What have we learned so far about Van Allen Probes Science Goals?

(work in process, not comprehensive)

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Minimum Mission Success = achieving Threshold Measurements + making progress on Science Goals

Science Goals

All of the following:

1. Electron belt characteristics/sources
2. Candidate processes
3. Flows and fronts
4. Global and storm-time effects
5. VLF/ELF/ULF wave effects

Plus one of following:

a. Global electrodynamics
b. Wave-particle interaction physics
c. Proton belt characteristics/sources
d. Physics of shock-related events

Significant progress

Nominal progress

3. Flows and fronts

- determine convective and impulsive flows
- Determine propagation properties of shock-generated propagation fronts
- infer total plasma densities

4. Global effects

- convert particle measurements to magnetically invariant coordinate systems
- infer loss cone size
- model effects of global dB, dE on observed particle distributions

a. Global electrodynamics

Understanding how large-scale magnetic and electric fields in the Earth's inner magnetosphere are generated and evolve

b. Wave-particle interaction physics

- Understanding, quantifying conditions that control production/propagation of waves
- Determining characteristics of wave medium
- Determining mutual interactions between particle populations and waves
- determining how plasma and wave characteristics control effects of on penetrating radiation particles
- Acceleration/loss of energetic particles from non-linear interactions with large amplitude wave structures.

c. Proton belt characteristics, sources

Estimating the relative importance of candidate processes of acceleration, transport, and loss, and statistically characterizing processes as a function of solar input conditions.

d. Physics of shock-related events

These events are rare but provide such unique and compelling opportunities for new scientific discovery that detailed measurements of only a single extreme shock-related event would produce scientific success.

1. Electron belt characteristics/sources

1. Understand & quantify energization, loss, transport
2. Understand & quantify source populations
3. Determine how 1 & 2 produce spatial-temporal variations
4. Enable improved radiation belt models

Plasmapause position important. Foster et al. show prompt reenergization outside. Inside slow decay due to pitch angle scattering by ***plasmaspheric hiss*** exceeding 10–20 days for electron >3 MeV. At lower energies, the decay is much more rapid [Thorne, et al.]. This explains the existence of the ***isolated, persistent storage ring*** of extremely high-energy electrons just inside the plasmapause (Baker et al.).

Diurnal effects important. Earth's rotation induces global diurnal variations of B and E that resonantly interact with electrons with drift period ~24 hours, modifying electron fluxes over a broad energy range into regular patterns comprised of multiple stripes over the inner radiation belt (Ukhorskiy et al.)

Loss. Rapid narrow precipitation features termed precipitation bands play a critical role in radiation belt losses; ~20 such events could empty the entire outer belt – precipitation into atmosphere [Blum et al.]. Using test-particle simulations, Hudson et al. showed evidence for loss due to magnetopause shadowing. Outside $4R_E$ loss due to magnetopause shadowing and precipitation, inside $4R_E$ loss due to precipitation due to pitch angle scattering by EMIC waves [Shprits et al.].

Energization. Local acceleration observed in radial profiles of PSD [Reeves et al.] Thorne et al. demonstrate conclusively that chorus scattering is solely responsible for the temporal evolution of the energy and angular distributions. Su et al. illustrate the complexity of electron radiation belt behaviors and the importance of chorus-driven local acceleration even during the nonstorm times. Schiller et al. show that geomagnetic storms are not necessary for causing dramatic enhancements in the outer radiation belt.

Balance of Energization and Loss. Tu et al. show outward radial diffusion to the solar-wind driven magnetopause, an event-specific chorus wave model, and a dynamic lower-energy seed population, are critical for modeling the dynamics.

2. Candidate processes

1. Distinguish between candidate processes of acceleration, transport, and loss
2. Statistically characterize these processes as a function of solar and magnetospheric input conditions

Local Energization. Local acceleration observed in radial profiles of PSD [Reeves et al.] Thorne et al. demonstrate conclusively that chorus scattering is solely responsible for the temporal evolution of the energy and angular distributions. Su et al. illustrate the complexity of electron radiation belt behaviors and the importance of chorus-driven local acceleration even during the nonstorm times. Schiller et al. show that geomagnetic storms are not necessary for causing dramatic enhancements in the outer radiation belt.

Global Energization. Mann et al show coherent acceleration due to resonance with ultralow frequency (ULF) waves on a planetary scale: a geophysical synchrotron.

Diffusive loss. O'Brien et al. identified a case of synchronized decay of electron flux likely corresponding to a pitch angle diffusion eignemode.

Competing mechanisms. Baker et al. show cases in the March 2013 period demonstrating the classic signatures both of inward radial diffusive energization as well as abrupt localized acceleration; both "competing" mechanisms of multi-MeV electron energization are at play in the radiation belts, often acting concurrently or in rapid succession. Turner et al. using 15 s/c investigated a geomagnetic storm period: main phase showed enhanced losses to the atmosphere at $L^* < 4$ consistent with pitch-angle scattering by EMIC waves. Local acceleration also active during the main and early recovery phases corresponding to IMF Bz southward, AE >300nT, and energetic electron injections and whistler-mode chorus waves were observed. When Bz turned northward, injections, chorus activity, and enhancements in PSD ceased.

5. VLF/ELF/ULF wave effects

- Determine types of waves causing adiabatic and non-adiabatic energization/loss of electrons
- Estimate diffusion coefficients/loss rates
- Infer total plasma densities
- Estimate relative contribution of ULF/irregular fluctuations to radial transport
- Provide statistical waves field maps as function of local and interplanetary geophysical conditions

ULF. Claudepierre et al. show localized drift resonance between polodial mode ULF waves and 60 keV electrons. Dai et al. identified the generation of a fundamental mode standing poloidal ULF wave through drift-resonance interactions in the inner magnetosphere. Mann et al. show coherent acceleration due to resonance with ULF waves on a planetary scale: a geophysical synchrotron.

FLR. Chaston et al. determined the characteristics of these waves and showed that variations were observed during injections of energetic plasmas into the inner magnetosphere.

EMIC. By combining both in-situ and ground-based data Paulson et al. found that the region satisfying EMIC wave generation conditions is azimuthally large while radially narrow. Usanova et al. computed radiation belt electron pitch-angle diffusion rates and demonstrated that rapid pitch-angle diffusion is confined to low pitch angles. They showed evidence of EMIC waves triggering ~2-8 MeV electron loss confined to pitch angles below around 45 degrees and not affecting the core distribution.

Hiss. Li et al suggest unusual low-frequency plasmaspheric hiss is likely to be amplified in the outer plasmasphere due to the injected energetic electrons.

Chorus. Santolik et al. identified fine structure of large-amplitude chorus. Li et al. constructed chorus wave distributions and demonstrated that the inferred chorus wave amplitudes agree reasonably well with Van Allen Probes data. Chen et al. demonstrate that time-dependent, global distributions of near-equatorial chorus wave intensities can be inferred from LEO measurements of precipitating low-energy electrons.