Charged deposition behind known shielding in a highly inclined orbit

by

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Organization of Talk

- Introduction
- Identify spatial regions covered and measurements used
- Show extended history of radiation belt variations in HEO and ICO orbits
- Relate radiation belt flux variations to simple capacitive model of internal charging time scales
- Summarize results

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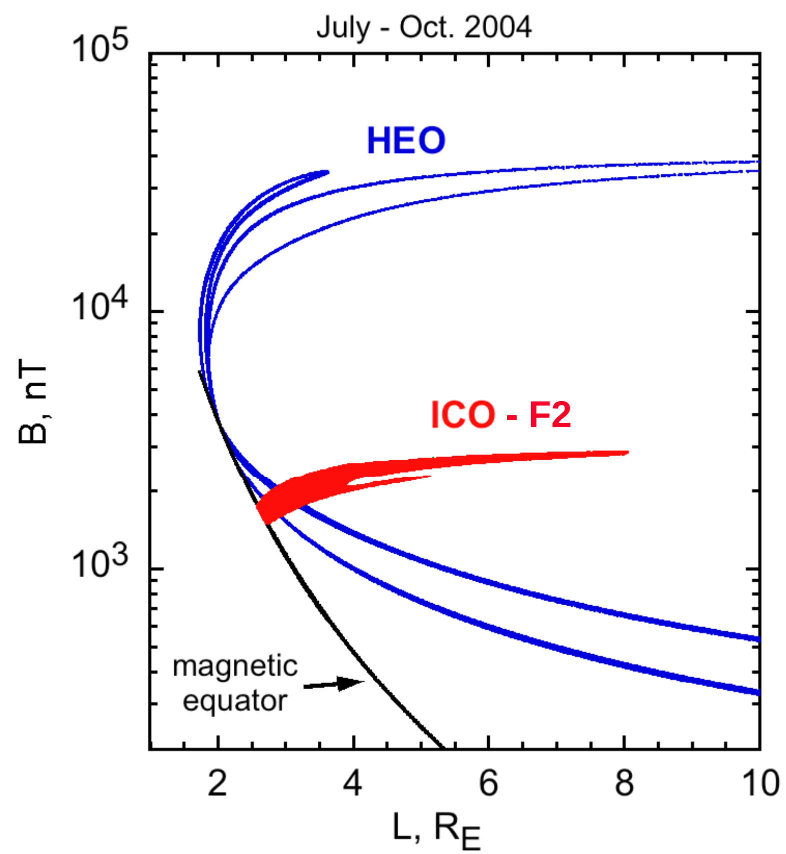
Introduction

- Internal charging and resultant discharges (IESD) are of concern for all satellites because it causes upsets and can cause circuit failures and malfunctions
  - Especially in those satellites that spend significant time in the outer radiation belt and those with limited shielding
- Several authors have attempted to provide guidance to the satellite industry as to what shielding requirements are that can protect satellite systems from IESD
- Modeling tools have become available for estimating internal charging rates given an input spectrum
  - Some have been published (Dictat) and some will be presented at this meeting (see presentation by Lemon and poster by Mulligan)
- Recently, Bodeau published an article (2009 AIAA paper) that examined energetic electron climatology from the perspective of estimating internal charging risk in GEO orbit (He has a poster here on the same subject)
  - He found that simple rules of thumb often used by industry about charging rates, such as keeping charging rates <100 fC for ≤10 hours, were not appropriate for GEO orbit when highly resistive materials were involved
- Using a similar process, we examine the energetic electron climatology for a HEO and a MEO orbit where we have several years of electron fluxes behind different shielding levels☐

HEO & ICO orbits in B-L space

- HEO satellites are close to the magnetic equator for 1.75<L<3 while the ICO-F2 satellite is close to the magnetic equator for 2.5<L<3
- ICO-F2 stays within the radiation belts (L≤8) all the time
- The HEO's spend a significant fraction of time outside the radiation belts
  - Percentage of time **outside** radiation belts, L>8, is ~ 70.5%
  - Percentage of time at low altitudes where fluxes are low (i.e. B>10^4 nT) is ~ 4.3%
- Only ~25% of HEO data is taken where electron fluxes can cause significant internal charging



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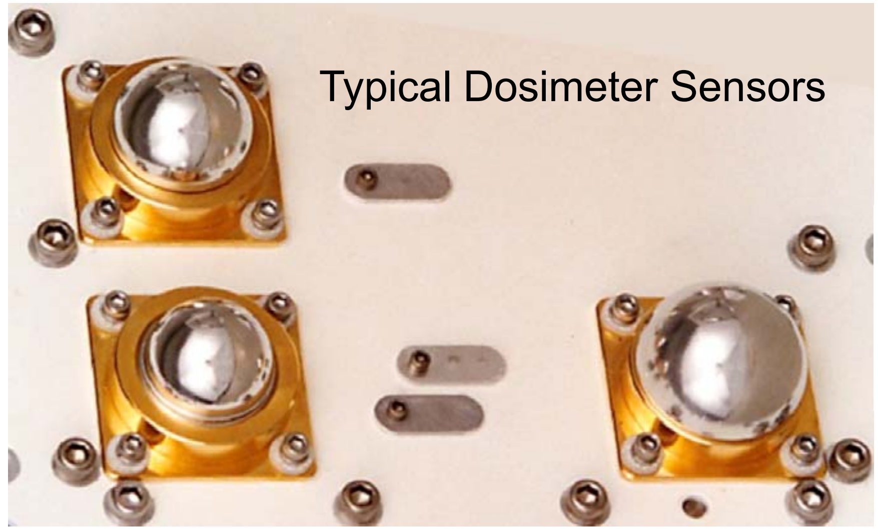
HEO-ICO Sensors

- The sensors use silicon diode detectors behind hemispherical shields
- The detectors are backed by a thick tungsten slug to limit response from the backside
- HEO Shielding & Nominal Energies

mils Al	Electrons	Protons
5	> 450 keV	> 5 MeV
12	> 630 keV	> 8.5 MeV
50	> 1.5 MeV	> 16 MeV
125	> 3.0 MeV	> 27 MeV
267	> 4.0 MeV	> 41 MeV

