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The Timescale of Surface Charging Events

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Title: The Timescale of Surface Charging Events

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Abstract:

The timescale for creating high potentials on shadowed spacecraft surfaces depends on the conductivity of the surface in question, whether the neighboring surfaces are tied to the spacecraft frame or not, and on the space environment input. It is understood from laboratory and spaceflight measurements that the likelihood of a large surface potential and the timescale over which it might occur depends on these variables, yet the complex interplay between them makes the hazard difficult to assess even in controlled experiments. In this paper we approach the specific question of the timescale of surface charging using several datasets in several orbit regimes: GEO, HEO, and LEO. The measurements we will show involve different approaches to the question of surface charging and subsequent ESD (GEO: surface charge monitors; HEO: direct plasma measurements; LEO: anomalies due to surface charging). However, the main strengths of the data derive from their long duration covering multiple years and their occasional overlap in time. At the meeting we will thus report on the timescale of surface charging events at different locations in the magnetosphere across ~11 years of geomagnetic activity. The results will be relevant for assessments of space system impact due to surface discharges and ESD, simulations of surface charging, and laboratory testing of flight systems designs.

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Objective & Outline

- Objective: Derive the worst-case timescales for surface charging in a variety of orbits

- Outline:
  - *Details of the three surface charging databases*
    - Examples from LEO, HEO, and GEO
    - Local time dependence
    - Seasonal dependence
  - *Results of the charging event duration study*
  - *Summary*

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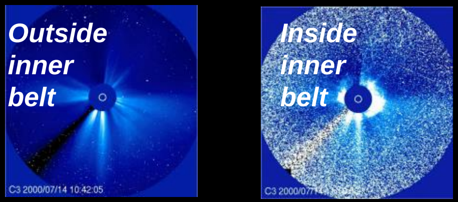
Space Environment Hazards

