Specification of electron radiation environment at GEO and MEO for surface charging estimates

N. Ganushkina (1, 2), S. Dubyagin (1),
J.-C. Matéo Vélez (3), A. Sicard (3), D. Payan (4), M. Liemohn (2)

(1) Finnish Meteorological Institute, Helsinki, Finland
(2) University of Michigan, Ann Arbor MI, USA
(3) ONERA, The French Aerospace Lab, Toulouse, France
(4) Centre National d'Etudes Spatiales, Toulouse, France

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Motivation

- **Surface charging** and subsequent anomalies important for operation and efficiency of spacecrafts at GEO and MEO; **worst at MEO orbit**:
environment much harder than in GEO and much less experience (flight heritage)

- Surface charging due to keV electrons:
electrostatic discharges causing **EM interferences** or local degradations, sustained **arcs** and system or mission destruction in the worst cases.

- Individual examples of **permanent losses due to charging in orbit**:
- loss of the Japanese spacecraft ADEOS-II
- 8 month outage and drift of Galaxy 15
- large permanent power losses on PanAmSat 6 and Tempo 2 spacecraft

- Several **spacecraft design guidelines** define rules and testing methods aimed at limiting the impact of electrostatic but they often rely on **very limited data** sets.

- A current need is to determine **the risks that extreme events** present to critical spacecraft in GEO and MEO.

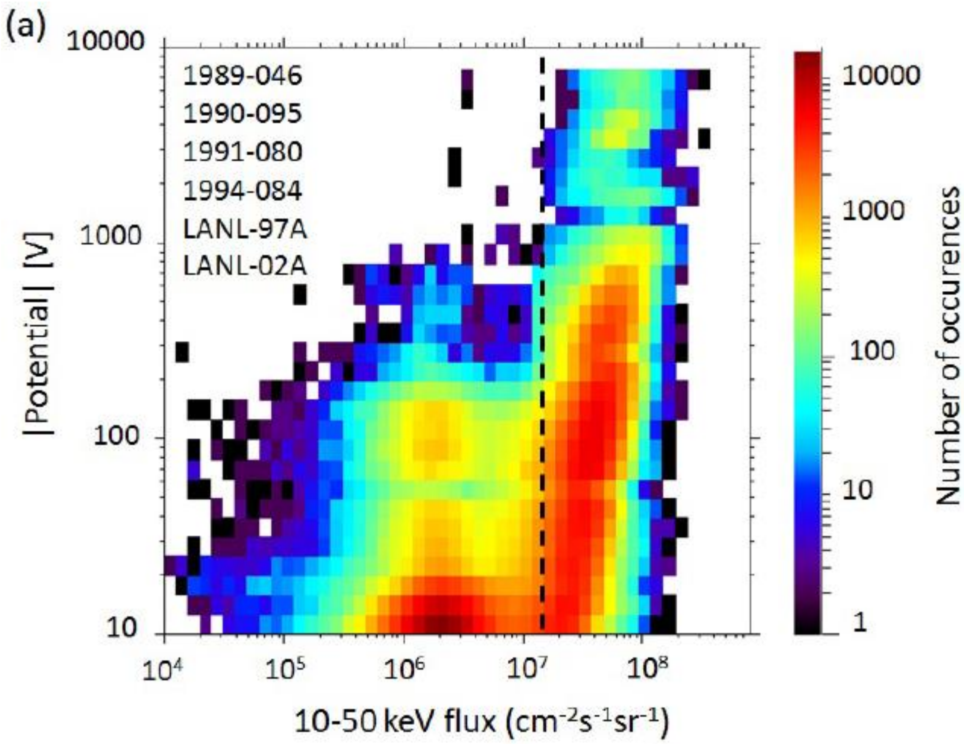
Analysis of LANL data

Matéo-Vélez et al., Journal of Spacecraft and Rockets, 2016,
Matéo-Vélez et al., Space Weather, 2017

15 years of Los Alamos National Laboratory (LANL) data at GEO from September 1989 to November, 2005 from 6 spinning satellites:
1989-046, 1990-095, 1991-080, 1994-084, LANL-97A and LANL-02A.

LANL data (ions and e-) used:
MPA: from 100 eV to 40 keV
SOPA: from 50 keV to 1.3 MeV
ESP: from 1 to several MeV
The time resolution used is 86 seconds.
The spacecraft potential routinely provided by LANL

The best correlation with potentials is for 10-50 keV electrons (consistent with the 8 keV and 9 keV thresholds from *Thomsen et al.* [2013], *Ferguson et al.* [2015]



The 10 to 50 keV electron flux thresholds as an indicator of surface charging risks at GEO.