- *Note: 5 mil Al ~ 10 mils dielectric (e.g. MLI) or equal to ~5 mil quartz cover glass on solar array and 40-50 mil Al is roughly the shielding provided by standard exterior satellite closeout panels*



•ICO-F2 Shielding & Nominal Energies

mils Al	Electrons	Protons
40	> 950 keV	> 15 MeV
98	> 1.97 MeV	> 24 MeV
197	> 3.52 MeV	> 33 MeV
335	> 5.45 MeV	> 44 MeV
472	> 6.75 MeV	> 54 MeV

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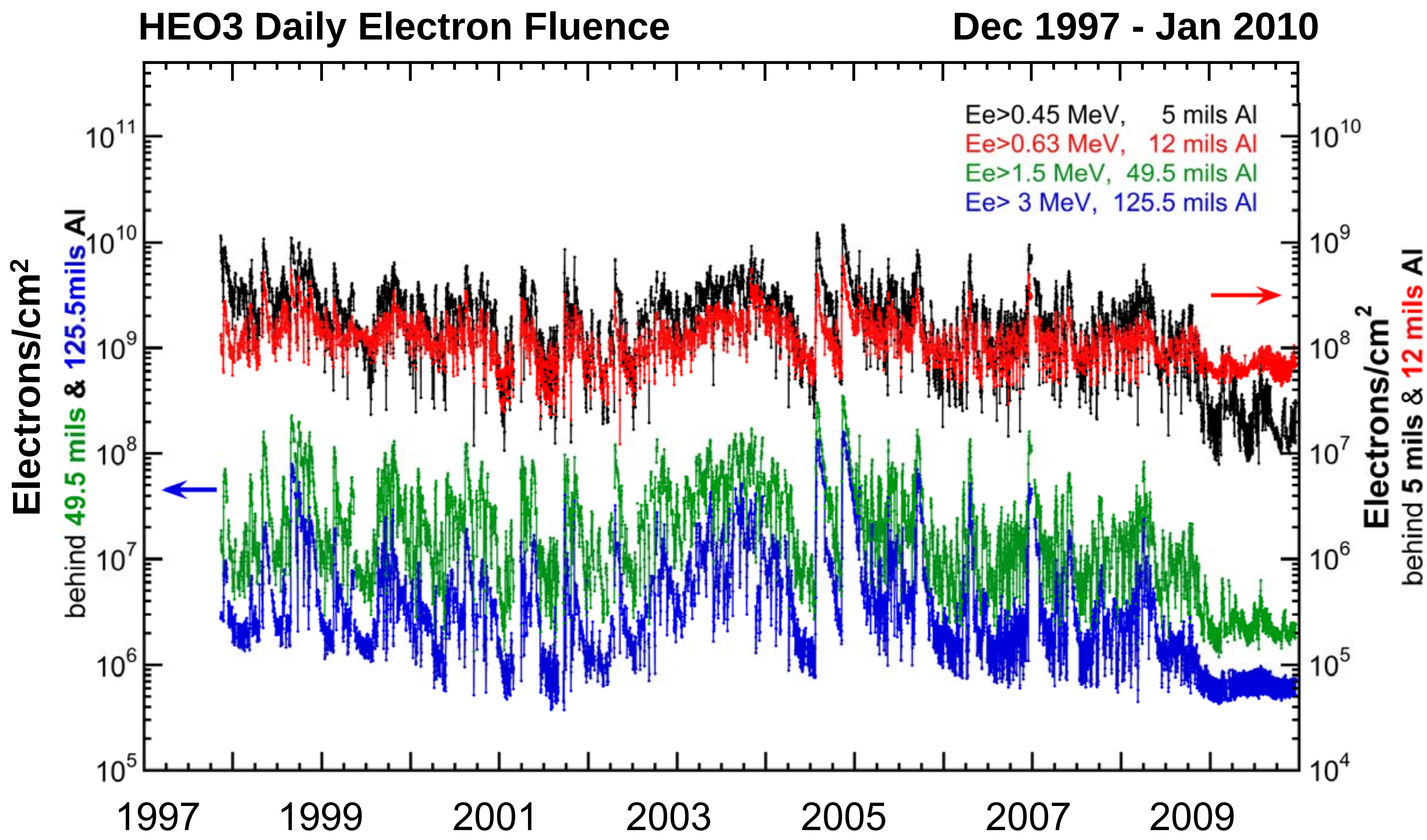
12 Year Response of Radiation Belts: HEO3



- HEO3 daily electron fluence behind four different shielding thicknesses
- Only 25% of time spent in L = 2-8 region
- The underlying electron fluxes behind each shield are measured every 15 sec

