Internal Charging Hazards in Near-Earth Space during Solar Cycle 24 Maximum: Van Allen Probes Measurements

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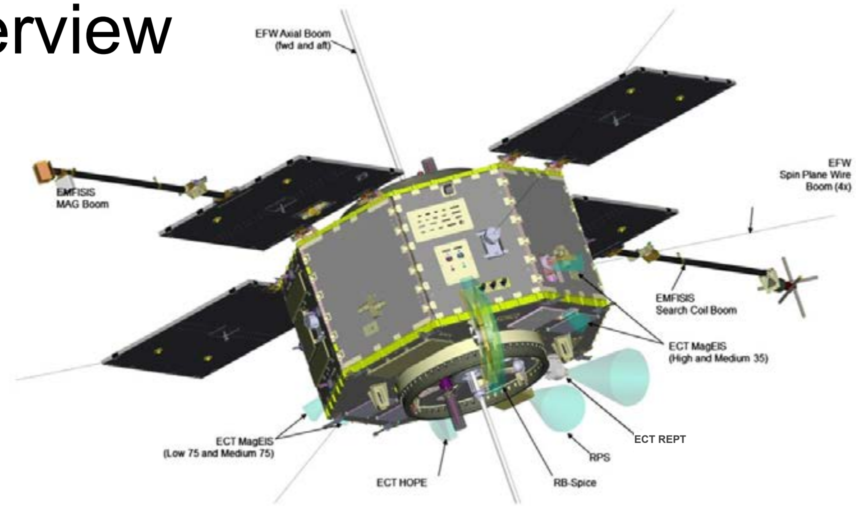
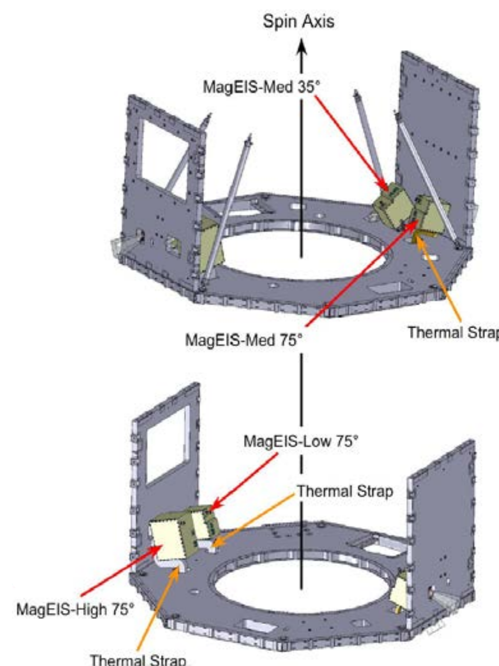
Outline

- Overview of Van Allen Probes MagEIS spectrometers and orbit
- Flux variations of the radiation belts over the current solar maximum and comparison with MEO and HEO variations over an entire solar cycle
- Charge deposition analysis methodology
- Relationship between radiation belt flux variations to internal charging time histories
- Conclusions and implications of results

Van Allen Probes MagEIS Overview

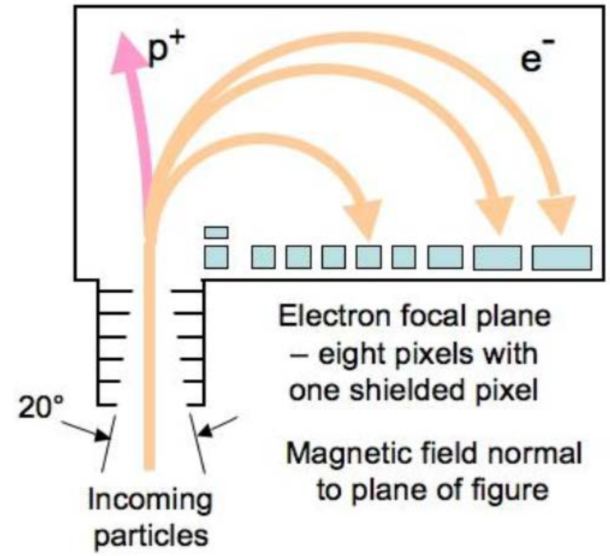
- MagEIS is comprised of four independent magnetic electron spectrometers
  - *1 low energy (Field of view, FOV centered at 75 deg to spin axis)*
  - *2 medium energy (FOV centered at 75 deg and 35 deg to spin axis for enhanced pitch angle coverage)*
  - *1 high (FOV centered at 75 deg to spin axis)*
  - *1 ion telescope (data not used for this analysis)*

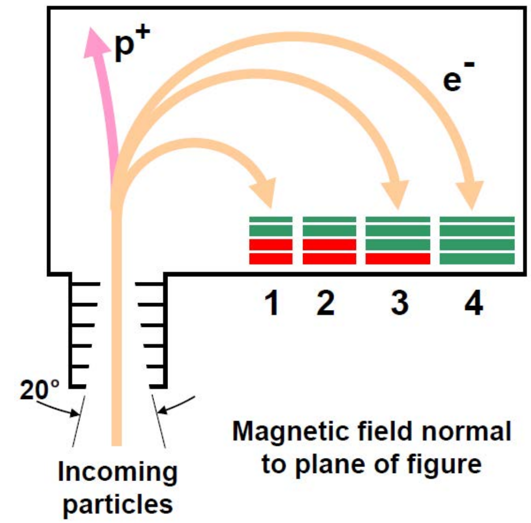




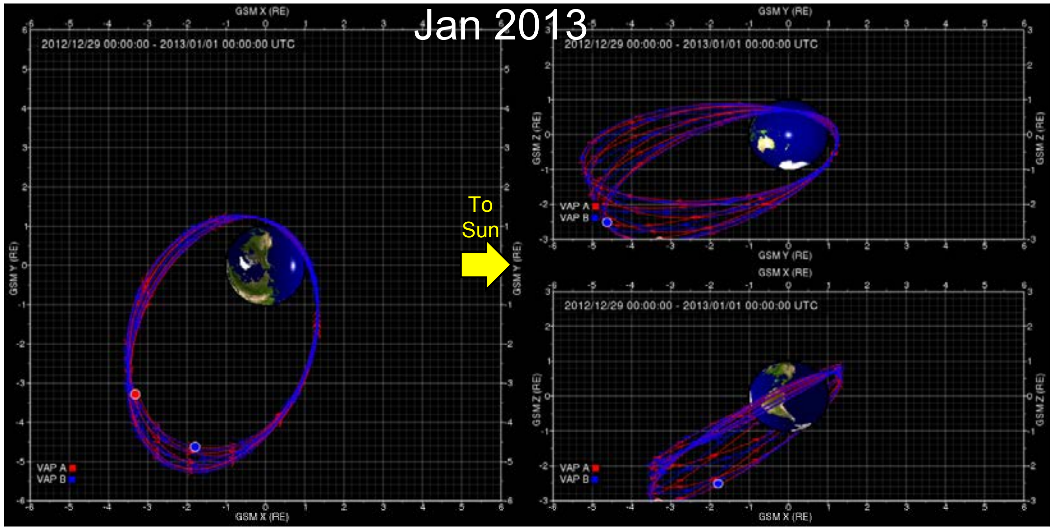
MagEIS Electron Spectrometers

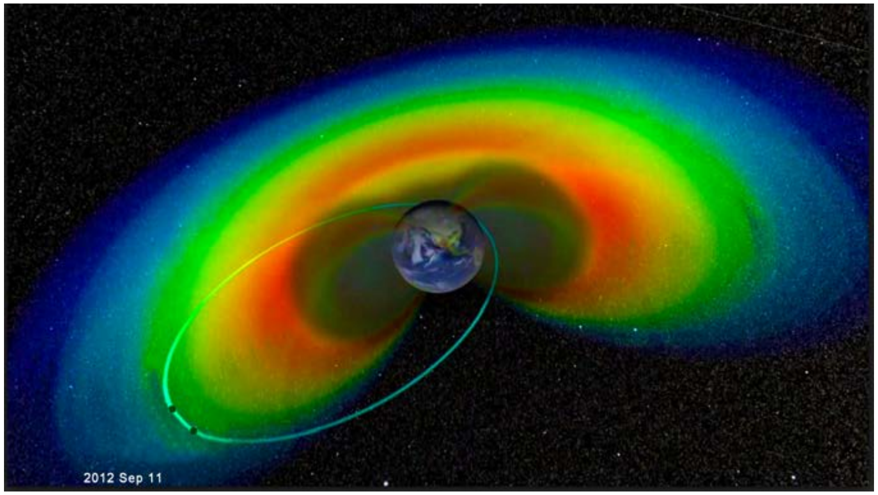
- Particles enter magnetic field chamber through a collimator-defined field of view
- Electrons are focused upon a multi-pixel silicon focal plane whose thickness is matched to the electron energy
  - *9-pixel focal plane for low & medium units (energy range: 20 keV – 1040 keV)*
  - *4-pixel focal plane for high unit (energy range: 1200 keV – 3770 keV)*
- Momentum selection by magnetic field results in differential energy deposit
- Positive particles are deflected away from the electron pixels





