MeV, 2MeV
	ECT/REPT	2 MeV, 5 MeV, 10 MeV
Energetic protons	ECT/HOPE	25 eV, 300 eV, 10 keV, 40 KeV
	RBSPICE	50 keV, 100 keV, 150 keV, 300 keV, 1 MeV, 10 MeV
	ECT/REPT	>20 MeV, >50 MeV, >70 MeV
	PSBR/RPS	>100 MeV, >400 MeV
Energetic helium ions	ECT/HOPE	25 eV, 300 eV, 10 keV, 20 KeV
Energetic oxygen ions	ECT/HOPE	25 eV, 300 eV, 10 keV, 20 KeV
Dosimeter Data	PSBR/RPS	Linear and Log outputs (Volts)

Unusual orbit provides greater insight into many regions of the radiation belts

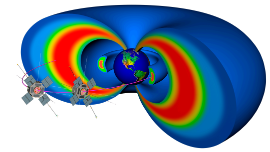


- The highly elliptical orbit of RBSP will provide data from the non-traditional orbital locations
  - Operational monitoring satellites are usually at or near geosynchronous orbit
- For 3-D specification models, these altitude-varying profiles will provide greater sampling of Earth's radiation environment

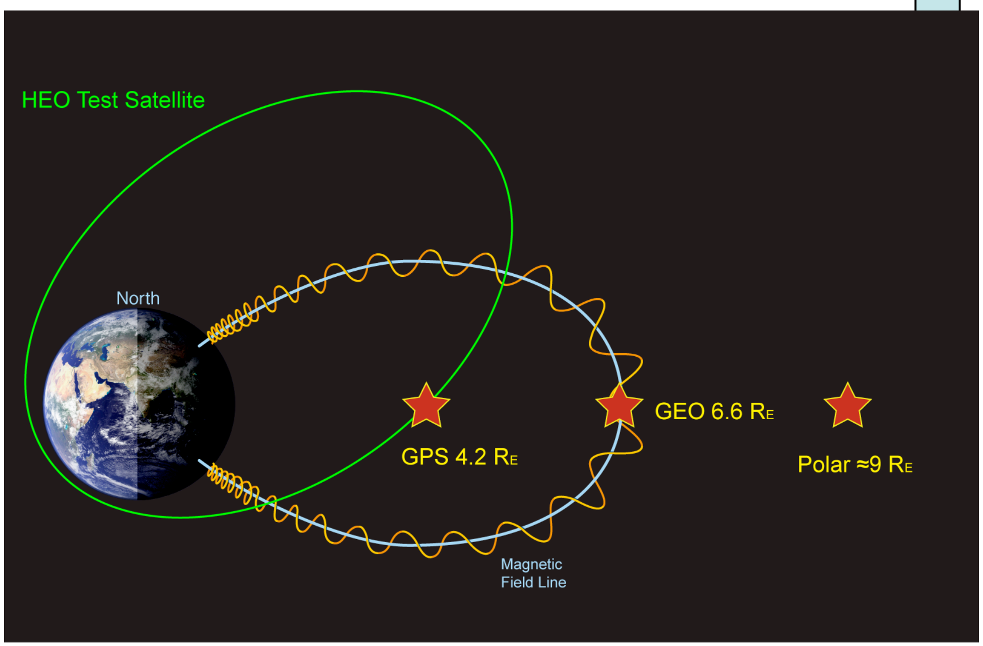


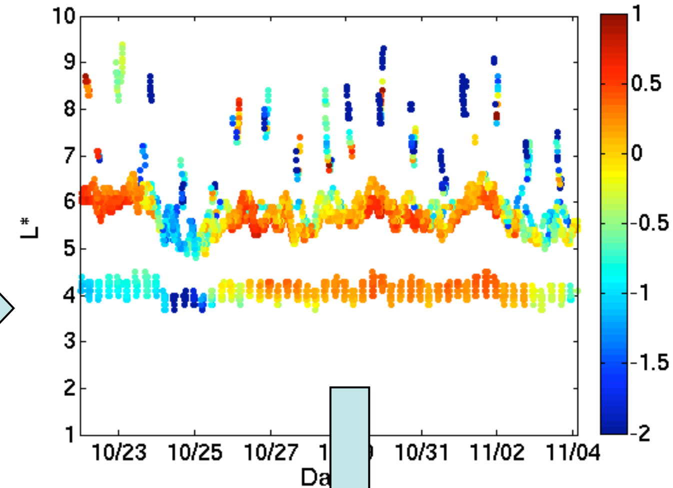
- 2 observations of the same region of space with identical instrumentation