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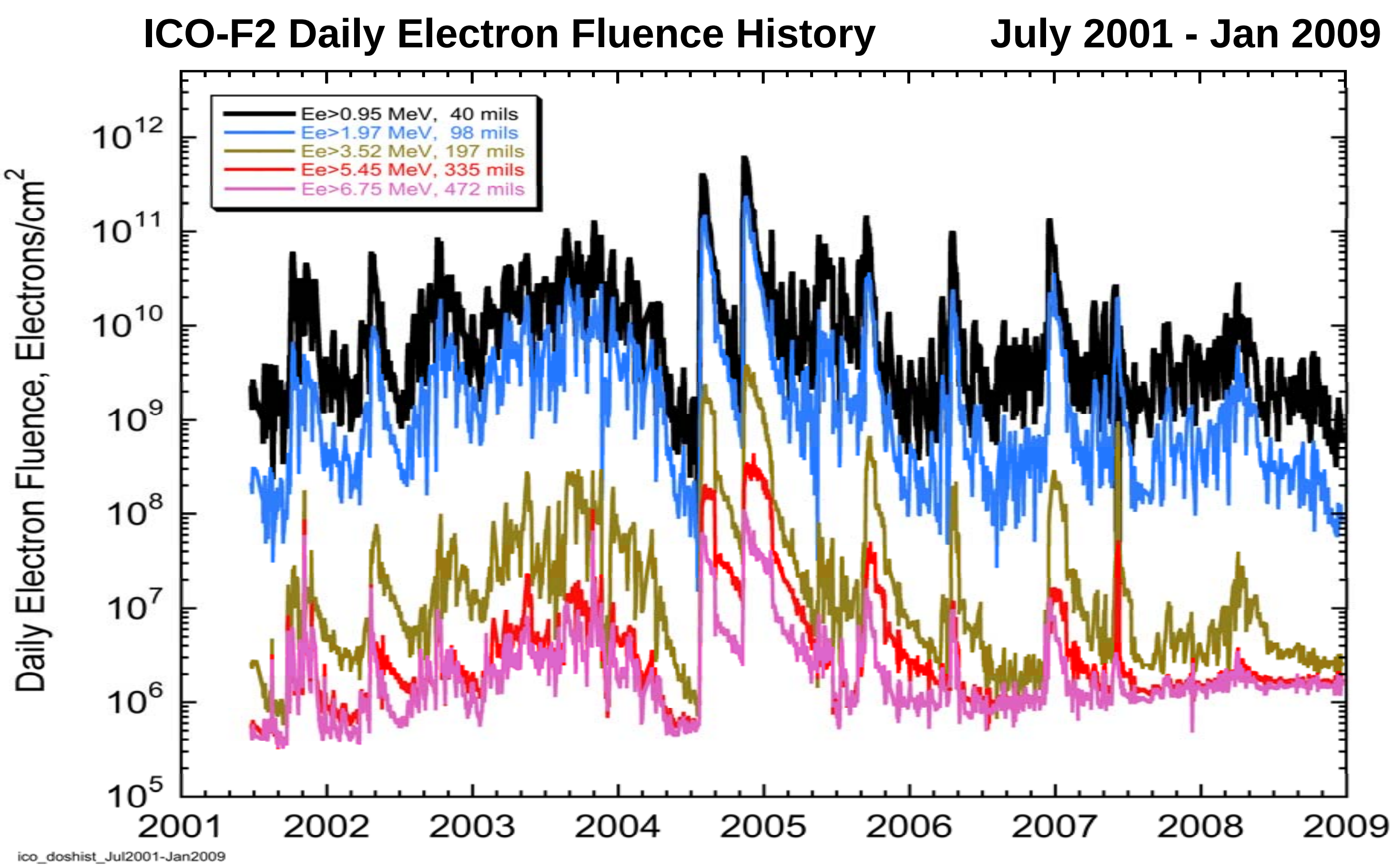
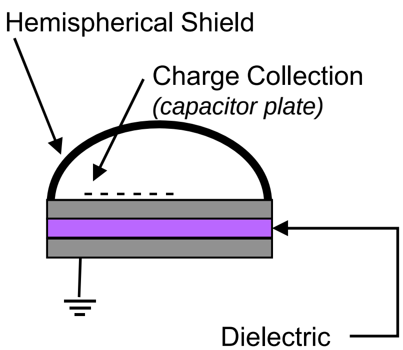
7.5 Year Response of Radiation Belts: ICO-F2



- ICO-F2 Daily electron fluence behind 5 different shield thicknesses
- 100% of time spent in the L = 2.5-8 region
- The underlying electron fluxes are measured every ~130 sec

Charge Deposition

- The daily electron fluence histories represent the underlying orbit integrated charge deposition rates behind different levels of shielding
- The result is a net charge density for a capacitor, which we model as composed of a dielectric bounded by two conductors, one floating and one grounded
  - Dosimeter shielding limits the charge deposition rate
  - Resultant charge density on the model capacitor is computed using the daily electron fluence behind each dosimeter shield and a charge leakage rate for a given dielectric resistivity
  - The resultant charge density on the model capacitor can be compared to the levels that have caused discharges to occur in dielectrics in the laboratory (~ 6-20 nC/cm^2)
    - Radiation induced conductivity was not included in this simplified picture
- The estimated charge density histories for different resistivity dielectrics, given the HEO and ICO fluence measurements, are shown on the following slides



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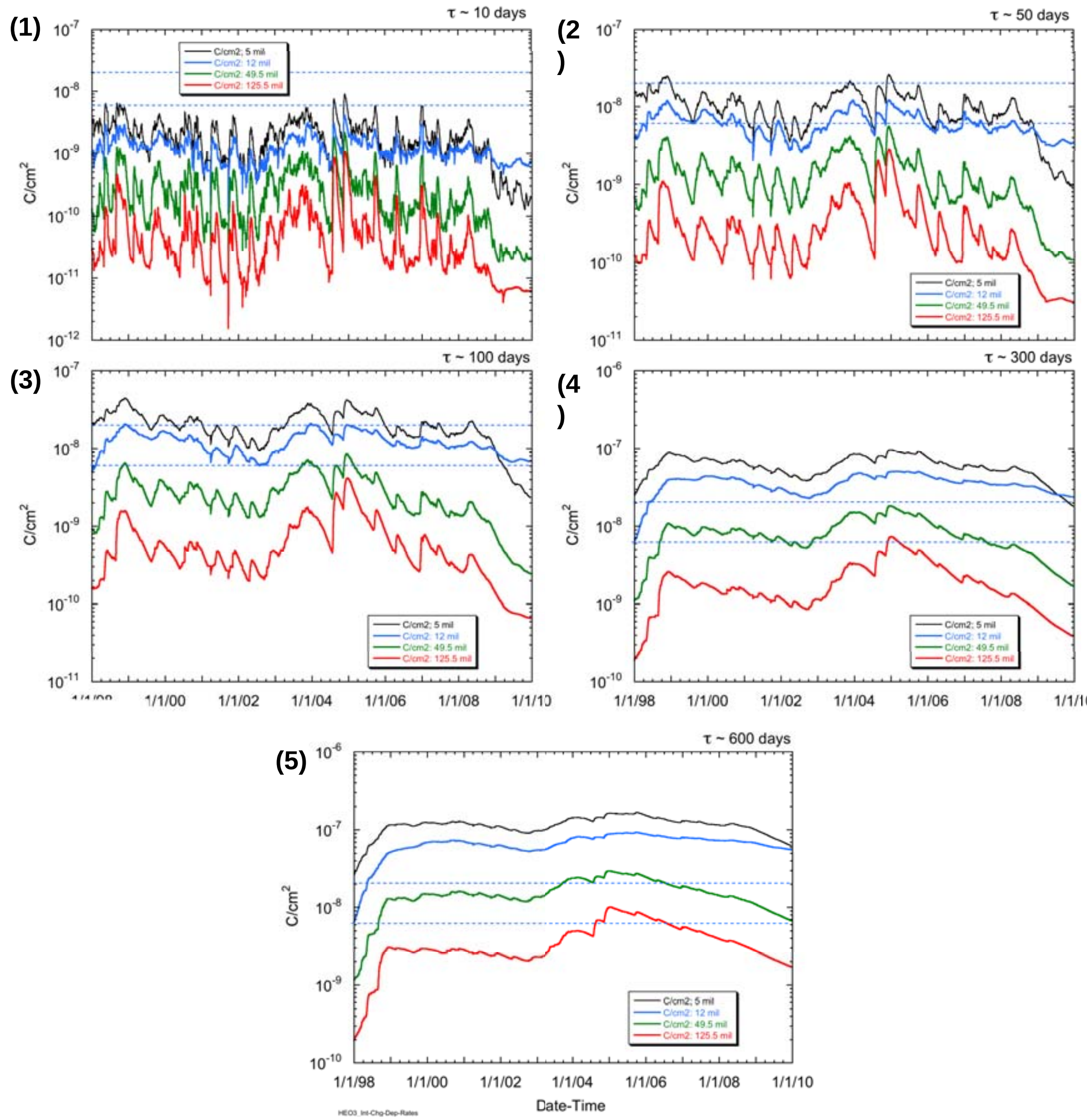
Charge Buildup from Long Term Flux Variation In HEO Orbit