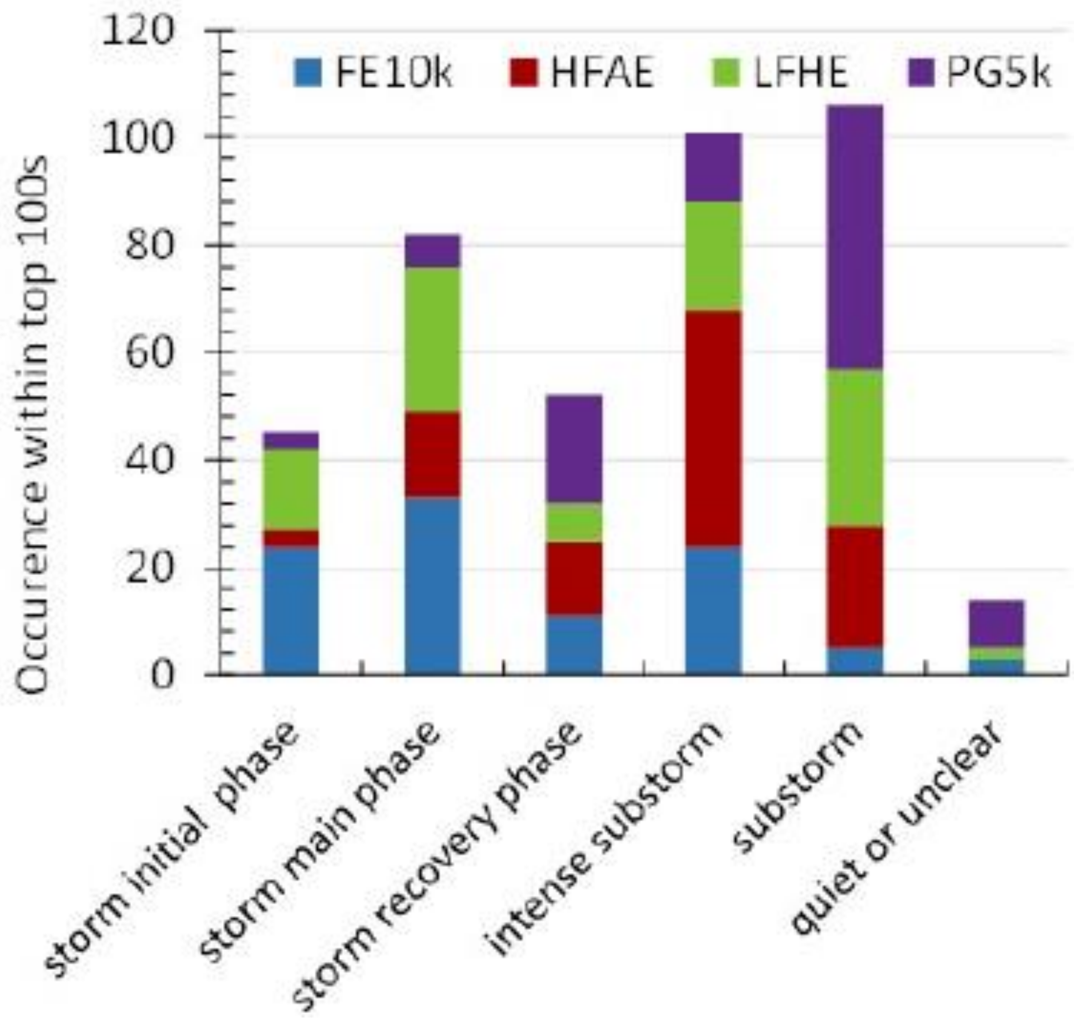
Four criteria for worst-case environments from LANL data

Criteria for defining severe conditions developed based on integral fluxes and measured spacecraft potential.
Fluxes averaged over 15 minutes, because severe conditions need to remain over a few minutes for differential charging to occur in geosynchronous orbit.