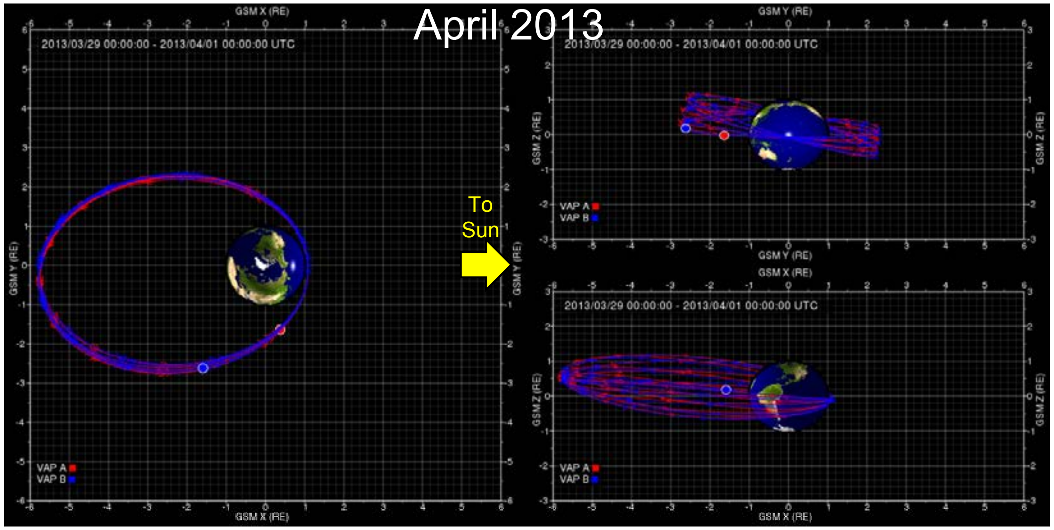
Van Allen Probes Orbit through the Radiation Belts

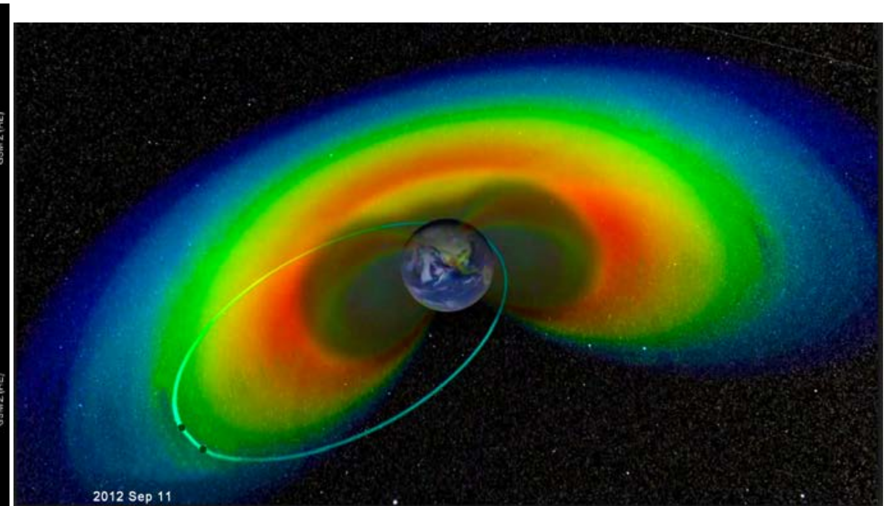




- The RBSP A and B Spacecraft are in nearly identical orbits with ~9 hr period:
  - *605 km x 30,140 km (10 deg inclination)*
  - *625 km x 30,544 km (10 deg inclination)*
- These slightly different apogees allow simultaneous measurements to be taken over the full range of observatory separation distances several times over the course of the mission.
- One observatory laps the other every 75 days
- The vehicles are spin stabilized with the spacecraft spin axis 15 - 27 degrees off the sun angle

Van Allen Probes Orbit through the Radiation Belts





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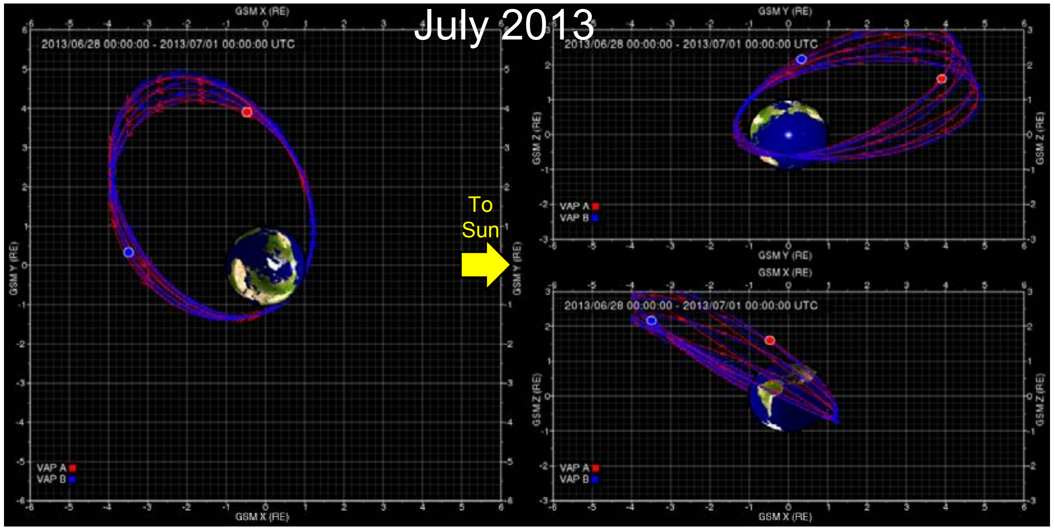