False stars in star tracker CCDs

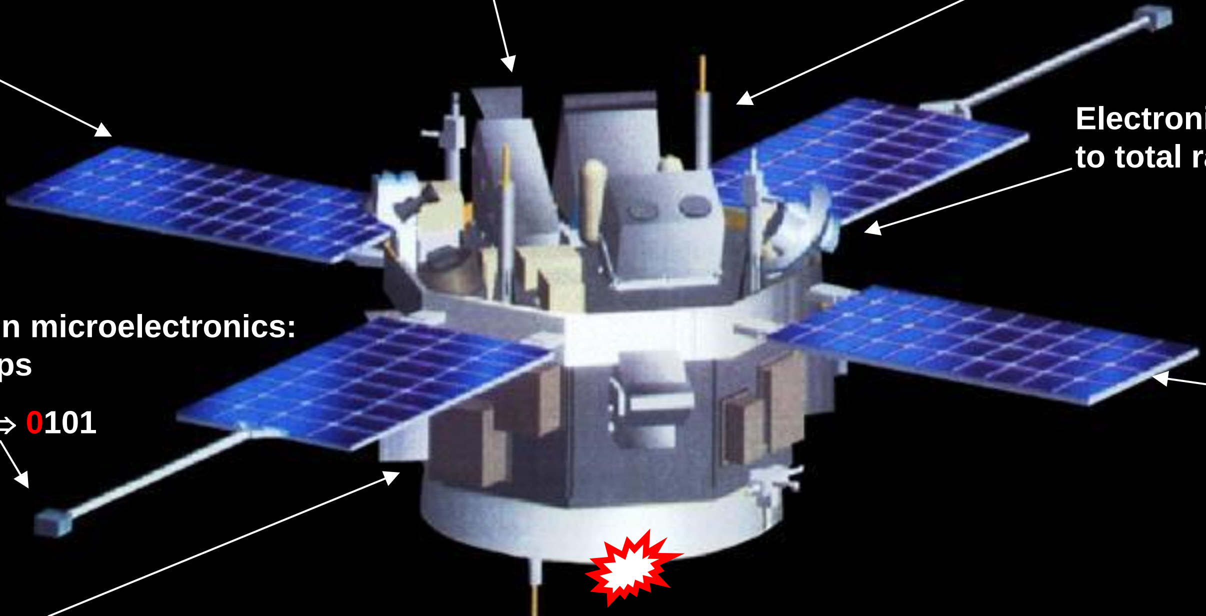


before *after*

Surface degradation from radiation

Solar array power decrease due to radiation damage

Electronics degrade due to total radiation dose



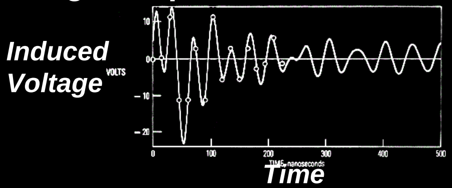
Solar array arc discharge

Single event effects in microelectronics: bit flips, fatal latch-ups

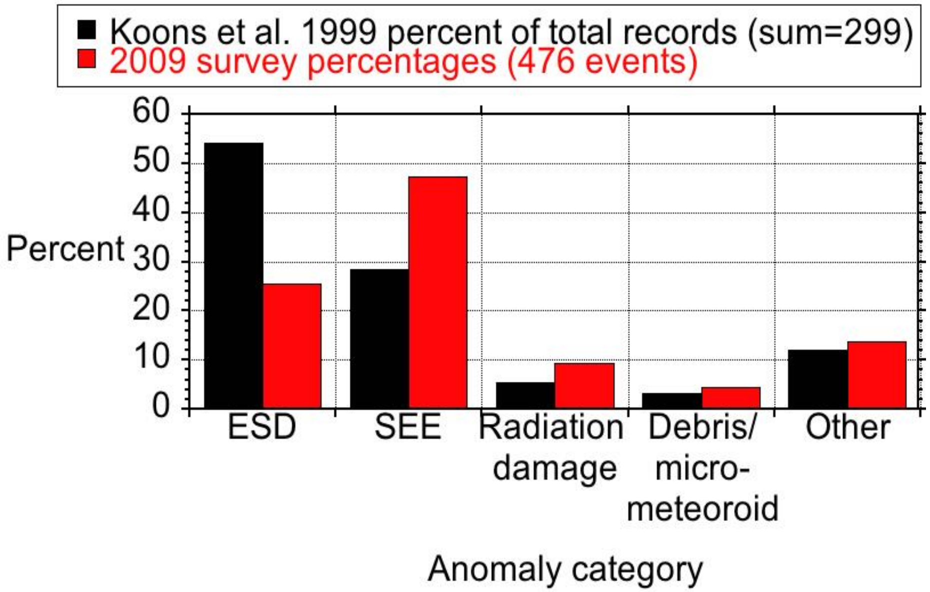
1101 ⇒ 0101

Spacecraft components become radioactive

Electromagnetic pulse from vehicle discharge

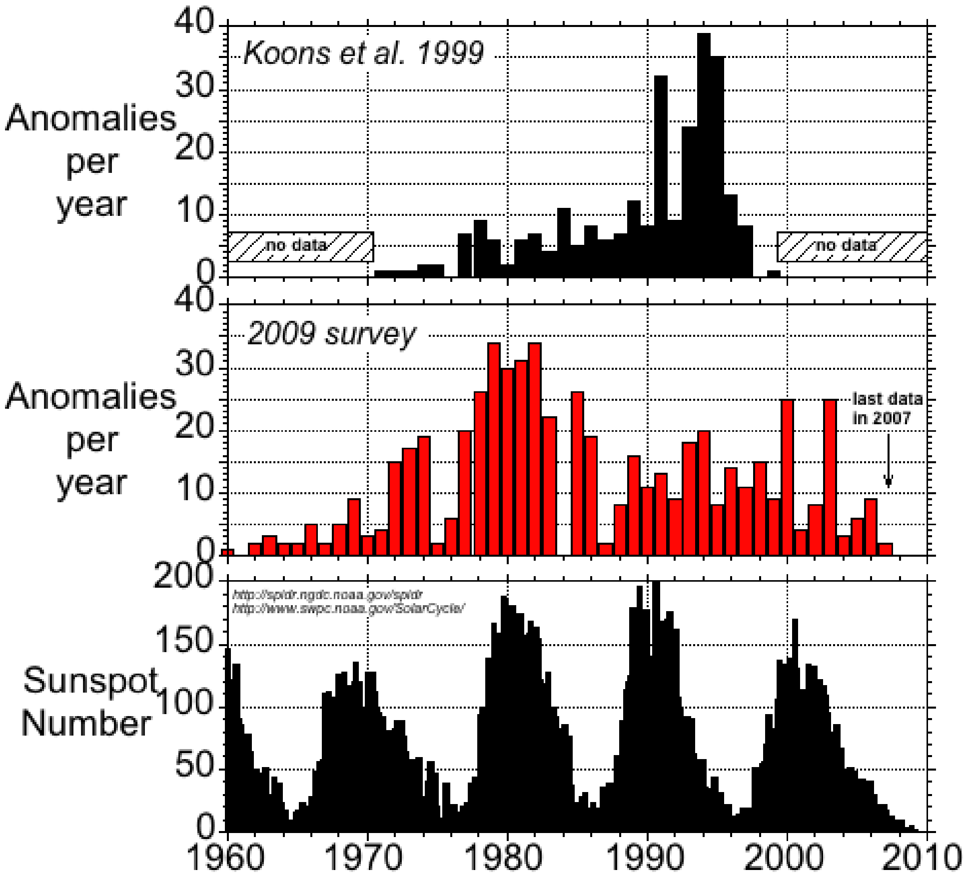


On-Orbit Anomaly Statistics



-Koons, et al., The Impact of the Space Environment on Space Systems, Aerospace Corp. report no. TR-99(1670)-1, 20 July 1999

-2009 preliminary study (unpublished)



- Anomalies occur at all phases of the solar cycle
- Vehicle charging and single-event effects are the most frequently cited causes of on-orbit anomalies

Surface Charging Databases

- This survey includes signatures of the surface-charging hazard observed in three orbital regimes: LEO, HEO, and GEO.
- Portions of the HEO and GEO measurements have been discussed previously in the literature and at previous satellite surface charging conferences, while the LEO example has not been as widely discussed.

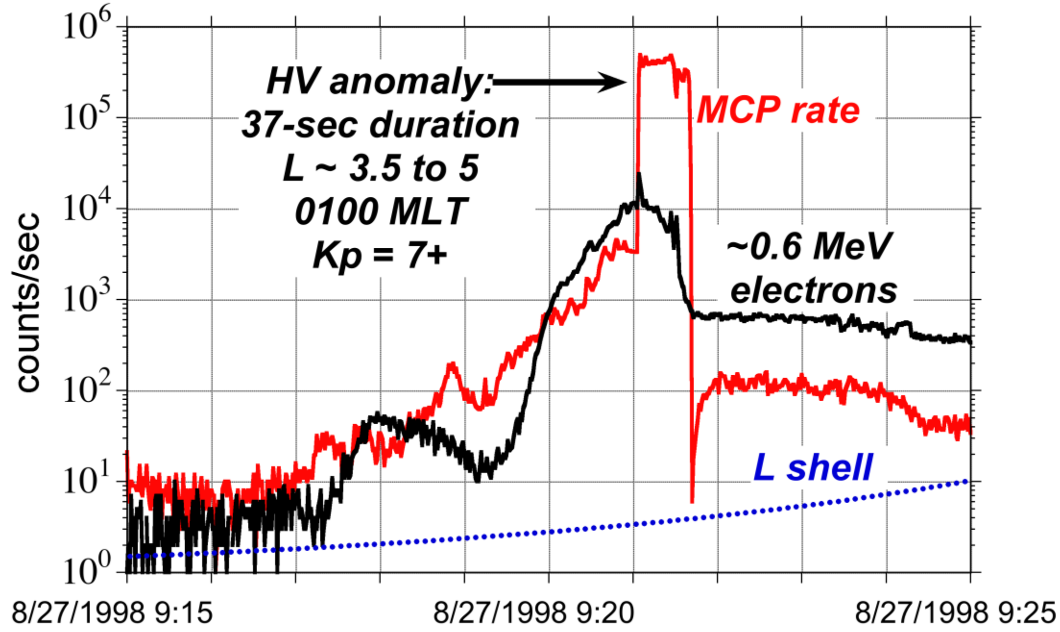
Orbit	Vehicle	Survey start date	Survey stop date	Surface charging measurement technique	Reference
LEO	SAMPEX	12/11/1992	8/4/2002	LICA instrument anomalies	This paper *
HEO	HEO2	8/8/1995	8/9/2002	Frame potential /Plasma analyzer	Fennell *et al.* 2008
GEO	Intelsat 802	7/10/1997	2/6/2002	Differential potential/Charge plate analyzer	Bogorad *et al.* 1995

**Mazur et al., IEEE Trans. Plasma Sci. submitted 2011*

An Example From the LEO Database

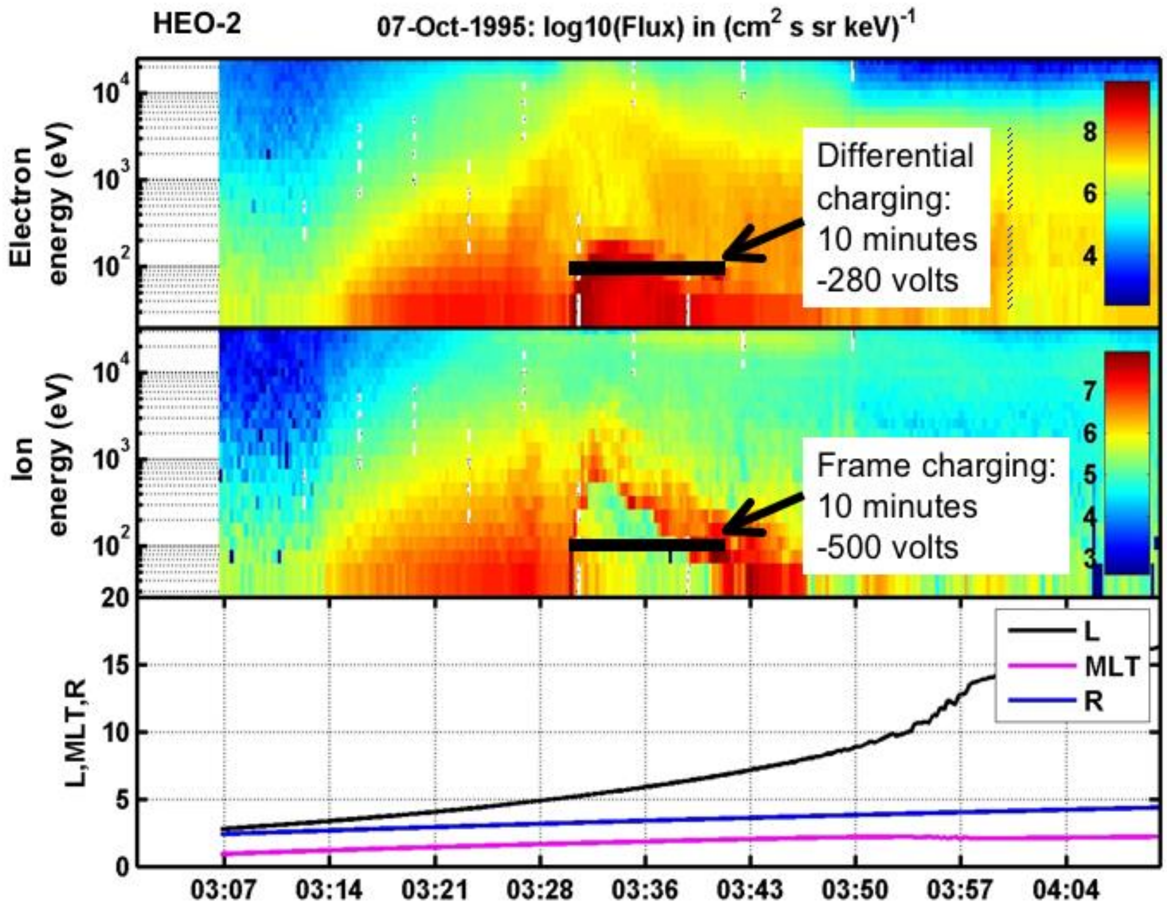
- A commonly cited example of satellite surface charging in LEO is from the DMSP vehicles (*e.g.* Gussenhoven *et al.* 1985; Frooninckx & Sojka 1992 & references therein).
- Thus, it was a surprise to encounter a set of LEO anomalies that have more in common with surface charging signatures at GEO rather than within the unique conditions of auroral arcs.