(**FE10k**): highest Fluxes of electrons at Energies above 10 keV
(**HFAE**): Highest Fluxes at All Energies (high fluxes at both <50 keV and > 200 keV which is related to charge deposited both at the surface and in the bulk of covering insulators);
(**LFHE**) : high fluxes at low energies together with a Low Flux at High Energy (high fluxes at <50 keV and low fluxes at >200 keV which is related to surface charging);
(**PG5k**) : longest events with a Potential Greater than 5 kV (in absolute) (events associated with large negative potential with plenty of time for differential charging to occur).
400 events with worst-case environments were identified

Comparison done with guidelines given by
1. Standard **ECSS-E-20-06** "Spacecraft charging" of European Cooperation for Space Standardization, *https://www.spacewx.com/Docs/ECSS-E-ST-10-04C_15Nov2008.pdf*
2. **NASA-HDBK-4002A** Mitigating In-Space Charging Effects Guidelines, *http://standards.globalspec.com/std/1309224/nasa-hdbk-4002*

Surface charging events vs. geomagnetic conditions



FE10k events: all storm phases and intense isolated substorms;
HFAE events: substorms;
LFHE events: equally distributed between storms and substorm periods;
PG5k events: storm recovery and moderate substorms.

These results show that **it is not necessary to have extreme conditions** to get severe spacecraft surface charging.

Matéo Vélez et al., Space Weather, *2017*

Inner Magnetosphere Particle Transport and Acceleration Model (IMPTAM) for low energy electrons

(*Ganushkina et al., JGR, 2013, 2014, Space Weather, 2015***)**

The inner magnetosphere particle transport and acceleration model:

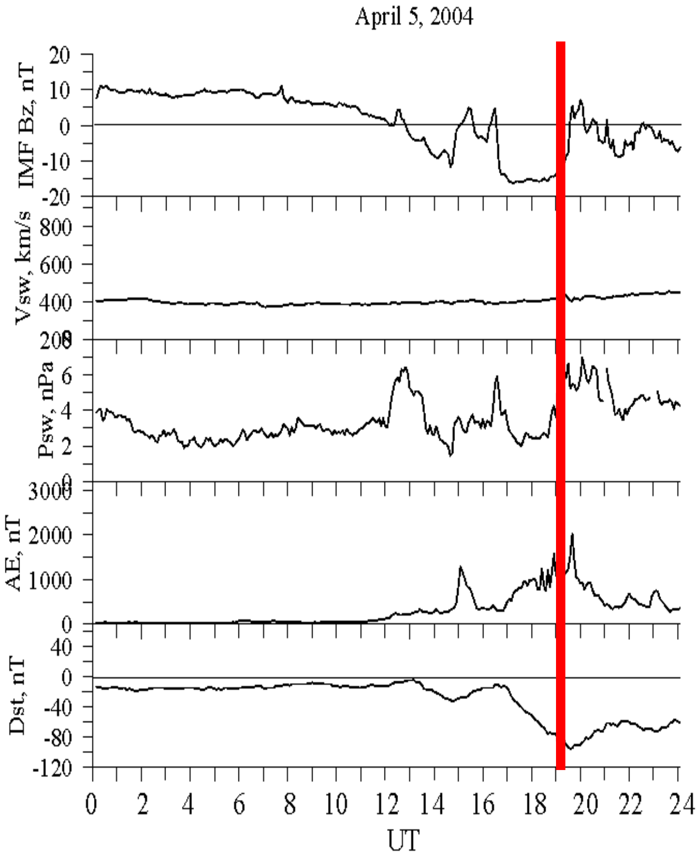
- follows distributions of ions and electrons with arbitrary pitch angles
- from the plasma sheet to the inner L-shell regions
- with energies reaching up to hundreds of keVs
- in time-dependent magnetic and electric fields.
- distribution of particles is traced in the guiding center, or drift, approximation

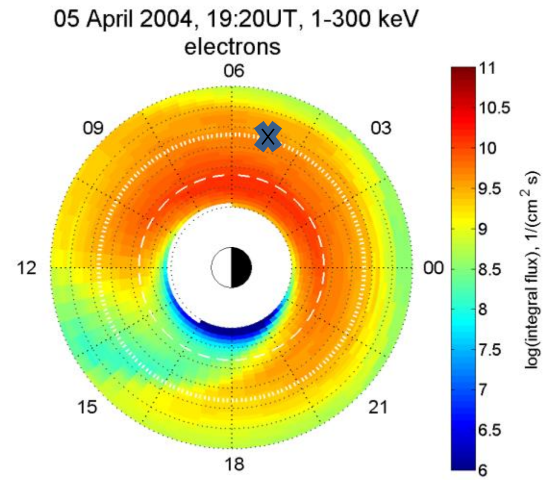
In order to follow the evolution of the particle **distribution function** f and particle **fluxes** in the inner magnetosphere dependent on the **position, time, energy, and pitch angl**e , it is necessary to specify:

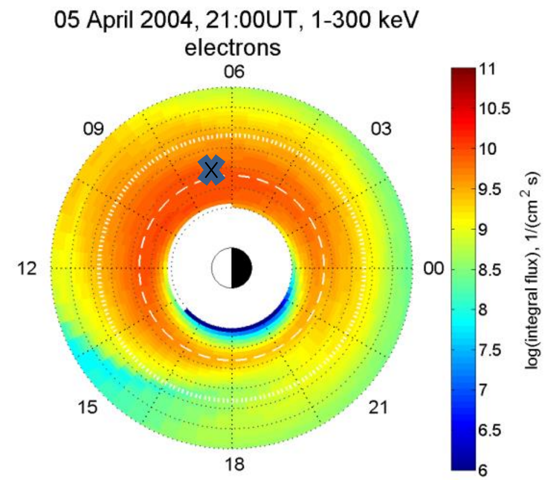
(1) particle distribution at initial time at the model boundary;
(2) magnetic and electric fields everywhere dependent on time;
(3) drift velocities;
(3) all sources and losses of particles.

Magnetic field model: TS05 (Dst, Psw, IMF By and Bz, and Wi, i = 1, 6)
Electric field model: Boyle (Vsw, IMF B, By, Bz)
Boundary conditions: n and T by *Dubyagin et al*. (2016) (Vsw, IMF Bz, Nsw)
Losses given as electron lifetimes: *Shprits and Orlova* (2014) and Orlova et al. (2016) electron lifetimes due to chorus and hiss WPI (**Kp, magnetospheric magnetic field)**