- Dielectrics generally will arc when charge density exceeds 6-20 nC/cm^2 (dashed blue lines) depending on dielectric
- Highly resistive dielectrics have long characteristic charge dissapation times (τ) and can reach high charge density levels on average (see panels 3, 4, and 5)
- Highly resistive dielectrics can reach breakdown levels at modest charging rates
- Lower resistivity dielectrics can be protected from IESD by relatively modest shielding
- Long dissipation time constants of some materials can lead to IESD occurrence that may be disassociated from the instantaneous electron flux levels



(1) R = 1×10^{19} ohm-cm has τ ~ 10 days
(2) R = 6×10^{19} ohm-cm has τ ~ 50 days
(3) R = 1×10^{20} ohm-cm has τ ~ 100 days
(4) R = 3×10^{20} ohm-cm has τ ~ 300 days
(5) R = 6×10^{20} ohm-cm has τ ~ 600 days

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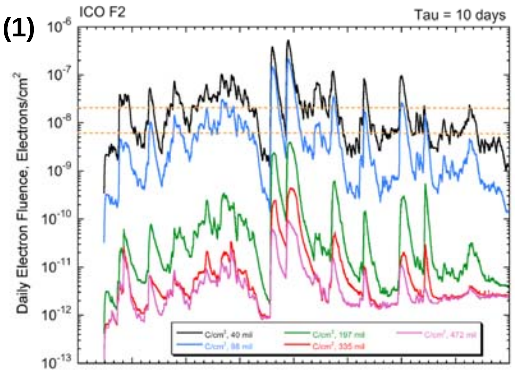
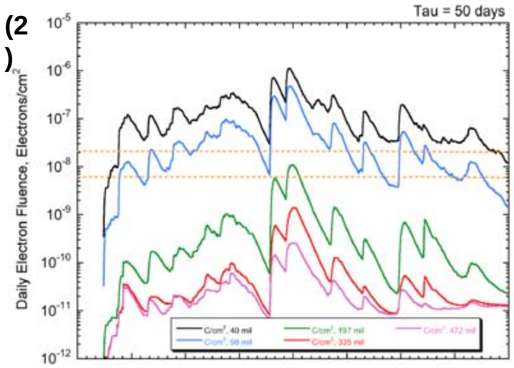
Charge Buildup from Long Term Flux Variation In ICO Orbit

- Like the HEO charge density history plots but for mid 2001 through 2008
- The 6-20 nC/cm^2 levels are indicated by the gold dashed lines
  - Minimum shielding is 40 mils AL
- As for HEO, we would expect high build up of charge density on our model capacitor in the 2003-2005 time frame
- Charge densities build to levels that could exceed breakdown for extended periods especially for shielding < 100 mils Al
- The ICO MEO orbit requires considerable shielding and careful design to tolerate the electron environment without IESD

(1)



(2)



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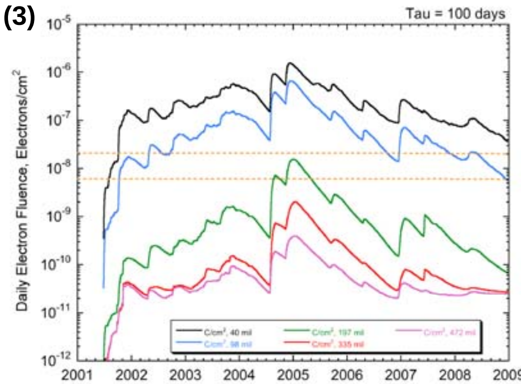

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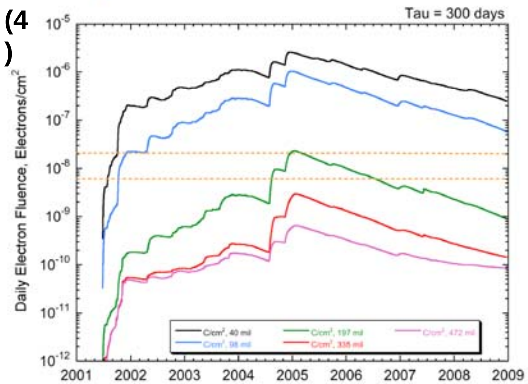