- This figure shows one such event from the SAMPEX satellite
- The subsequent figures in this talk show more evidence for why we believe these anomalies are a unique signature of surface charging in LEO



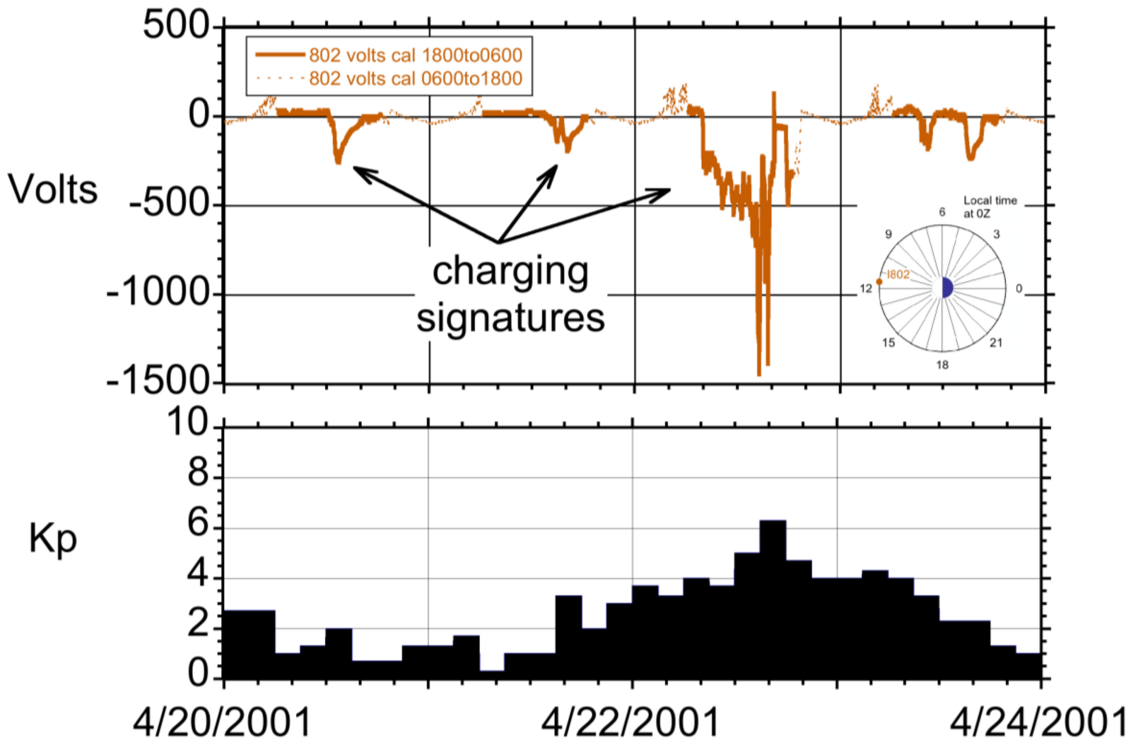
An Example From the HEO Database

- Fennell *et al.* [2008] recently reviewed the statistics of HEO charging events using a plasma analyzer on board the HEO2 spacecraft
- For this paper we used the same dataset as the Fennell *et al.* [2008] study



An Example From the GEO Database

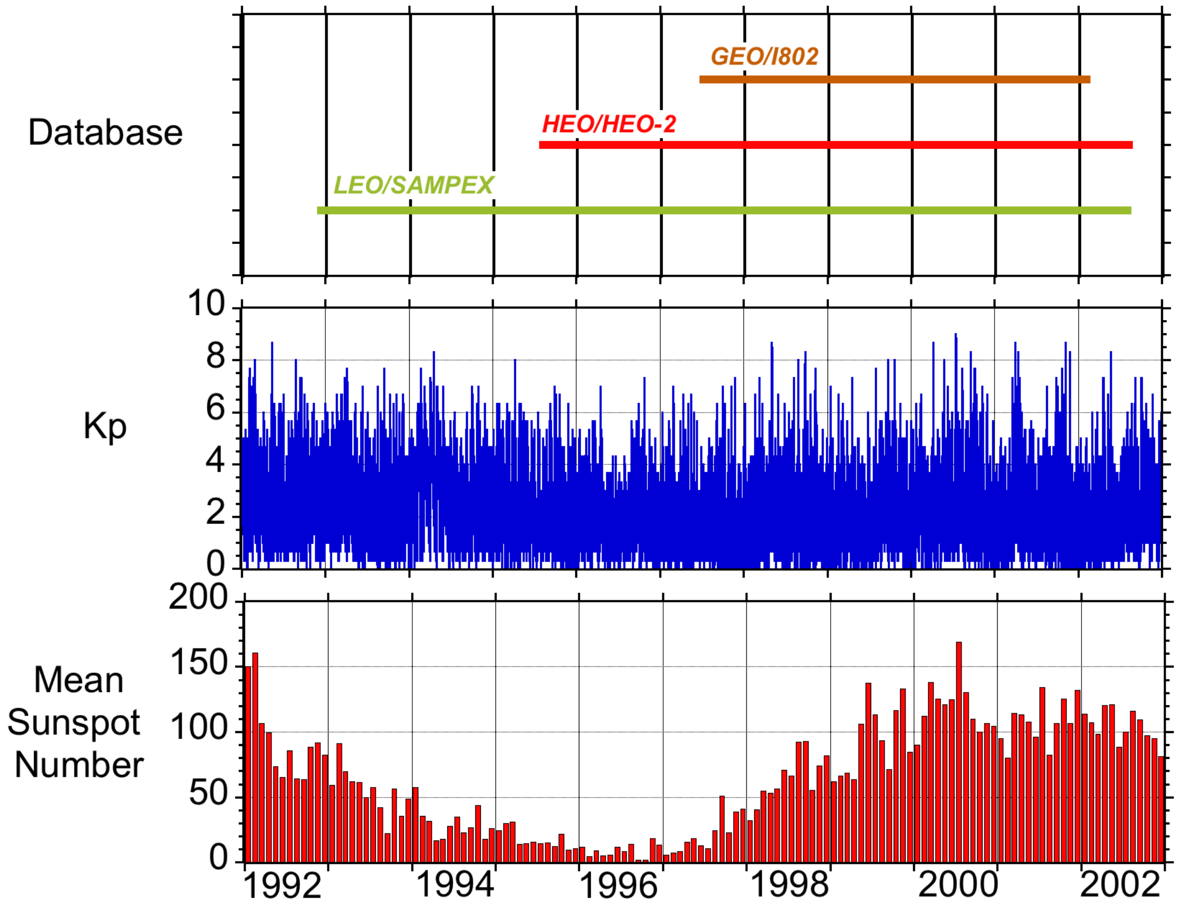
- There are many published examples of surface charging in GEO
- Here we used the charging signature from a charging plate analyzer (Bogorad *et al.* 1995**)** on board one of the Intelsat satellites (e.g. Ozkul *et al.* 2001; Koons *et al.* 2006; Likar *et al.* 2009).