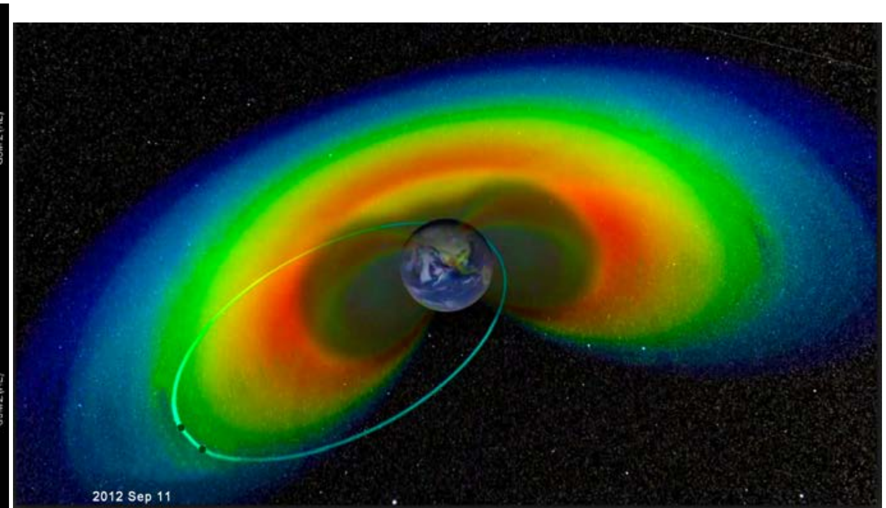

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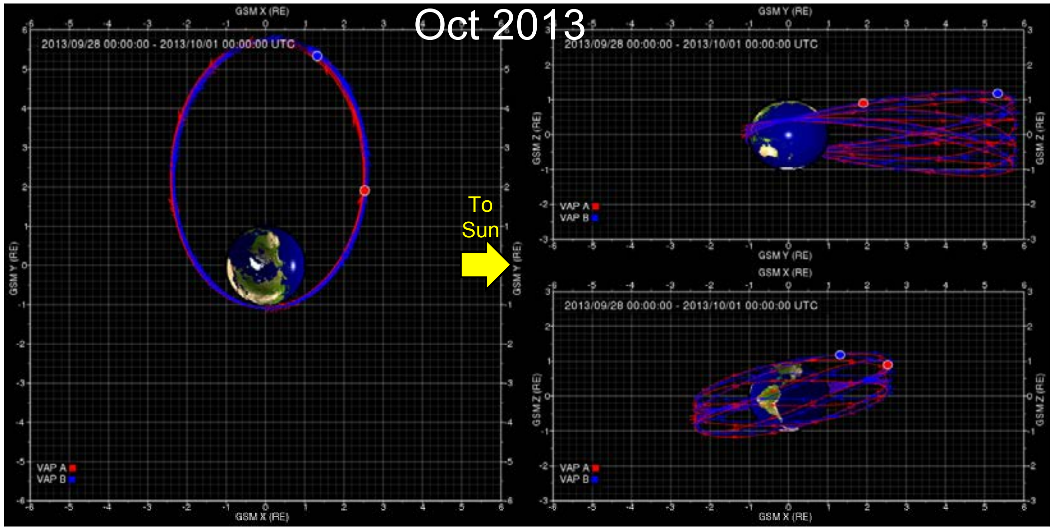

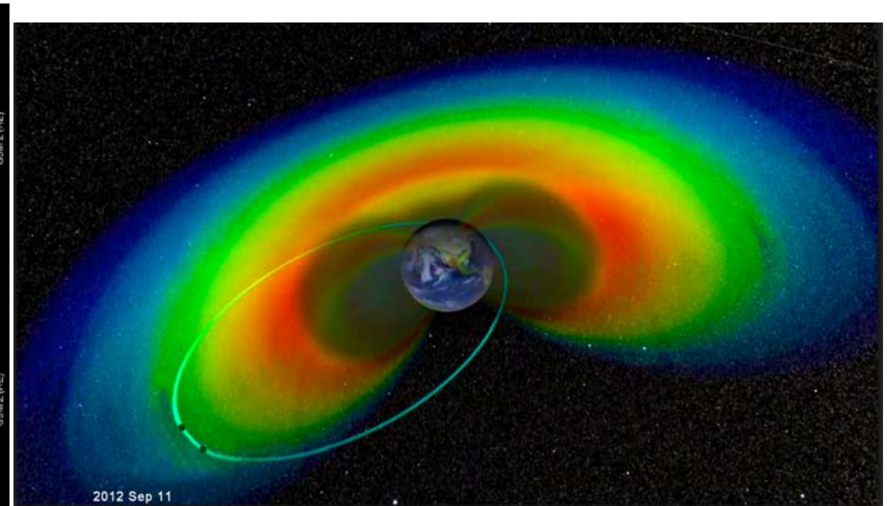

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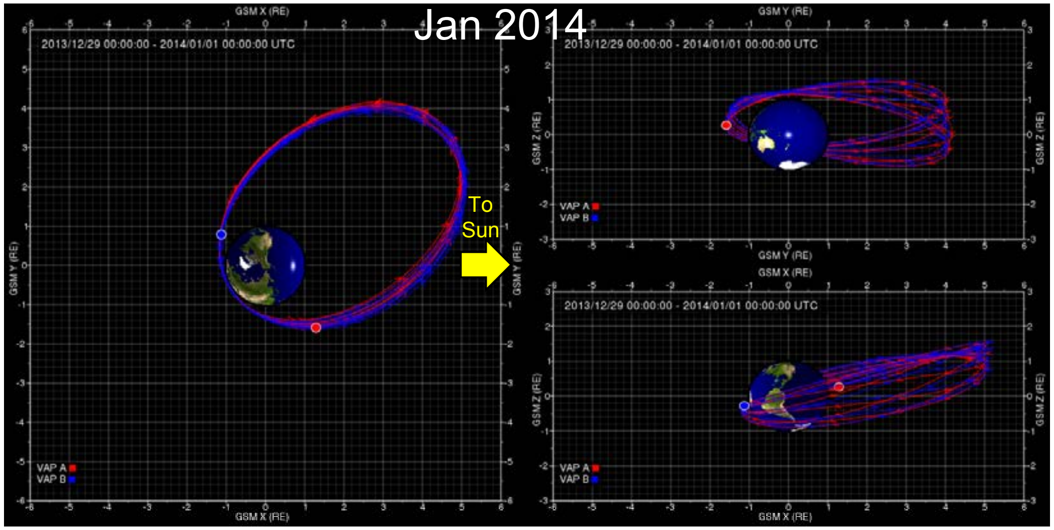

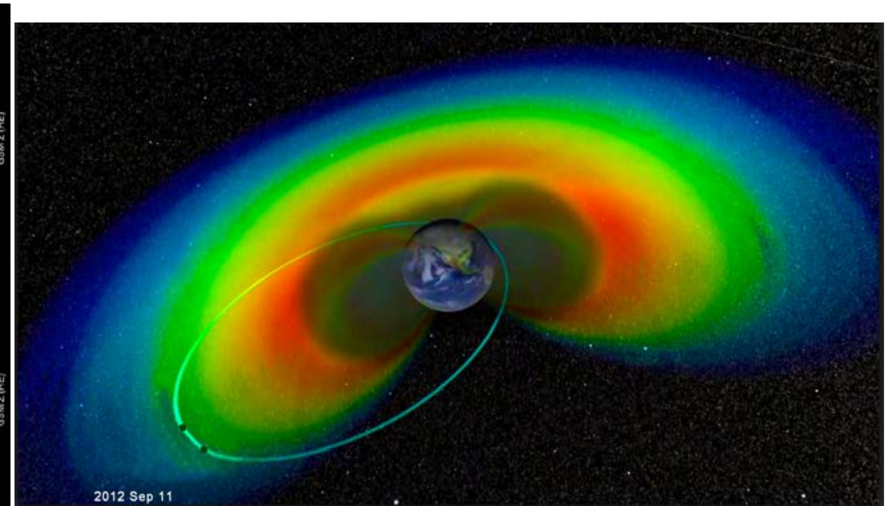

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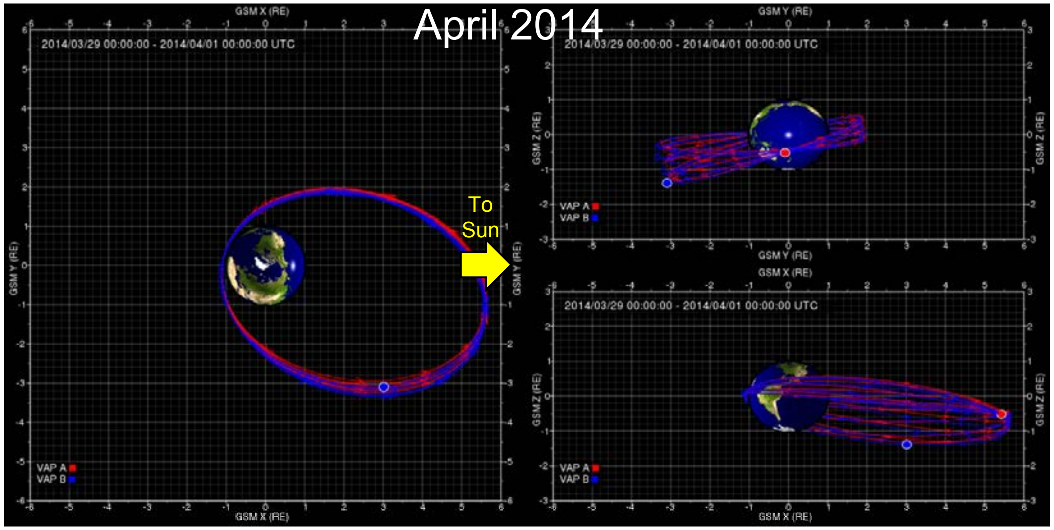