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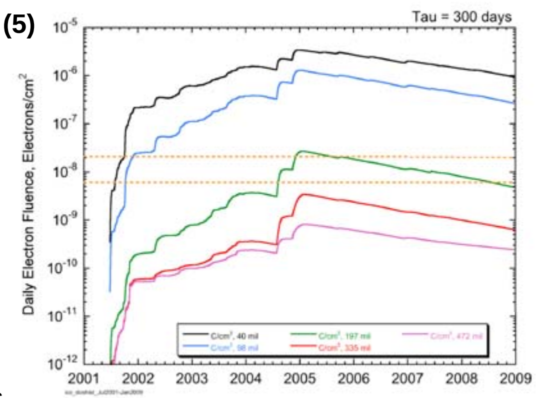

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Summary

- The solar cycle history of the radiation belts shows a strong rise in the fluxes in 1998 followed by a downward trend toward 2009 except for the period 2003-2005
- The HEO electron flux histories show that charge accumulations in highly resistive shielded dielectrics can reach breakdown levels for long intervals over a solar cycle
- This will give rise to internal charging generated electrostatic discharges
  - This is a Space Environment Effect
    - Partly climatological, i.e. not necessarily localized to the strong flux rises associated with magnetic storms but is a long-term response for highly resistive dielectrics
  - This is Partly a Space Weather Effect
    - Can be localized to short-term enhancements in the electron fluxes for moderately resistive dielectrics

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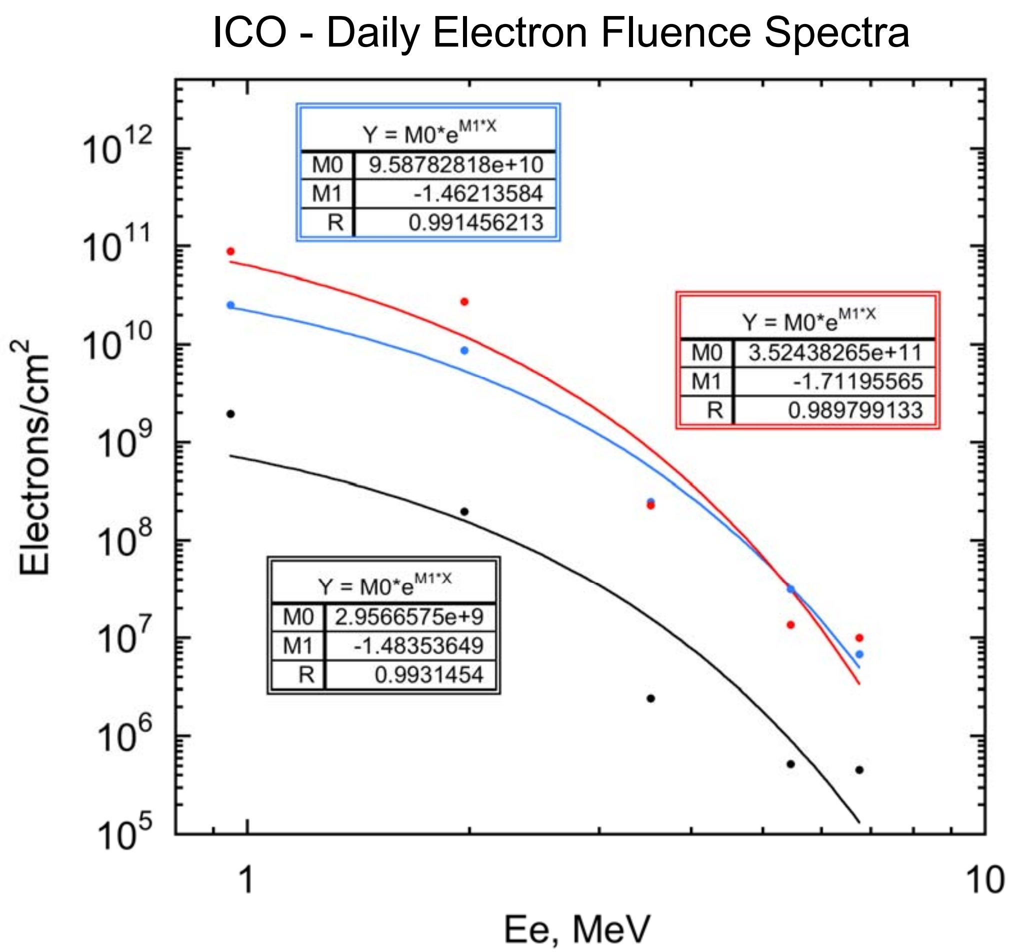
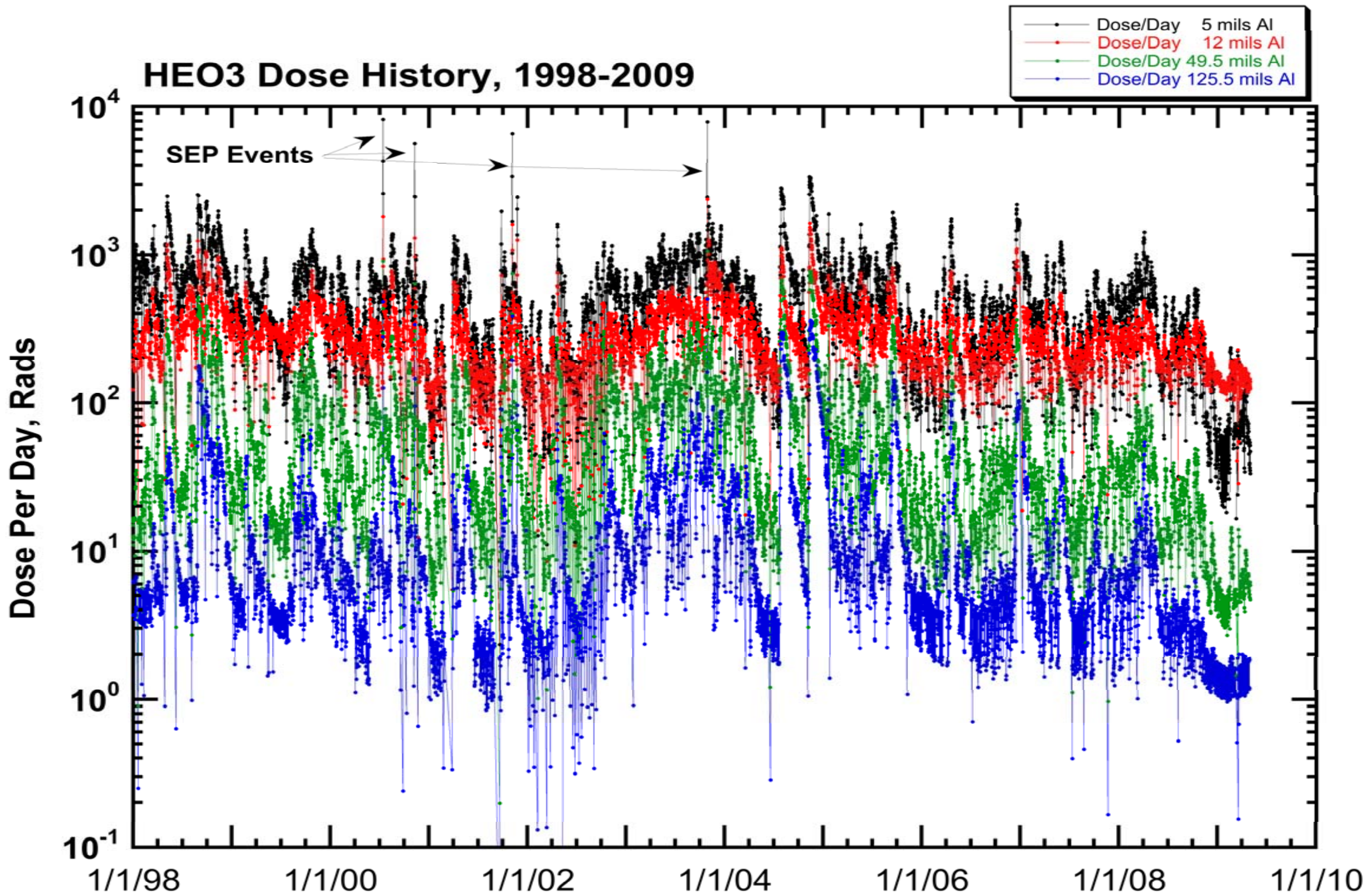
Backup Slides