- The Intelsat database benefits from very long time coverage, a clear response to plasmasheet electrons when the sensor is in shadow, and the ability to place a wide range of thresholds on the charging level

Solar Cycle Coverage

- Our three charging datasets overlapped in time during solar cycle 23
- The LEO database is the only one that included the descent to the 1996 solar minimum when several recurrent high-speed solar wind streams led to severe geomagnetic storms
- However, geomagnetic activity that leads to surface charging occurred within every dataset



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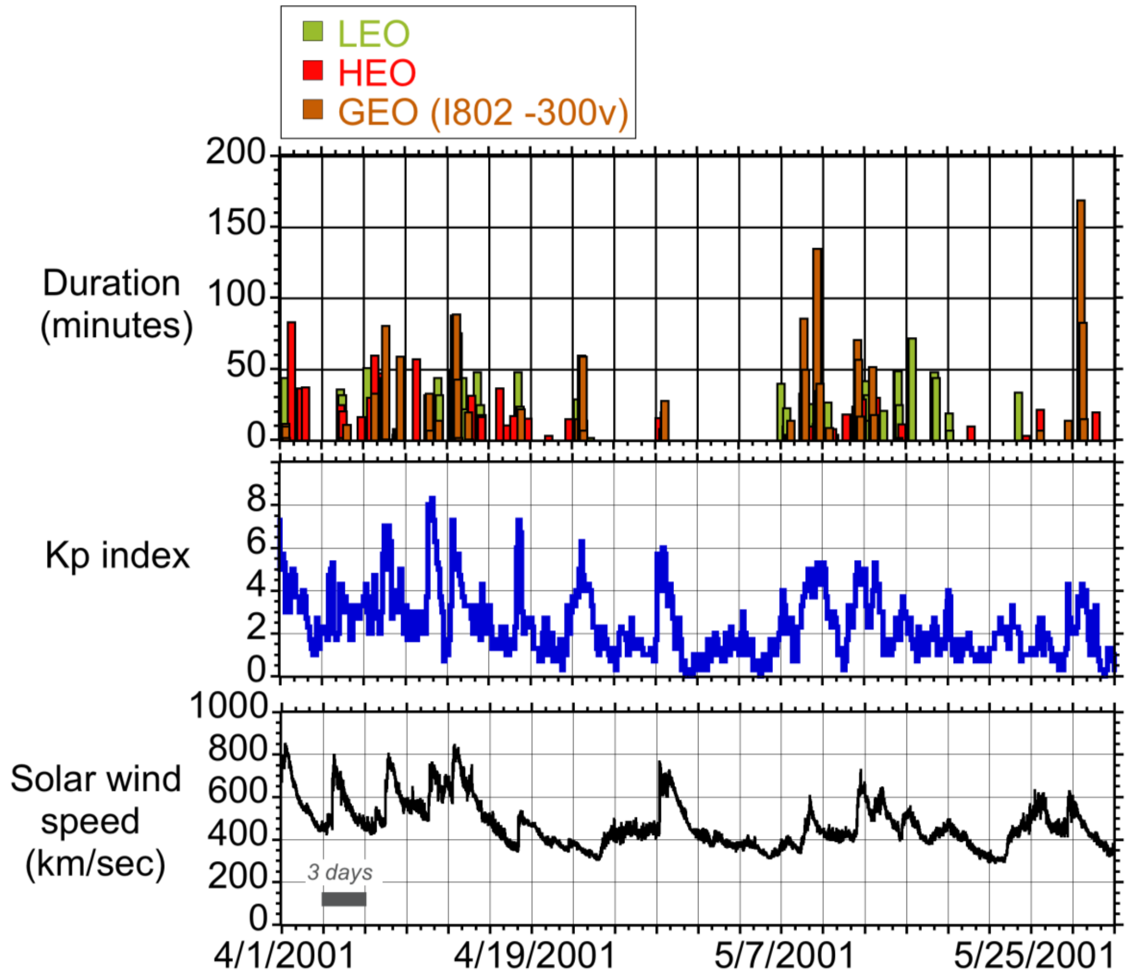
Coincident Charging Signatures

- The figure shows a 2 month period in 2001 in order to establish that our charging signatures responded to the same environmental inputs, at least on the timescale of a few days
- We chose not to focus on the studies of specific events across the three orbits



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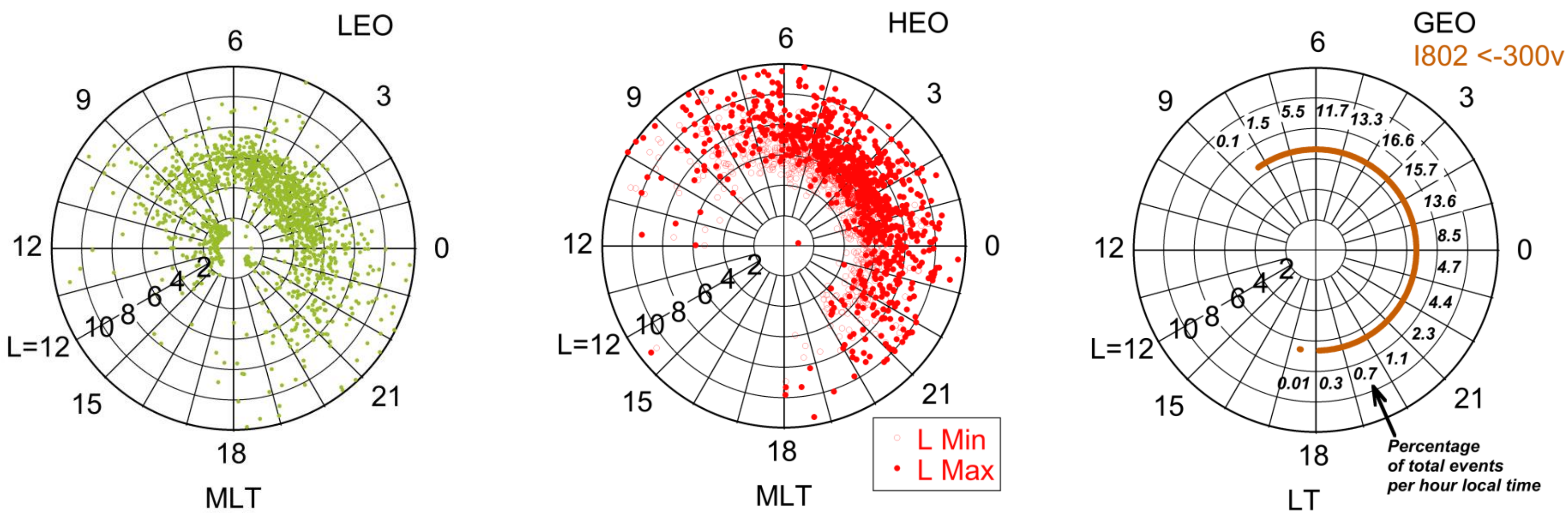
Organization By Local Time