Severe Events for Surface Charging: April 5, 2004



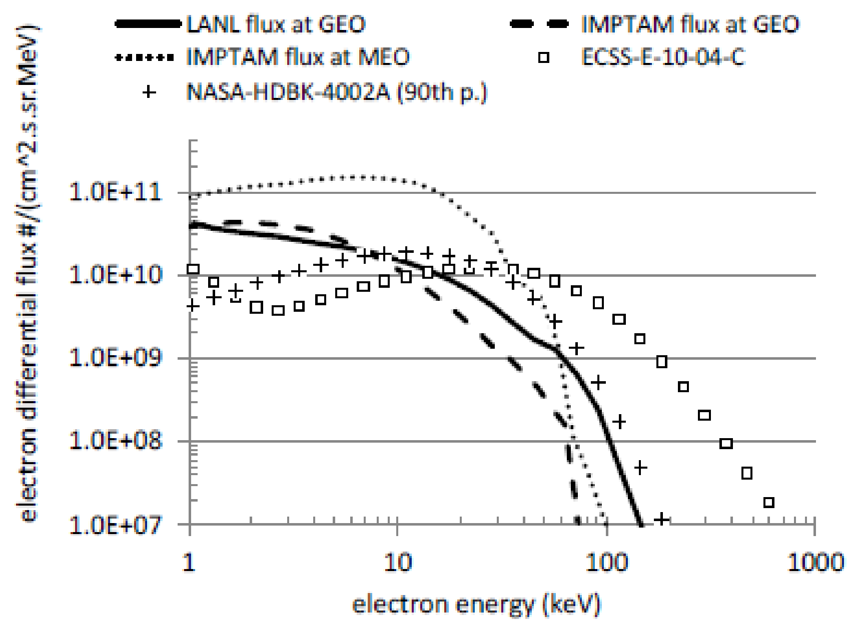




IMPTAM electron fluxes at LANL surface charging event at GEO

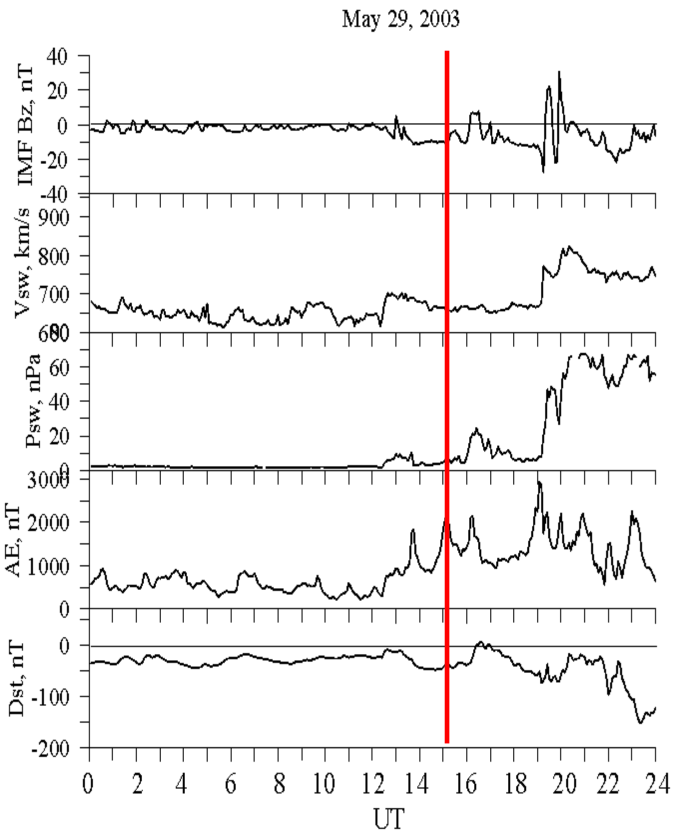
IMPTAM electron fluxes at maximum flux at MEO

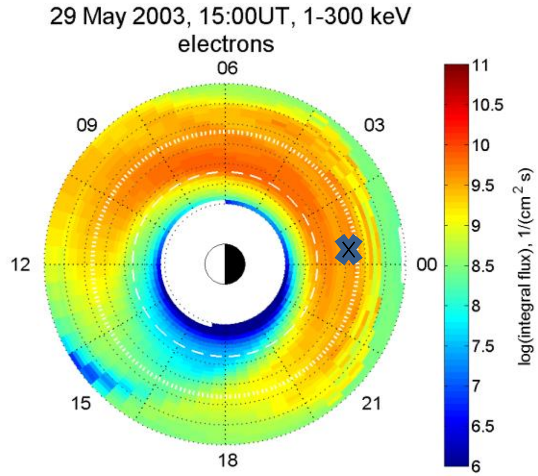
Top 100 15 minutes worst case of FE10k, at LANL-1994-084 at 192119 UT, at 5.1 MLT, **before the storm max** of a CME-driven storm.

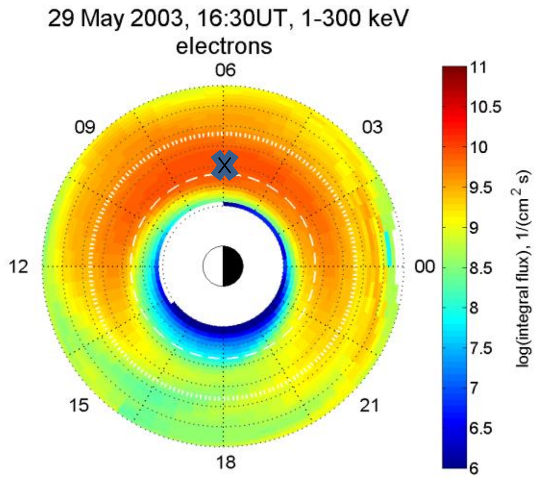


IMPTAM fluxes globally reproduce LANL
Max IMPTAM flux at MEO exceeds GEO flux and ECSS and NASA worst-cases by a **factor of 2 to 10**.