ICO Daily Fluence Spectrum Samples

- Spectra were best fit by and exponential with characteristic energies Eo ~ 1.5 to 1.7 MeV



HEO3 Radiation Dose History 1998 - 2009



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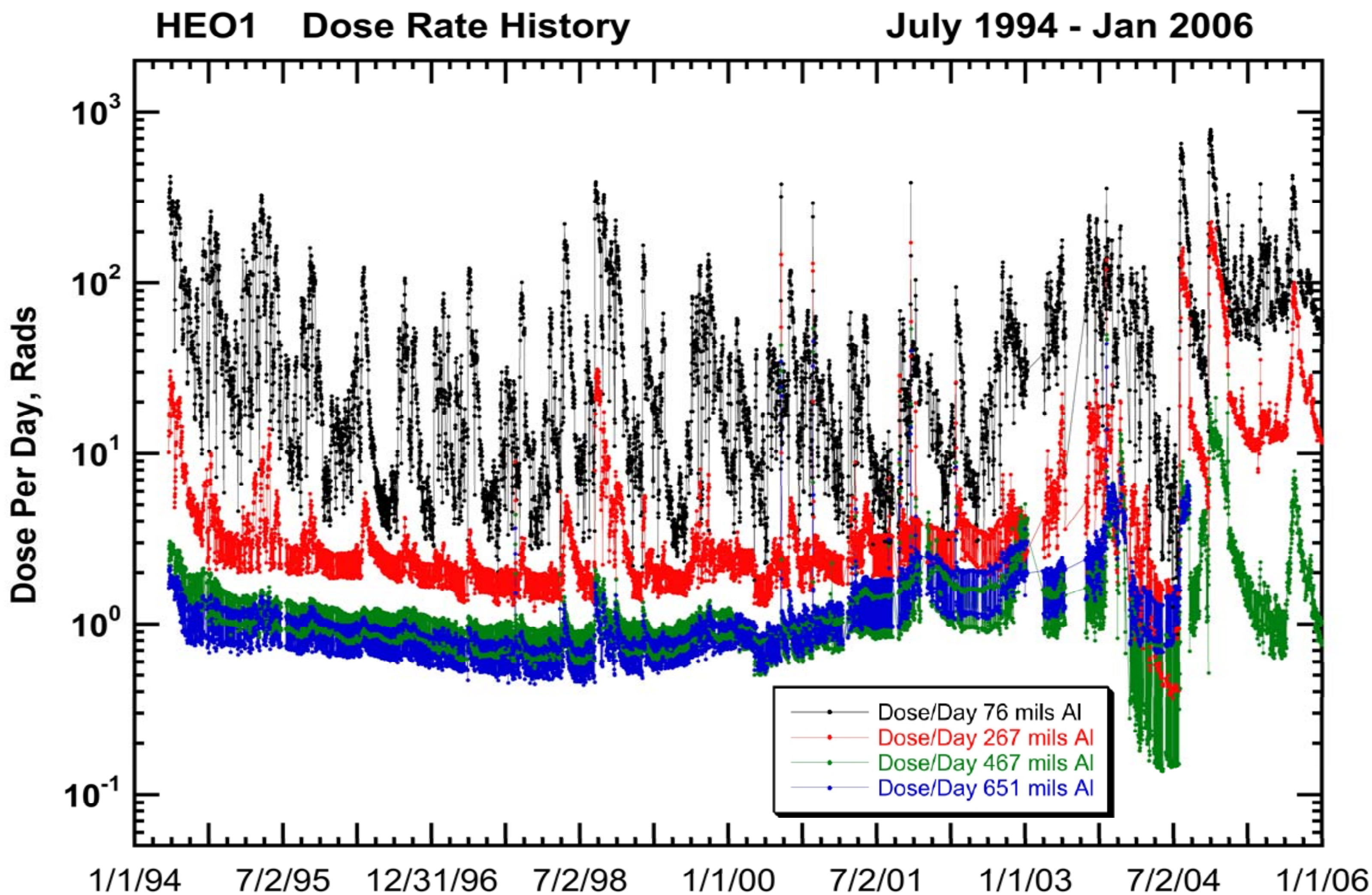
HEO 1 Dose History -- 1994 - 2006