- Event occurrence versus L shell and local time is a common way of organizing the data to show the unique signature of the drift of plasmasheet electrons from the magnetotail towards dawn local time.
- This has been done with the GEO and HEO databases already (Ozkul *et al.* 2001; Fennell *et al.* 2008) but we combine all the datasets here to emphasize the point that they show the same phenomenon.

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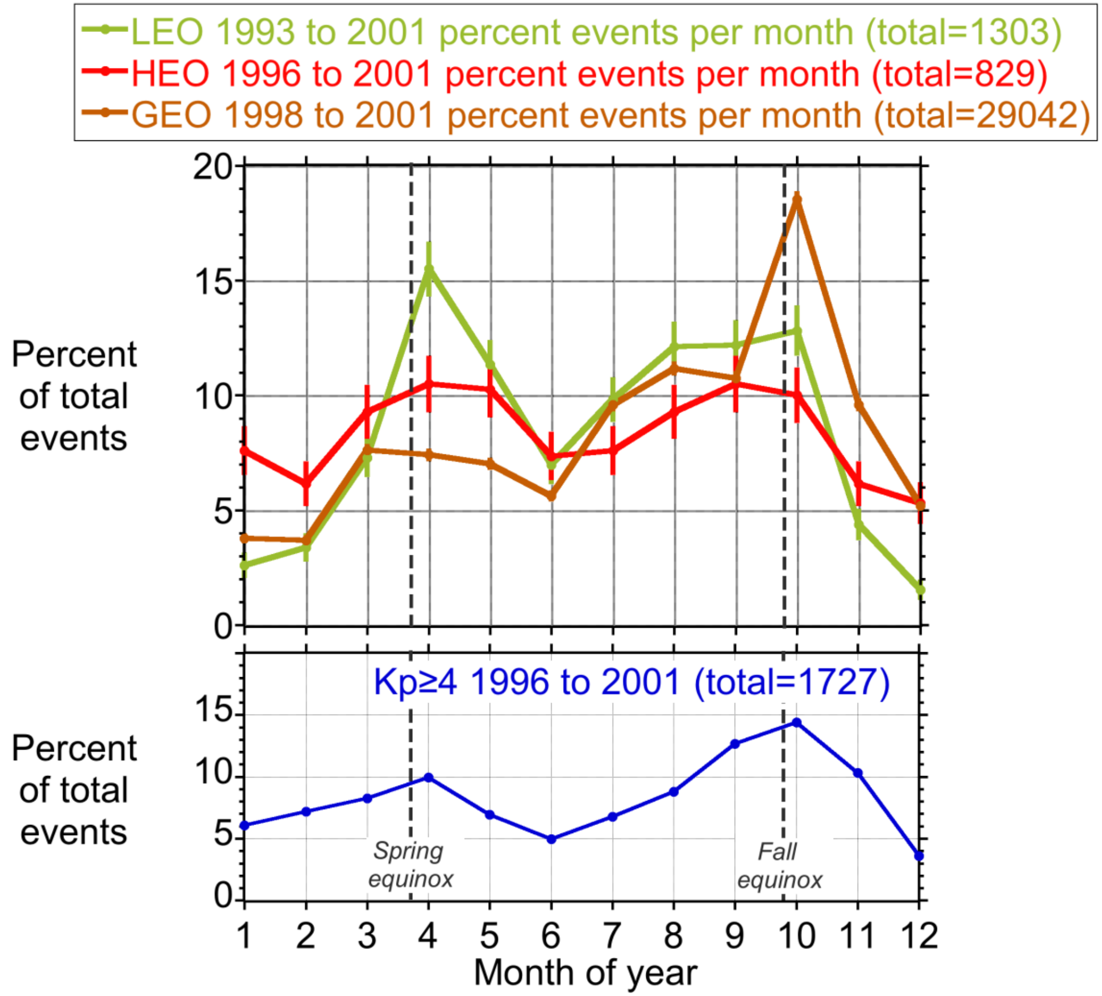
Seasonal Probabilities

- One expects a semiannual variation in the charging signatures because the driving geomagnetic activity exhibits such a pattern due to the projection of the interplanetary magnetic field on the magnetosphere. (Russell & McPherron 1973)
- To our knowledge, this is the first time such a seasonal variation has been shown for charging in a wide range of orbits



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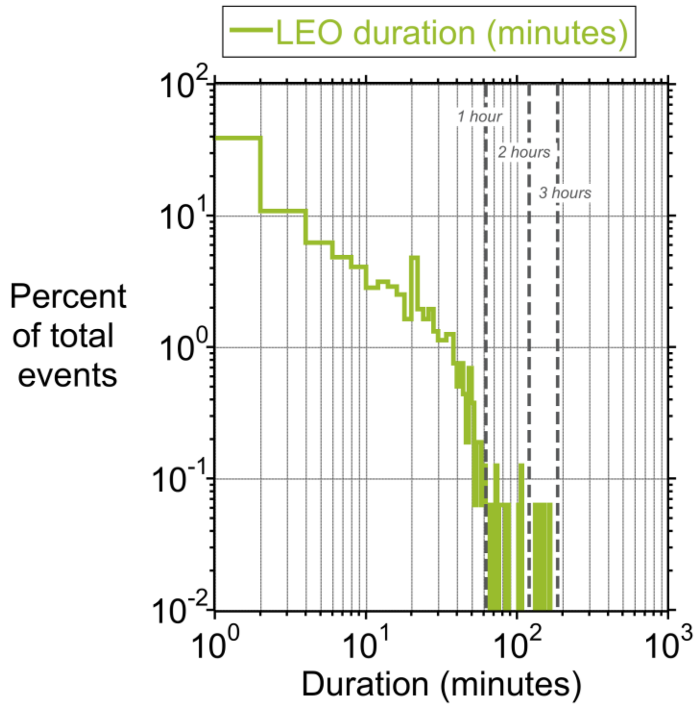
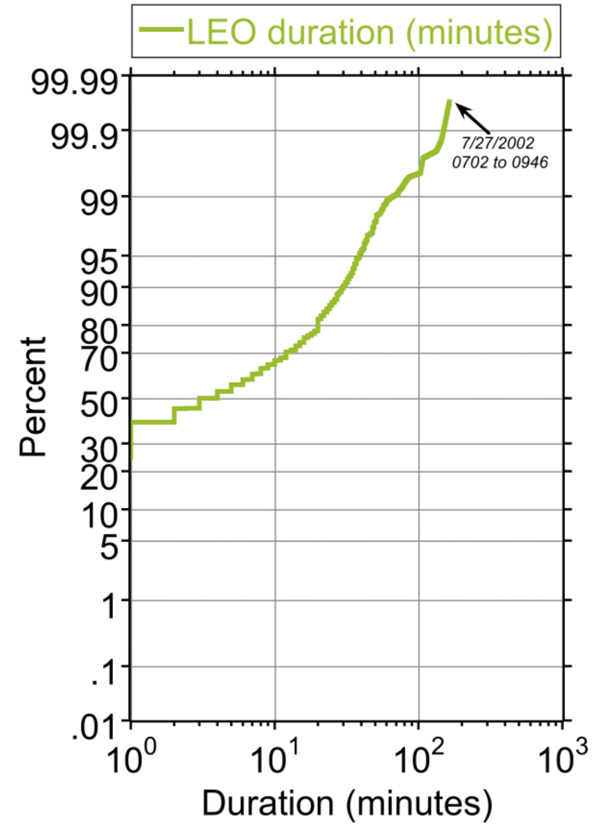
LEO Duration