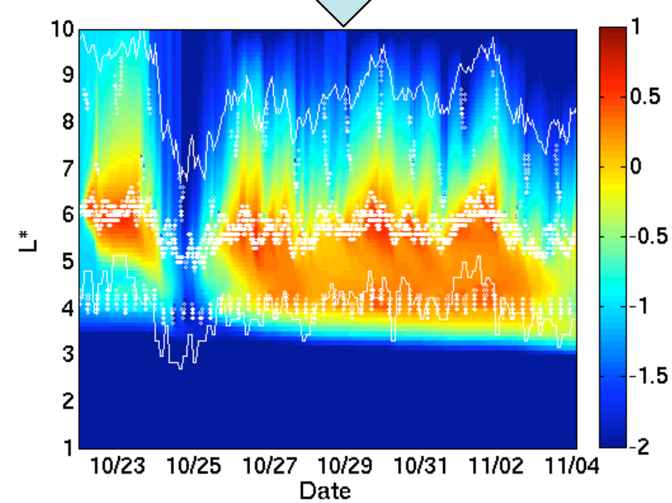
Example of Data Assimilation combining sparse observations and physical models



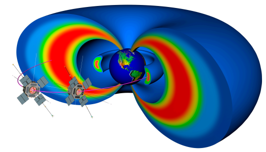
- DREAM: The Dynamic Radiation Environment Assimilation model uses:
  - Data from 3 points in space (GPS, GEO Polar)
  - A physics model with radial diffusion and losses in three spatial regions
- DREAM can predict the environment in a completely different orbit





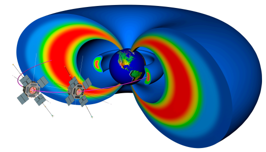


Implementing RBSP space weather return



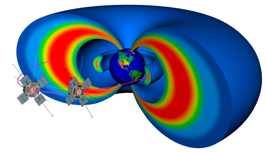
- The RBSP concept provides up a 1 kbps space weather broadcast
- 5-m dish with a 400K system noise temperature will close link out to apogee
- The space weather data will be broadcast at all times, through the primary spacecraft science downlink antennas, when an observatory is not in a primary mission-related ground contact.
  – This requires a network of ground stations to be identified in order for the space weather data to be received by customers.
  – The real time coverage is reduced by an average of 1.5 hours for each observatory per day due to primary mission contacts.
    - One of the two observatories should still be available because most contacts with each observatory do not overlap.
  – Downlink is limited by the availability of space weather ground stations and antenna coverage – we do not “stare” at Earth 24/7.

Implementing RBSP space weather return



- Current concept is for APL to act as the data host.
  - APL will "pull" the data from participating ground stations
  - The data will be cleaned and merged and displayed on the web as soon as possible
  - The space weather data will be available for 5 days
    - then these will be replaced by the fully processed science data products
  - The raw space weather data will be archived permanently at APL
- An announcement was sent out via the SPA and GEM Newsletters
  - We are now starting to work with potential "receivers" and "users"
  - We are very interested to hear how these data could benefit the user community and to work with you to make this happen
- For more information on the mission:
  - http://rbsp.jhuapl.edu
  - Nicola.fox@jhuapl.edu

RBSP resolves important & universal science questions that have practical consequences



- RBSP advances NASA's Strategic Plan and Heliospheric Science Objectives by:
  - Advancing our understanding of the dramatic and puzzling responses of Earth's radiation belts to varying solar activity
  - Advancing our understanding needed to engineer solutions for technological systems.
  - Resolving fundamental science processes that occur throughout our Universe.
- Much has been learned about radiation belt physics but:
  - Radiation belt dynamics is not understood.
  - Untangling the interaction of complex processes is needed.
- RBSP provides the needed multi-point sampling and integrated measurements to make transformational advances in understanding.
- Near real-time data from RBSP are available to
  - Monitor and analyze current environmental conditions.
  - Forecast natural environmental changes
  - Support anomaly resolution