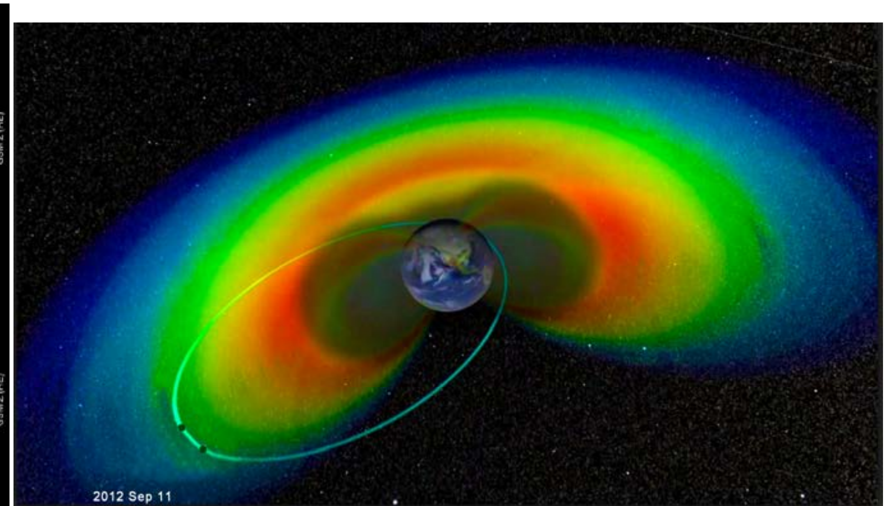

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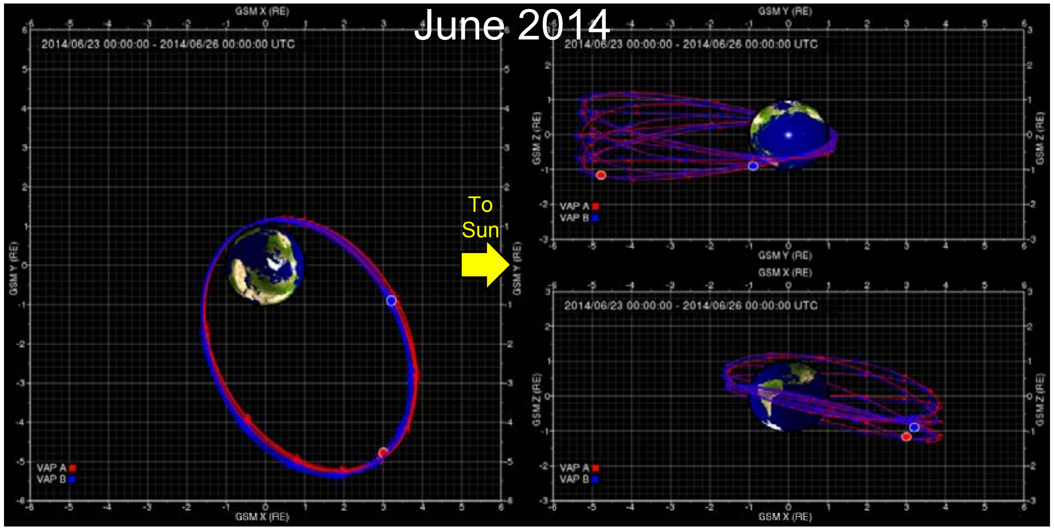