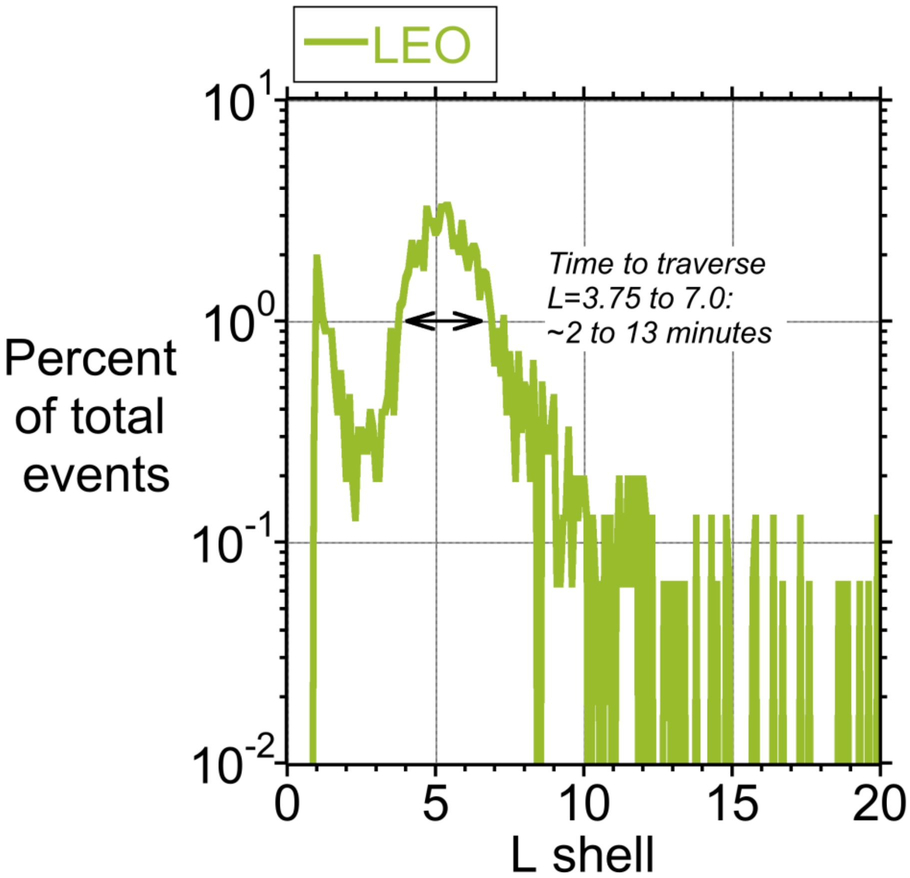




- It is puzzling that we encountered charging-related anomalies that lasted a significant fraction of the LEO orbital period (~ 90 minutes)
- Timescale to traverse L=3.75 to 7 is 2 to 13 minutes
- The worst-case in July 2002 lasted 164 minutes

LEO: L Shell Traversal Rate

- It took the SAMPEX vehicle as long as 13 minutes to traverse this range of L, but the most likely traversal time was closer to 2 minutes.
- Thus, anomalies sometimes continued well beyond the spatial region within which the plasmasheet electrons were likely located.
- One might have expected that the charging-related anomaly would cease if the electron input was no longer present; this was clearly not the case



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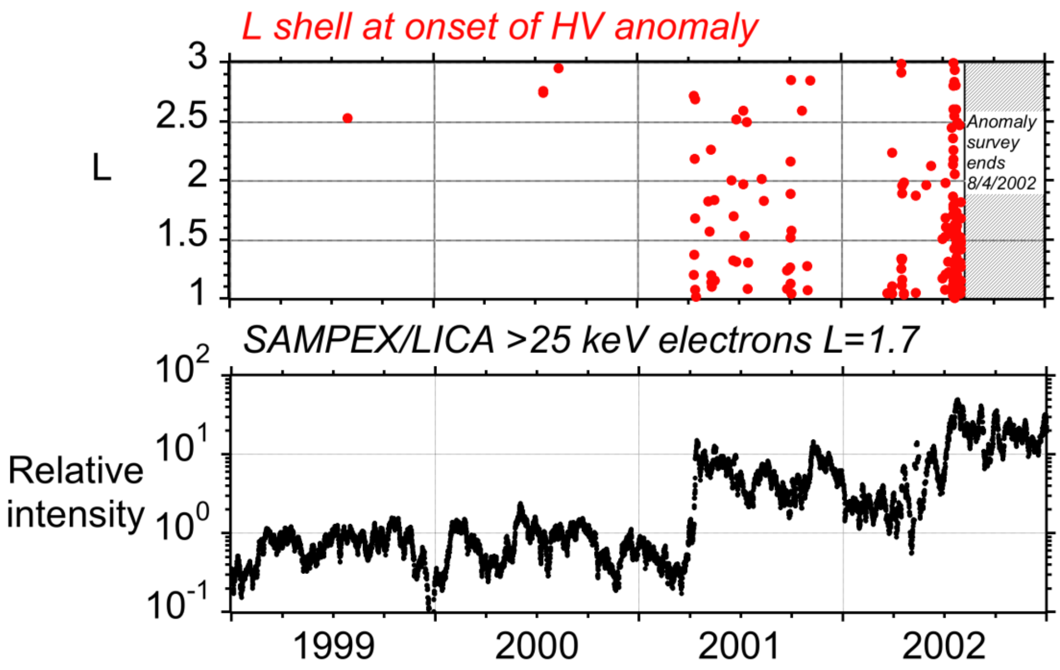
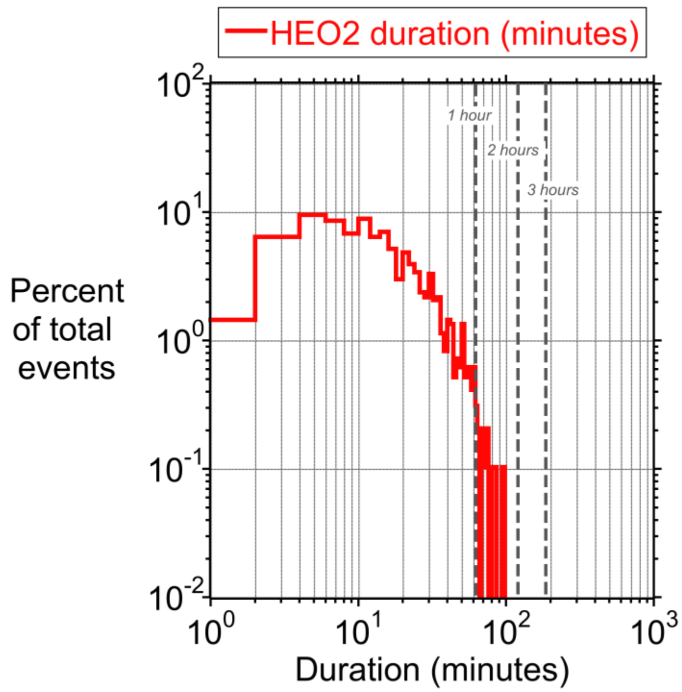
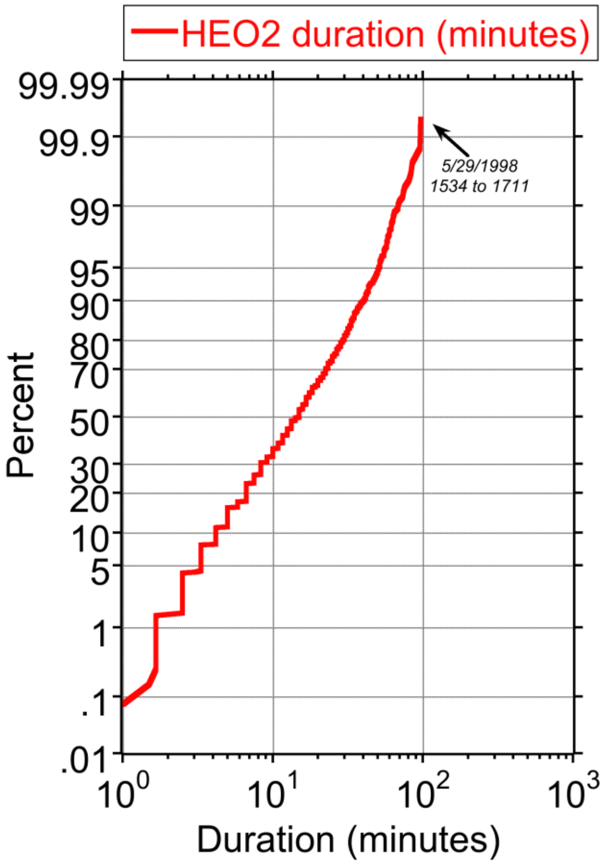
Unique Low-L LEO Events