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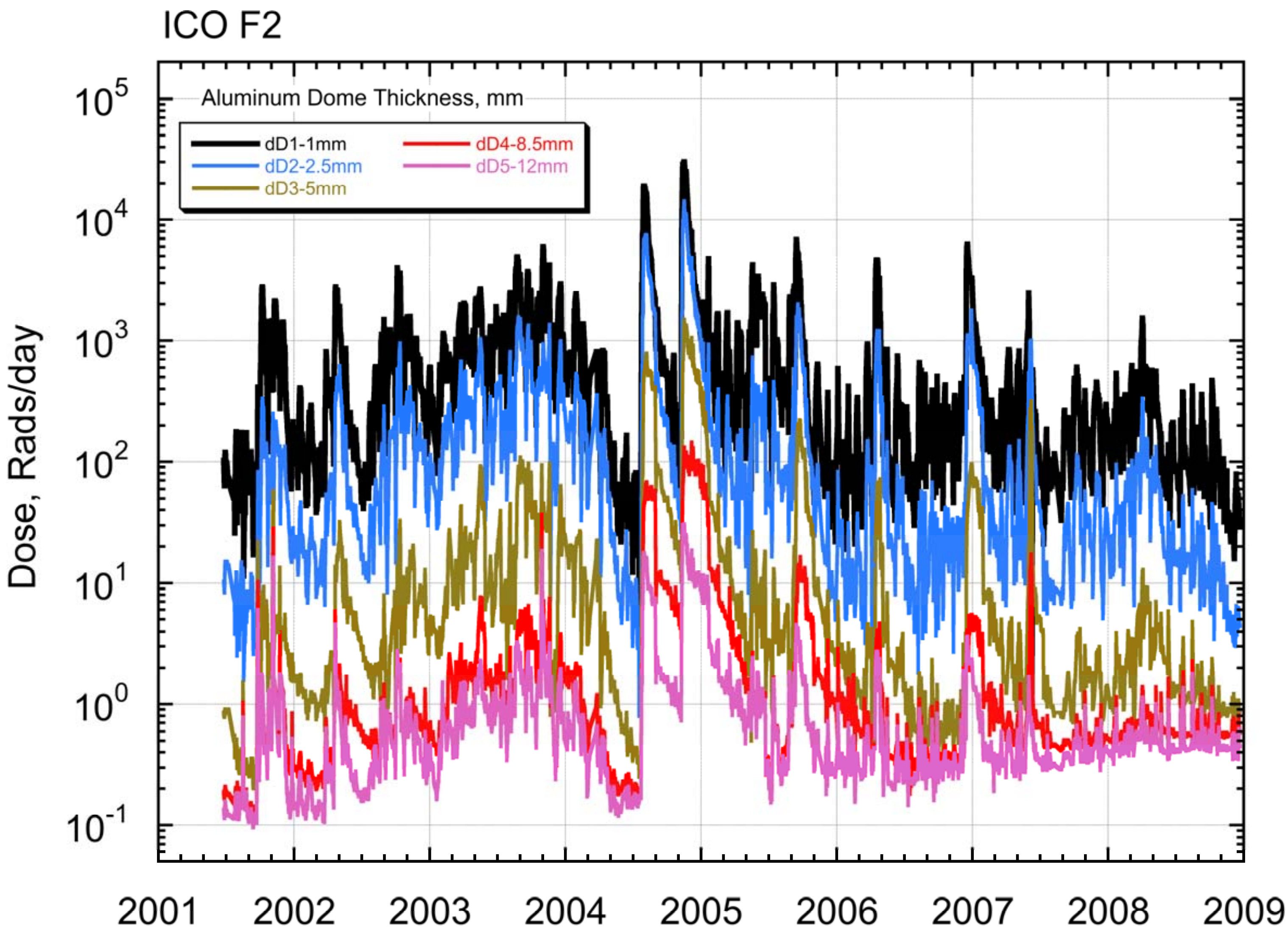
ICO F2 Dose History -- July 2001 to Jan 2009