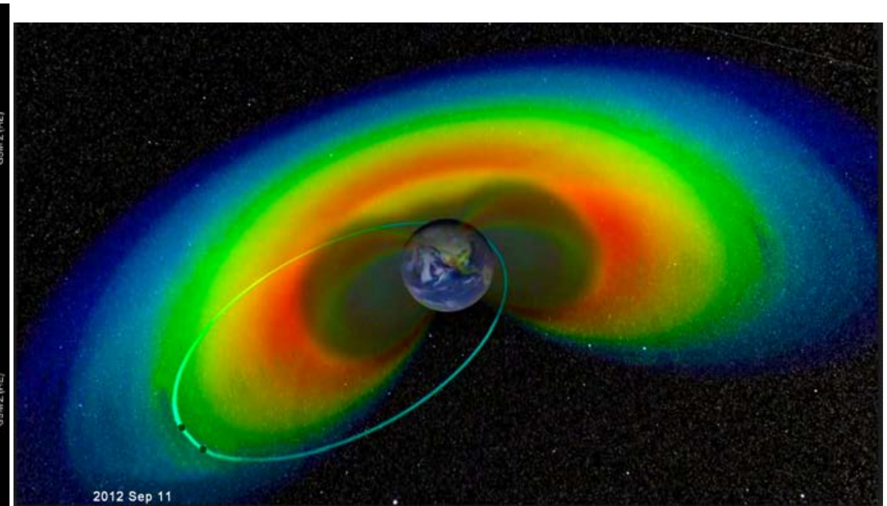

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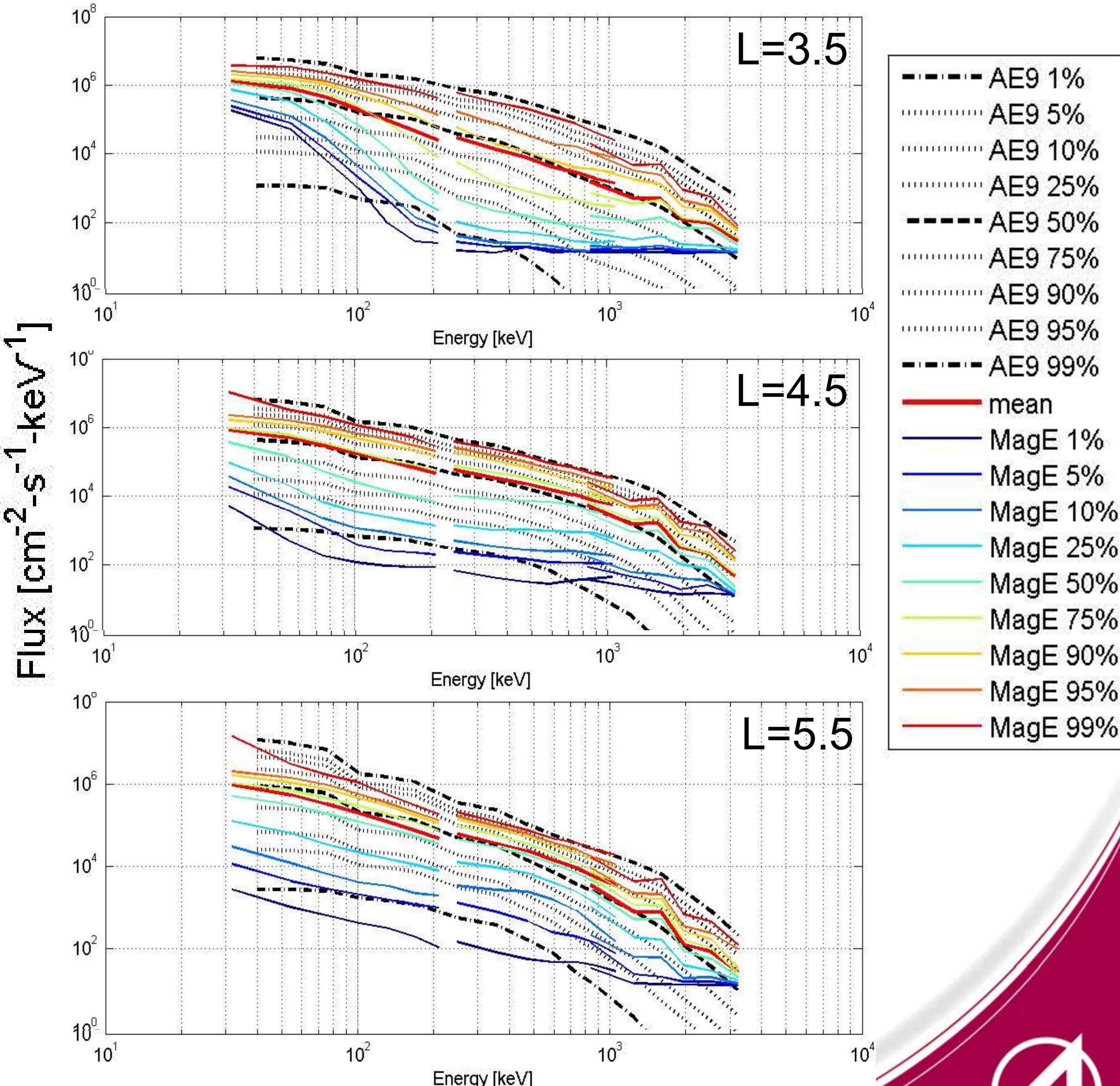
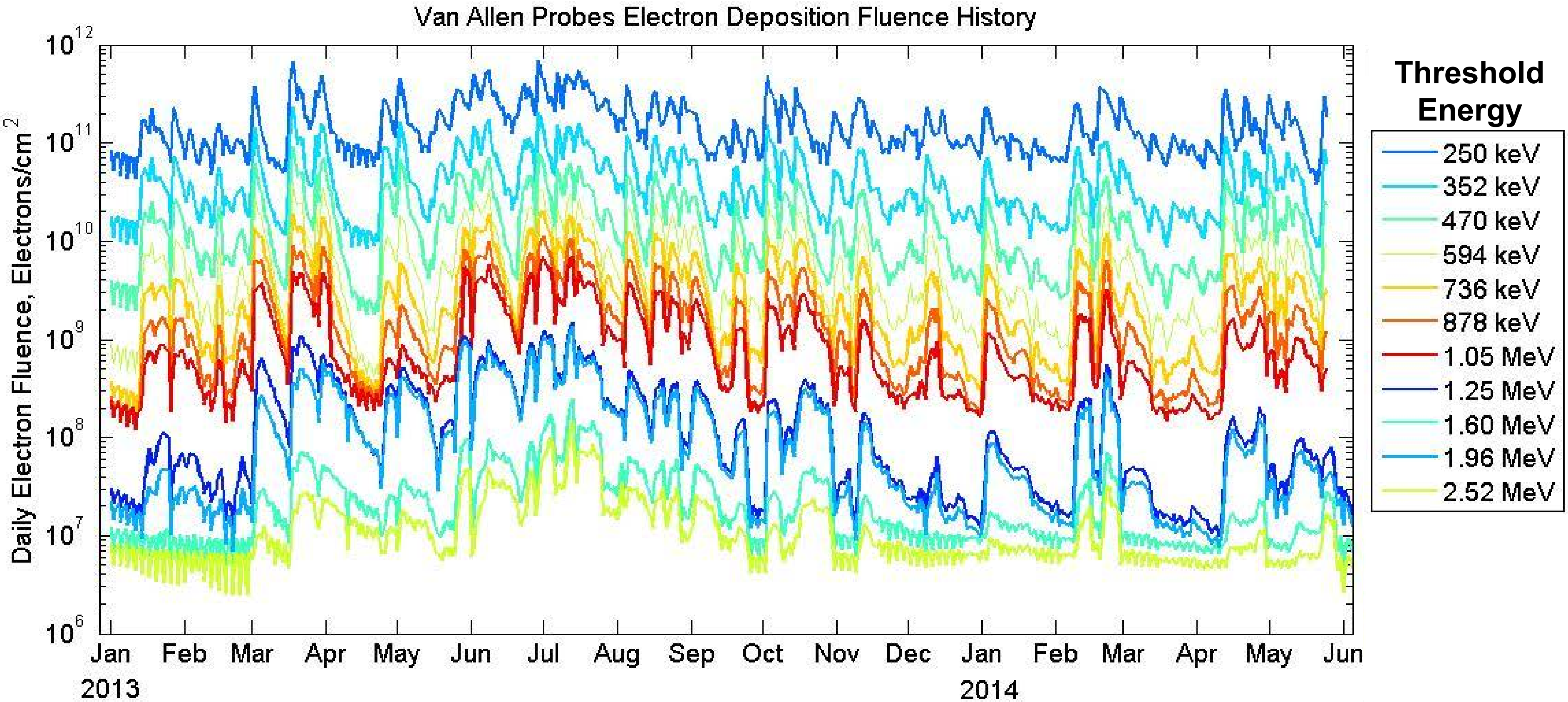
Radiation Belt Energy Spectra over Radial Distance

- 3 examples of electron energy spectra at different radial distances from Earth
- Energy ranges from 40 keV – 3 MeV
- Percentiles calculated over entire year 2013 show probability of observing particular flux level
- Black lines show good agreement with AE9 model over broad range of energies and radial distances
- Complexity shows why models should be used for environment specification



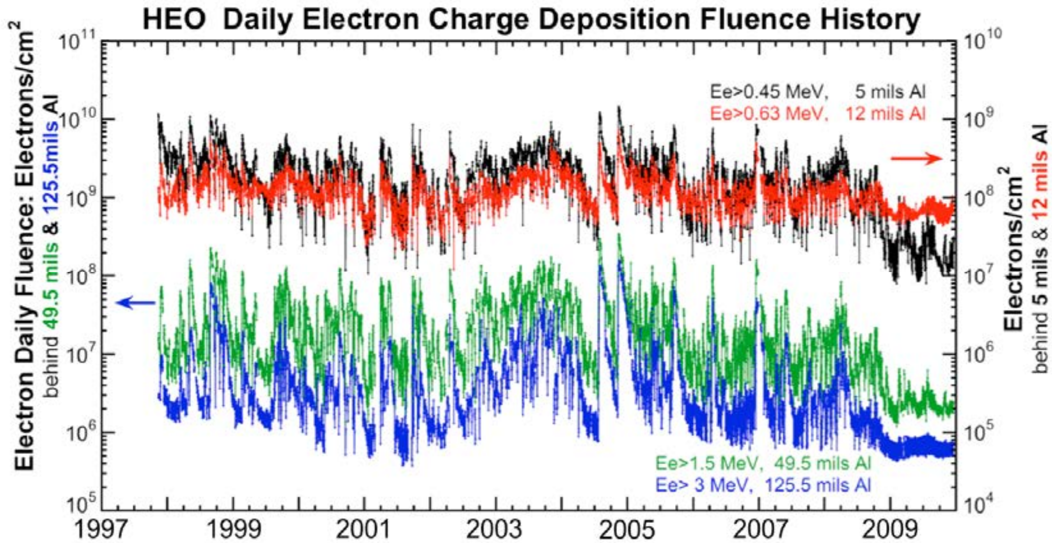
Radiation Belt variations during current solar maximum

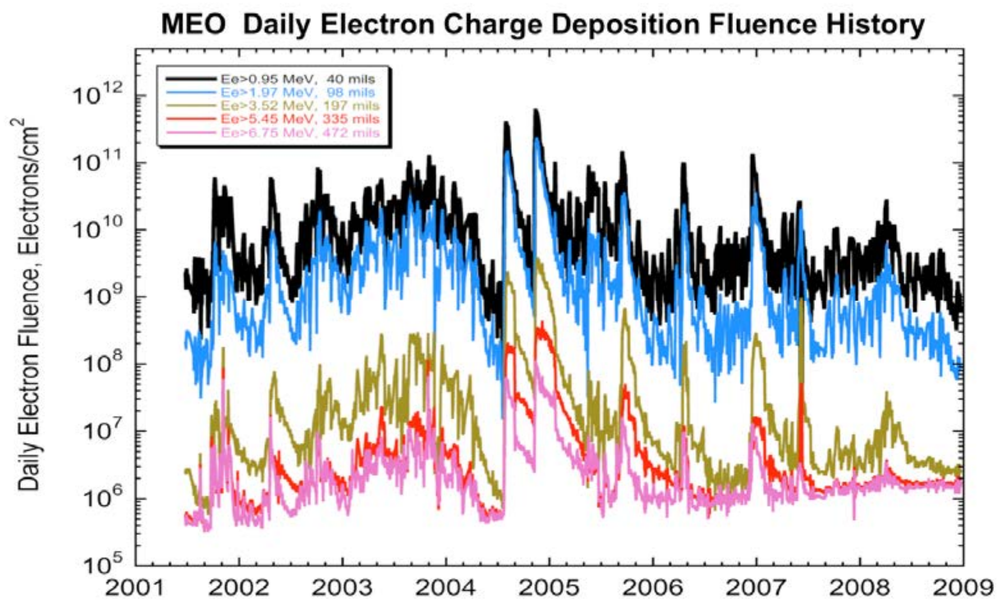


- Van Allen Probes daily integrated fluences
- Obtained by integrating electron fluxes above a threshold energy specified by the MagEIS energy channels
- The fluence is dominated by the flux of electrons in the outer radiation belt and slot regions