- One unique aspect of this LEO database is the presence of events well inside the typical inner edge of the plasmasheet.
- The anomalies that occurred below L=2 appeared after April 2001 and were most prevalent in July 2002.
- We suggest that they were related to intense and long-lived injections of electrons into the inner radiation belt that appeared in mid-2001

HEO Duration





- As was the case for LEO, we also had events that appear to last longer than the time required to traverse the nominal charging region
- Timescale to traverse L=4 to 7 is 3 to 45 minutes
- The worst-case in May 1998 lasted 97 minutes

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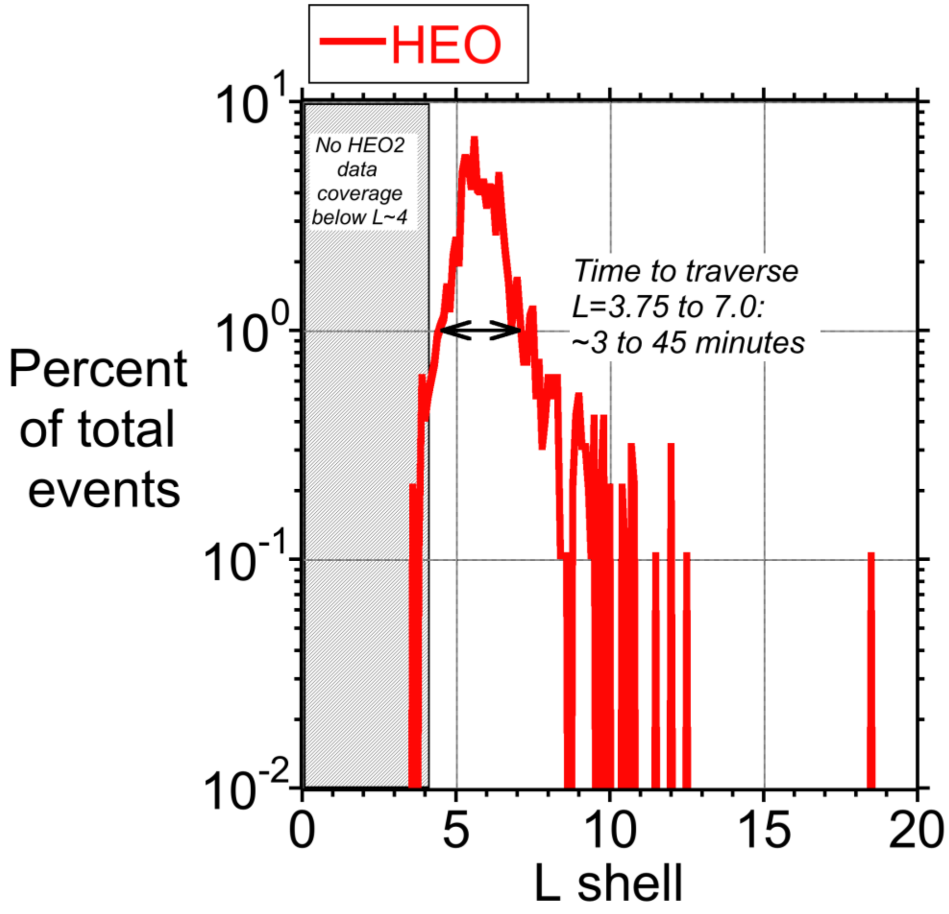
HEO: L Shell Traversal Rate

- The typical timescale for traversals of L=3.75 to 7 ranges up to 45 minutes, yet there were 22 events that lasted longer than 60 minutes
- These long-duration events correlated with the maximum L shell of the charging, meaning that while the longest lasting events began near L=4 to 5, they continued up to higher L, beyond GEO