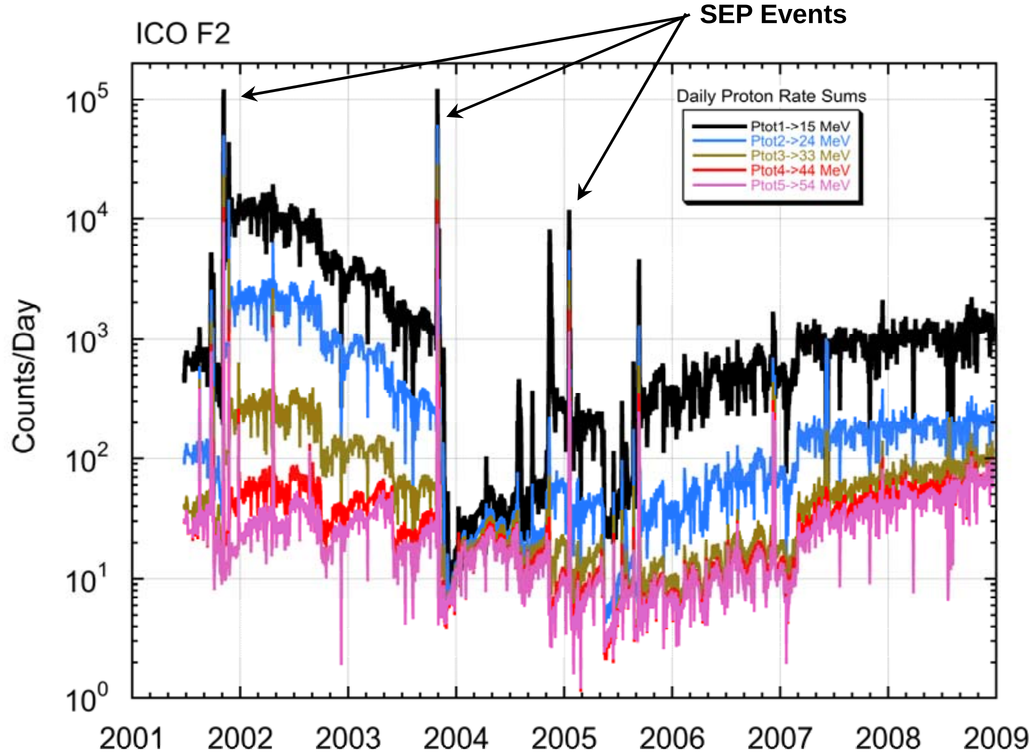


ICO F2 -- Orbit Summed Proton Response

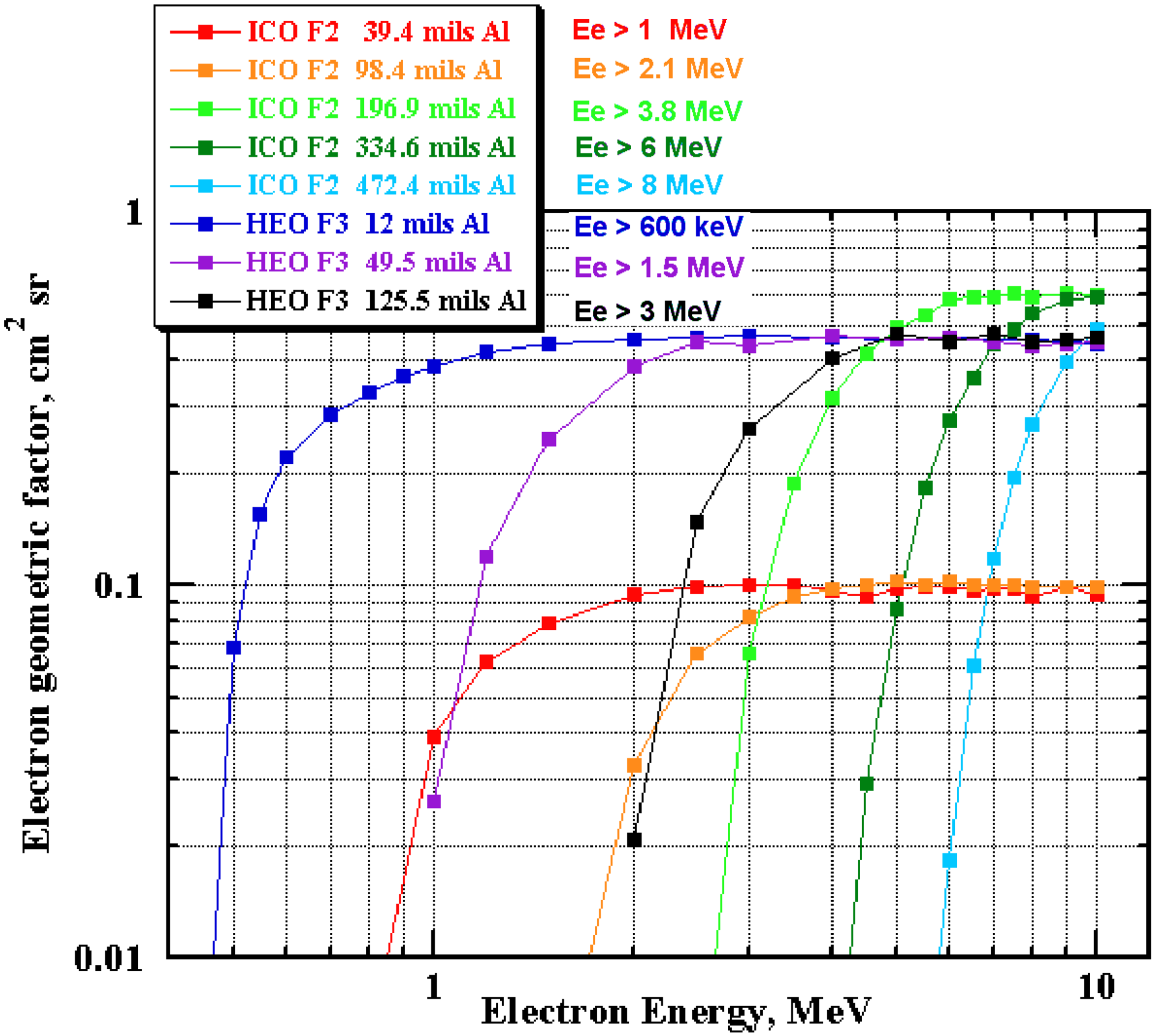
ICO F2 Orbit-summed proton rates for the period July 2001 to January 2009

Intense spikes are solar energetic proton (SEP) events

Sudden drop in late 2003 was caused by the large magnetic storm that started in late October, the so called Halloween Storm



HEO3 and ICO F2 Geometric Factors



Abstract:

We use data taken by shielded dosimeters on satellites in HEO/Molniya type orbits to measure the electron deposition rates that can cause internal charging. The dosimeters use silicon diode detectors to measure both the total energy deposited (dose) and the omni-directional fluxes of electrons and protons that penetrate the shielding. The shielding levels that are used for this study range from 5 to 267 mils Al. The data set from each HEO vehicle covers a 11-year interval or a full solar cycle. We show examples of charge deposition rates during times of nominal and high levels of penetrating fluxes in the inner magnetosphere. The charge deposition rates will be related to charging levels that could be experienced by shielded dielectrics with different resistivity. We will show the long term long charge deposition-rate temporal profiles and estimated charge density levels as an indicator of the internal charging rates that satellites in the inner magnetosphere could experience. The results will be compared to charge densities that can induce internal ESD (IESD).

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