Historical Radiation Belt flux variations: HEO and MEO Orbits

- Comparison with HEO and MEO data from Fennell et al., (2012) shows that Van Allen Probes experience higher fluences than satellites in high-Earth orbit (HEO) from 1997-2009
- Satellites in MEO (during 2001-2009) experience higher fluences than Van Allen Probes in current solar cycle





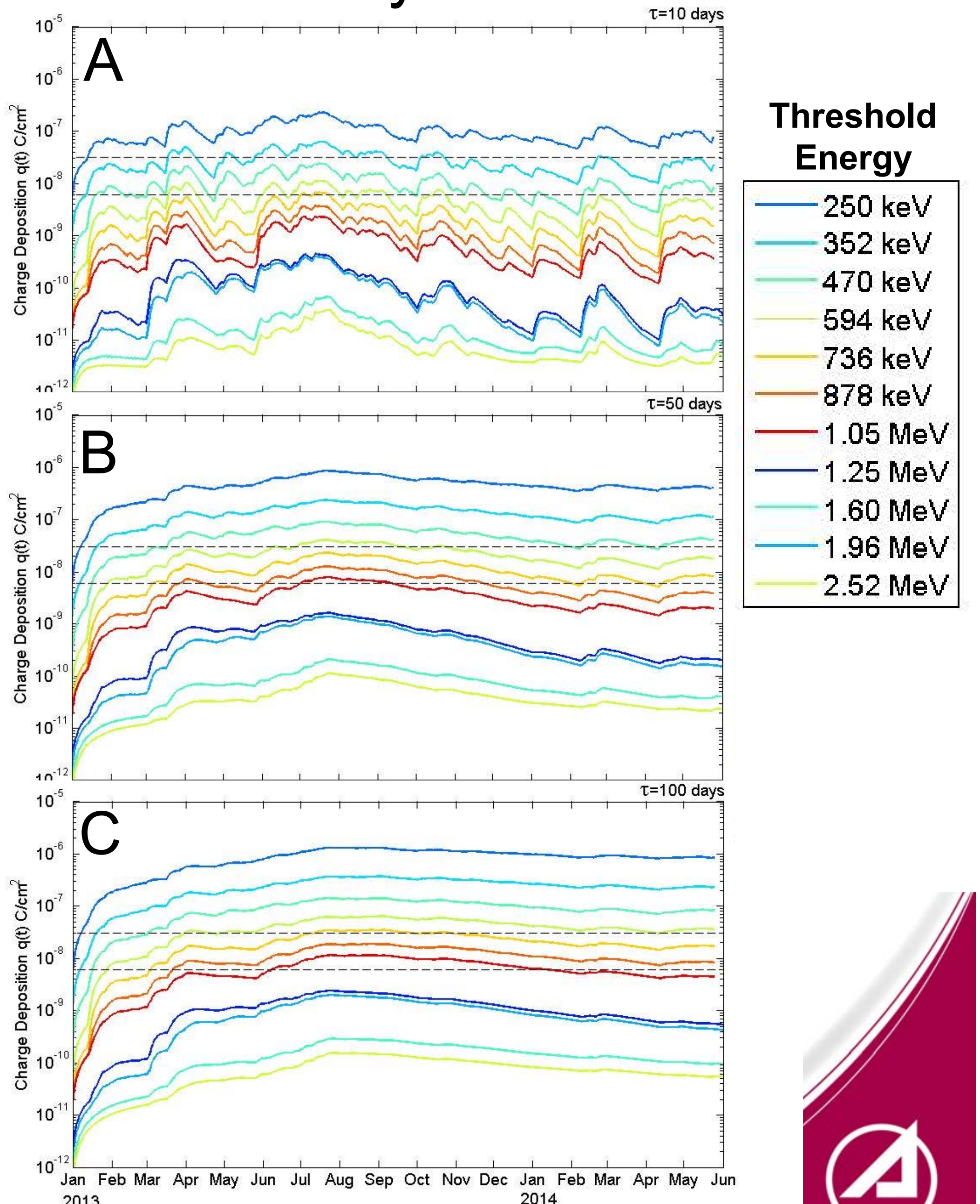
Methodology: Charge Deposition in Dielectrics

- Daily summed electron fluxes over an energy threshold specified by the MagEIS energy channels are used to estimate the charge deposition rates behind shielding
- The charge deposition rates plus the material discharge rates are estimated for a range of material resistivities resulting in a net charge density for a capacitor composed of the material bounded by two conductors
  - *The outer conductor is represented by the lower energy threshold of the integrated energy bins, which limits the charge deposition rate (analogous to spot shielding an electronic component)*
  - *discharge rate is determined from the material resistivity*
- The resultant charge density is compared to levels that have caused discharges to occur in dielectrics in the laboratory (6-20 nC/cm^2)
- The estimated charge density histories for five different resistivity materials are shown on the next slide

Estimated Charge Accumulation History for Dielectrics

- Dielectrics will arc when charge density exceeds 6-20 nC/cm² (dashed black lines)
- Highly resistive dielectrics have long characteristic decay times (τ) and reach high charge density levels on average
- Many highly resistive materials exceed high voltage break-down levels during both storm and non-storm times due to continuous charge accumulation (e.g. circuit boards; wire insulation)
- Highly resistive materials can exceed breakdown levels for extended periods
- The RC time constant of materials can cause IESD occurrences to be disassociated from the instantaneous electron flux levels

a) R = $1x10^{19}$ ohm-cm has τ ~ 10 days
b) R = $6x10^{19}$ ohm-cm has τ ~ 50 days
c) R = $1x10^{20}$ ohm-cm has τ ~ 100 days
d) R = $3x10^{20}$ ohm-cm has τ ~ 300 days
e) R = $6x10^{20}$ ohm-cm has τ ~ 600 days