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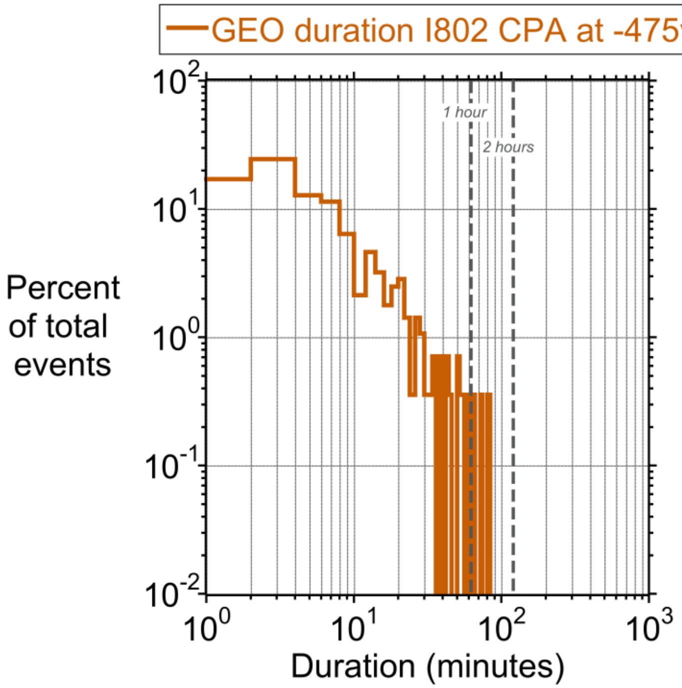
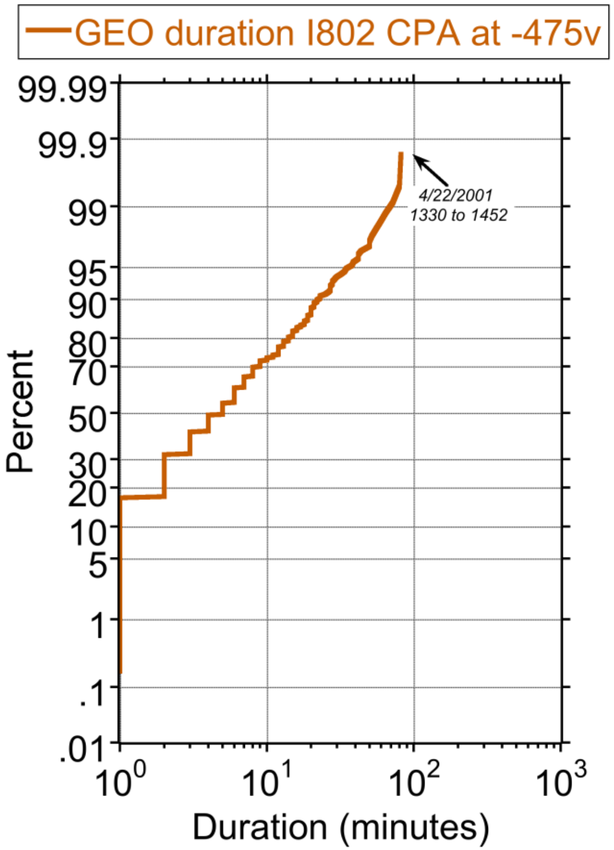
GEO Duration





- For GEO we have the added variable of charging threshold; here we show the 99.9% worst-case charging level.
- The slope of the duration distribution changes little with the threshold potential, and we are able to almost arbitrarily define the worst-case charging duration from as long as ~12 hours to as short as ~80 minutes.
- These histories are directly proportional to the timescales of changes in the charging environment itself.

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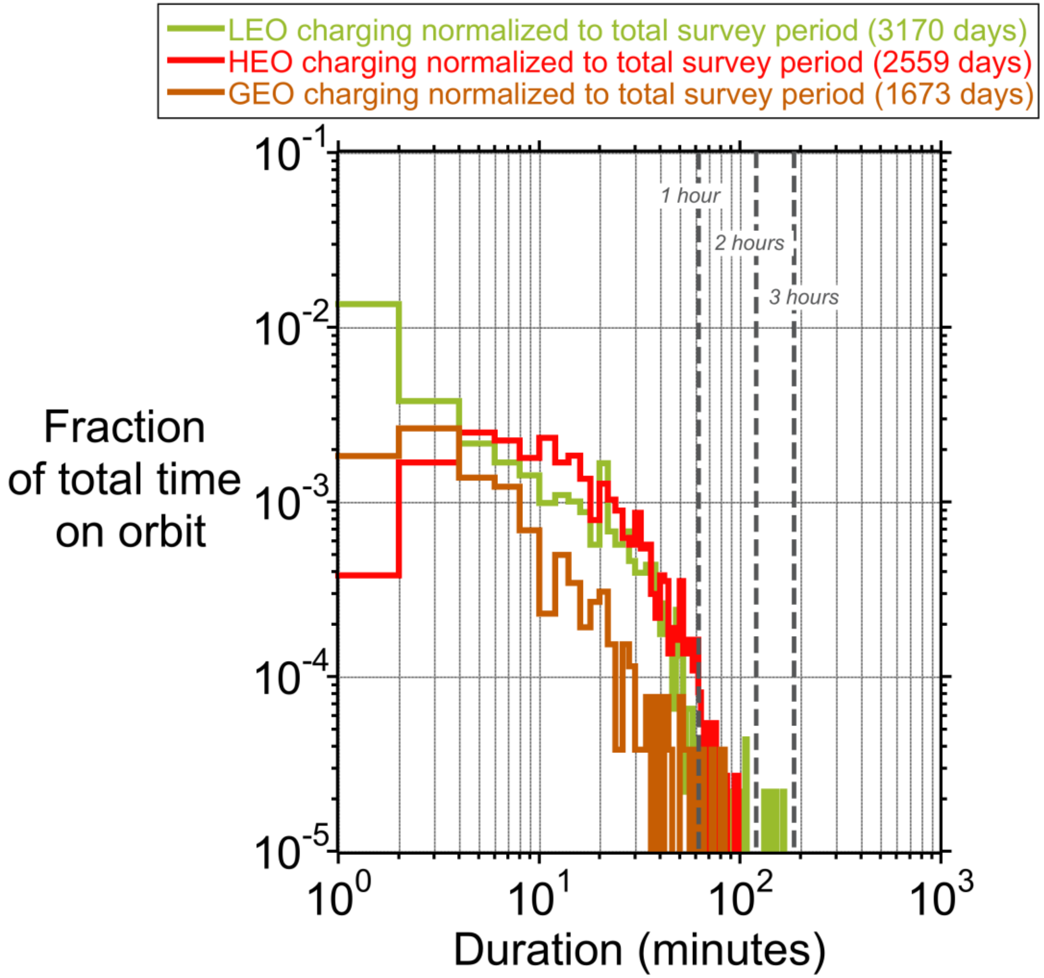
Normalized Distributions

- These distributions imply that for surface charging lasting a few to 10 minutes, the LEO and HEO frequencies of occurrence were comparable.
- All three orbits had worst-case durations between 1 and 2 hours
- It is interesting that if one chooses a lower GEO potential than shown here, then the worst-case duration at GEO can be an *order of magnitude* longer than HEO's 97 minutes



Summary (1 of 2)

- The databases had these major shortcomings:
  - *unknown charging level (and exact anomaly mechanism) for LEO*
  - *minimum L shell of ~4 for HEO*
  - *unclear choice of appropriate charging level to choose for GEO.*
- We note that the HEO charging level was low (-30 volts), so the HEO dataset was not restricted to the worst-case levels.
- The LEO and HEO events had similar occurrence probabilities suggesting a sensitivity to relatively low-level charging in LEO, although we cannot prove this directly with the LEO anomalies.

Summary (2 of 2)

- We find several compelling aspects of vehicle surface charging in the magnetosphere that are quantitative, reproducible, and might serve as a reference for future measurements or laboratory work on the surface charging phenomenon:

    1. Worst-case durations for LEO (164 minutes) and HEO (97 minutes)
    2. Both LEO and HEO longest-duration events were much longer than the orbital residence time within the nominal L=4 to L=6 surface charging region (on the order of 10 and 50 minutes for LEO and HEO, respectively)
    3. Worst-case duration for GEO that varied from 667 minutes at -100 volts to 82 minutes at -475 volts
    4. Within these databases, there were comparable likelihoods for LEO and HEO charging events to occur and last the same amount of time at both orbits (e.g. at a 10 minute duration, both LEO and HEO likelihoods were ~ 2e-03)
    5. New evidence for LEO vehicle charging inside L=2 during intense injections of electrons into the inner magnetosphere

- It is clear that a simple residence time argument is insufficient to characterize the worst-case duration for surface charging in LEO and HEO
- For GEO, the worst-case duration depends more on the charging level than on traversal rate through the relevant local times.

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