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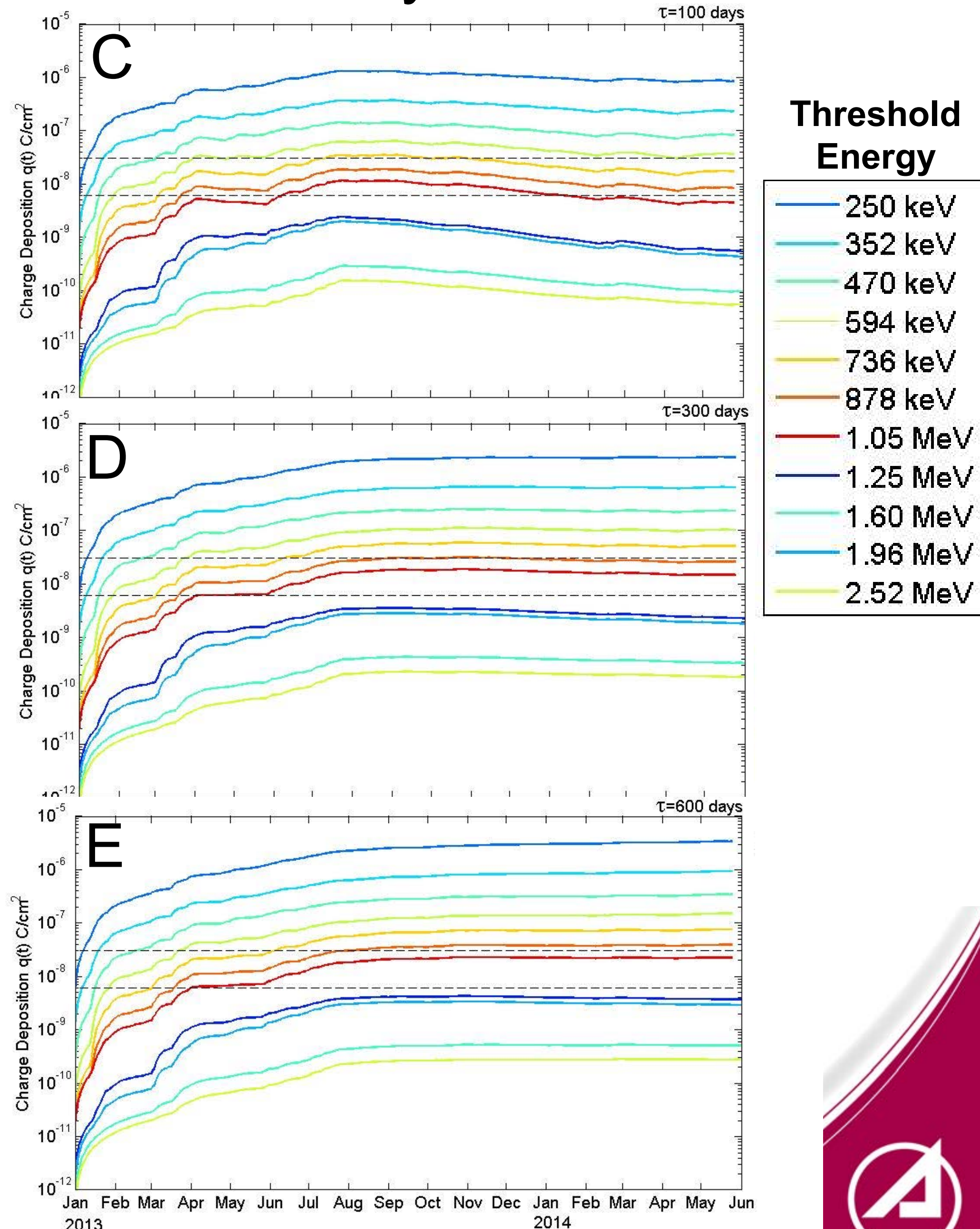
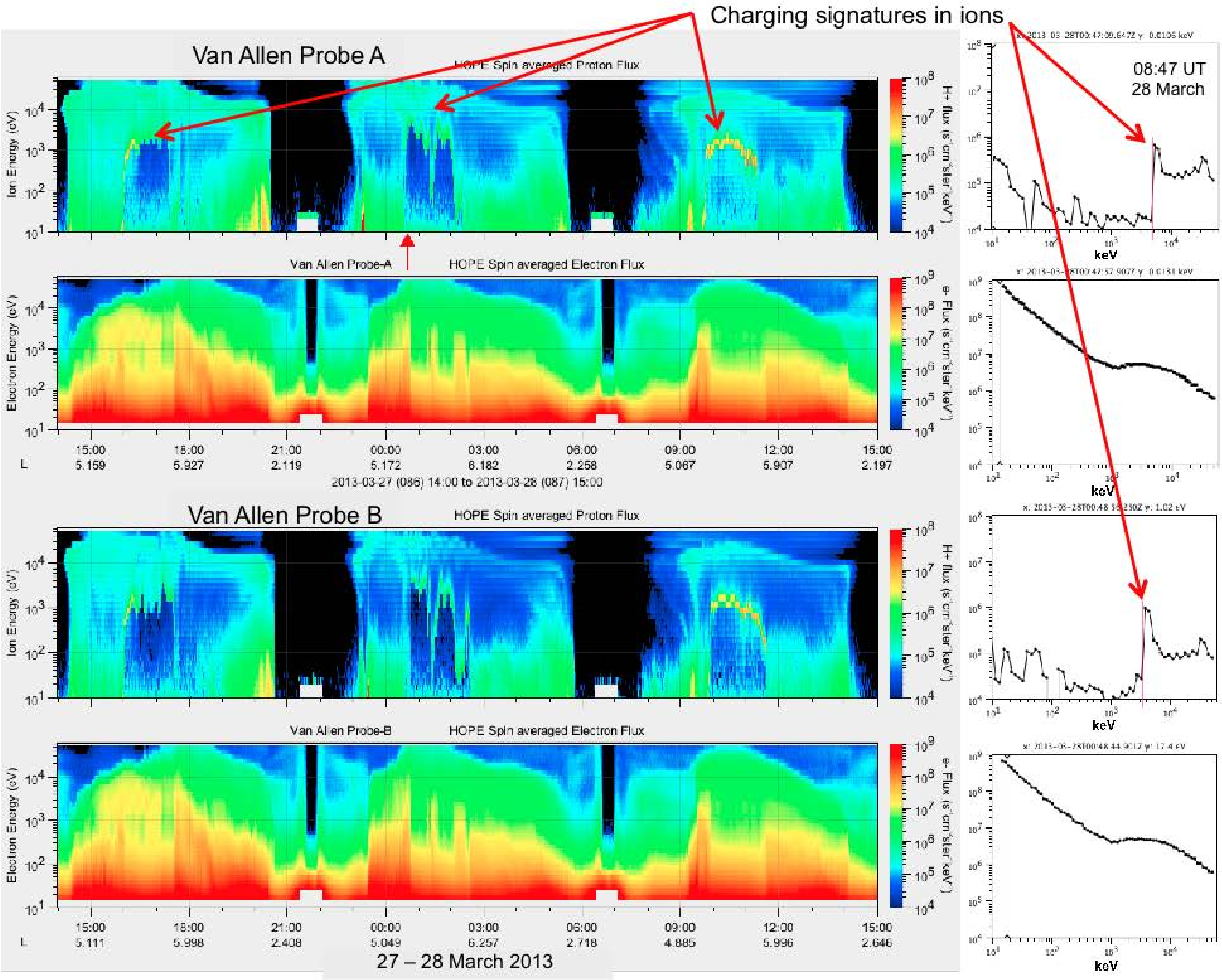


Surface Charging on the Van Allen Probes

- Example of charging on Van Allen Probes
- Surface charging exceeds 1000V after injections of hot electrons occur on night-side regions
- No ESD or upsets thus far



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Conclusions and Implications

- The current solar maximum is unusual due to lack of large geomagnetic storms, but allows study of the quiet-time radiation belt response
- Solar cycle (24) is weaker than previous cycle (23) with respect to intensity of magnetic storms and electron belt response, but does not prevent high resistivity dielectrics from reaching ESD potential
- Charge accumulation in highly resistive dielectrics can reach breakdown levels for long intervals, even during low flux levels at quiet times giving rise to internal charging generated electrostatic discharges
- Although this is primarily a space environment effect:
  - *Climatological, ESD not necessarily directly related to or coincident with the strong flux rises associated with magnetic storms*
  - *Long-term response is more obvious for highly resistive dielectrics*
- It is also a Space Weather Effect
  - *It can be localized to short-term enhancements in the electron fluxes for less resistive dielectrics*

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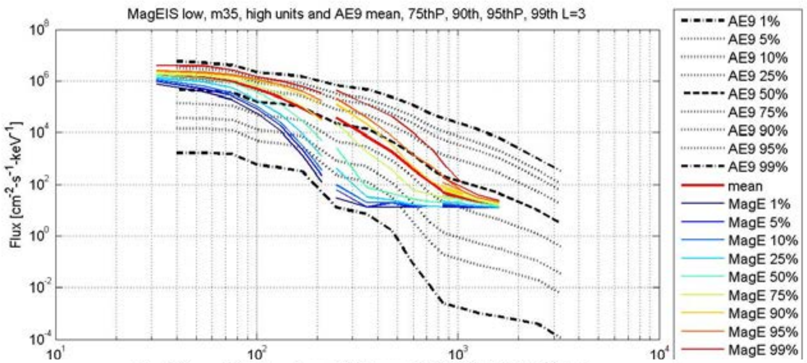
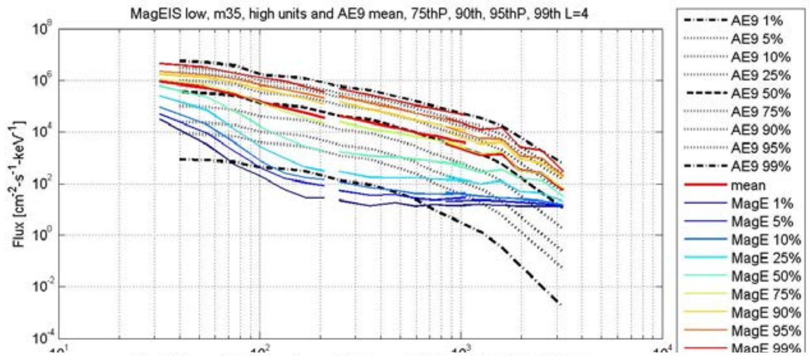
Assuring Space Mission Success

Supplemental

Abstract:

The Van Allen Probes mission provides an unprecedented opportunity to make detailed measurements of electrons and protons in the inner magnetosphere during the weak solar maximum period of cycle 24. Data from the MagEIS suite of sensors measures energy spectra, fluxes, and yields electron deposition rates that can cause internal charging. We use omni-directional fluxes of electrons and protons to calculate the dose under varying materials and thicknesses of shielding (similar to Fennell et al., 2010). We show examples of charge deposition rates during times of nominal and high levels of penetrating fluxes in the inner magnetosphere covering the period from late 2012 through 2013. These charge deposition rates are related to charging levels quite possibly encountered by shielded dielectrics with different resistivity. Temporal profiles showing the long-term long charge deposition-rate and estimated charge density levels are an indicator of the level of internal charging rates that satellites in the inner magnetosphere could experience. These results are compared to charge densities that can induce internal ESD (IESD).


MagEIS low, m35, high units and AE9 mean, 75thP, 90th, 95thP, 99th L=3
Flux [cm^{-2}-s^{-1}-keV^{-1}]
AE9 1%
AE9 5%
AE9 10%
AE9 25%
AE9 50%
AE9 75%
AE9 90%
AE9 95%
AE9 99%
mean
MagE 1%
MagE 5%
MagE 10%
MagE 25%
MagE 50%
MagE 75%
MagE 90%
MagE 95%
MagE 99%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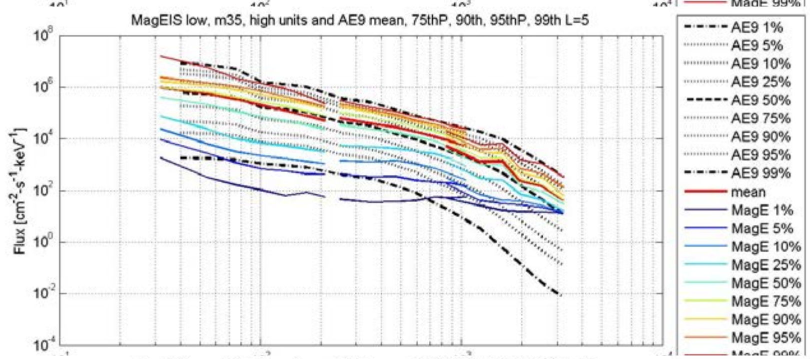
Flux [cm^{-2}-s^{-1}-keV^{-1}]
AE9 1%
AE9 5%
AE9 10%
AE9 25%
AE9 50%
AE9 75%
AE9 90%
AE9 95%
AE9 99%
mean
MagE 1%
MagE 5%
MagE 10%
MagE 25%
MagE 50%
MagE 75%
MagE 90%
MagE 95%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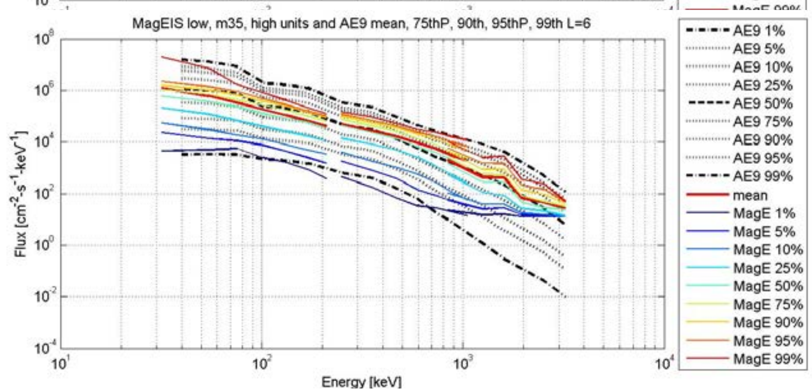
Flux [cm^{-2}-s^{-1}-keV^{-1}]
AE9 1%
AE9 5%
AE9 10%
AE9 25%
AE9 50%
AE9 75%
AE9 90%
AE9 95%
AE9 99%
mean
MagE 1%
MagE 5%
MagE 10%
MagE 25%
MagE 50%
MagE 75%
MagE 90%
MagE 95%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Energy [keV]
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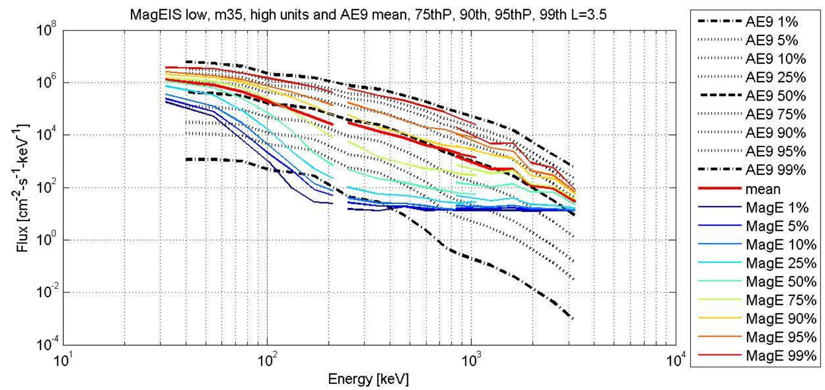
AE9 5%
AE9 10%
AE9 25%
AE9 50%
AE9 75%
AE9 90%
AE9 95%
AE9 99%
mean
MagE 1%
MagE 5%
MagE 10%
MagE 25%
MagE 50%
MagE 75%
MagE 90%
MagE 95%
MagE 99%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Flux [cm^{-2}-s^{-1}-keV^{-1}]
Energy [keV]
AE9 1%
AE9 5%
AE9 10%
AE9 25%
AE9 50%
AE9 75%
AE9 90%
AE9 95%
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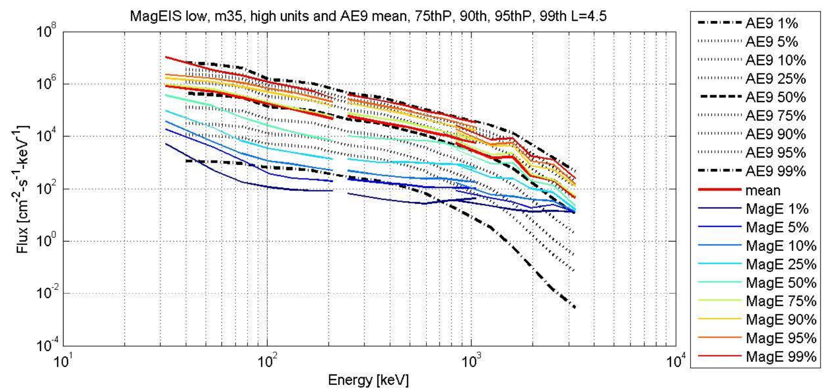
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Flux [cm^{-2}-s^{-1}-keV^{-1}]
Energy [keV]
AE9 1%
AE9 5%
AE9 10%
AE9 25%
AE9 50%
AE9 75%
AE9 90%
AE9 95%
AE9 99%
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MagE 1%
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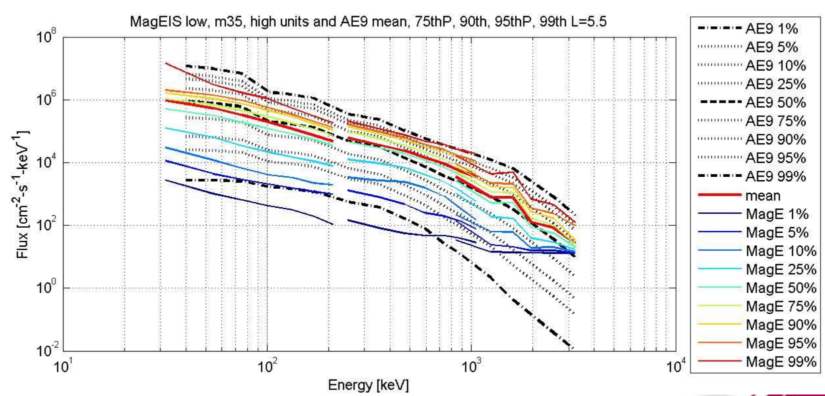
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Flux [cm^{-2}-s^{-1}-keV^{-1}]
Energy [keV]
AE9 1%
AE9 5%
AE9 10%
AE9 25%
AE9 50%
AE9 75%
AE9 90%
AE9 95%
AE9 99%
mean
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MagE 50%
MagE 75%
MagE 90%
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