Severe Events for Surface Charging: May 29, 2003







IMPTAM electron fluxes at LANL surface charging event at GEO

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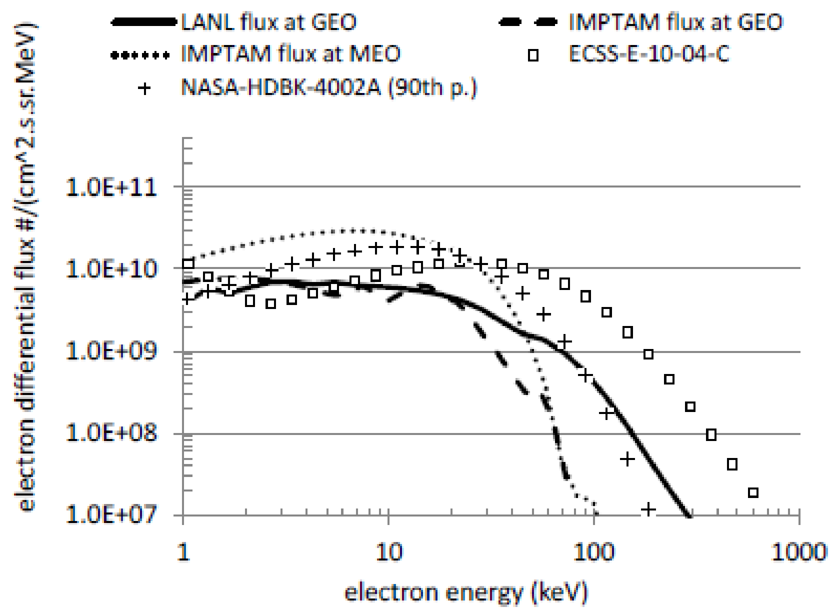
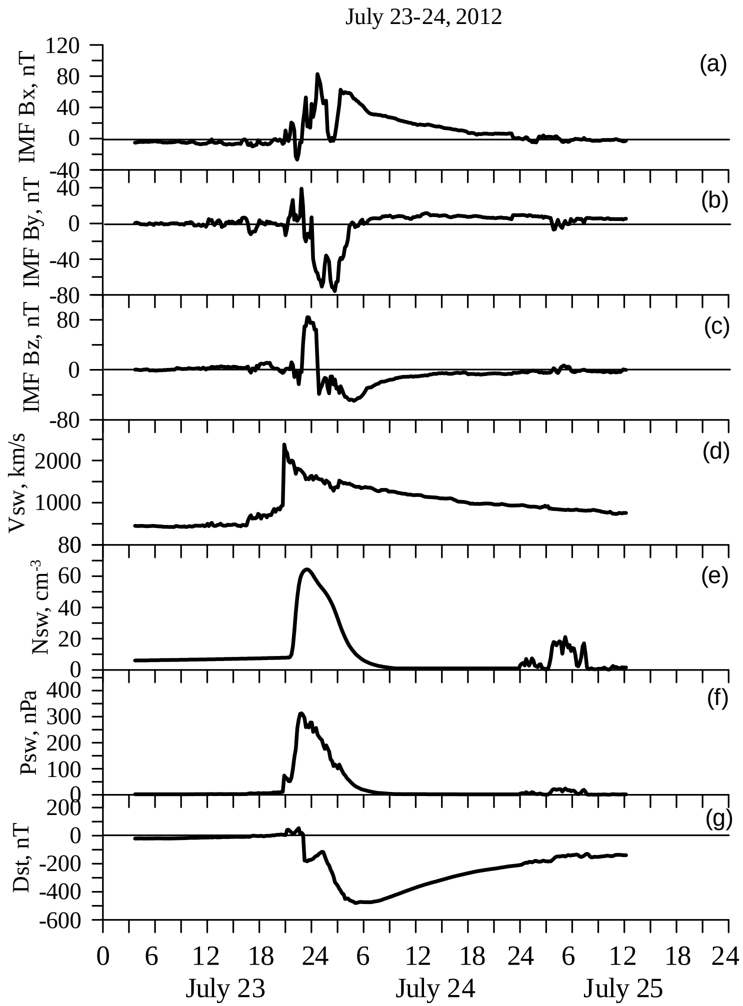


Top 100 15 minutes worst case of HFAE, at LANL-1994-084 at 150106 UT, 0.7 MLT; prolonged Dst<0, intense substorm, AE of 2000 nT.

IMPTAM fluxes globally reproduce LANL

Max IMPTAM electron flux at MEO exceeds GEO flux and ECSS and NASA worst-cases by a factor of 2 to 5.

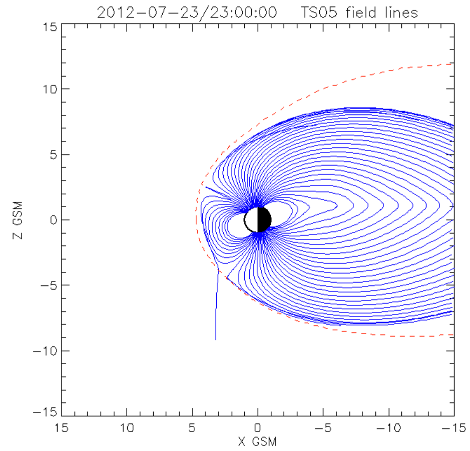
Large CME-driven storm, July 23-24, 2012 (event that missed the Earth)

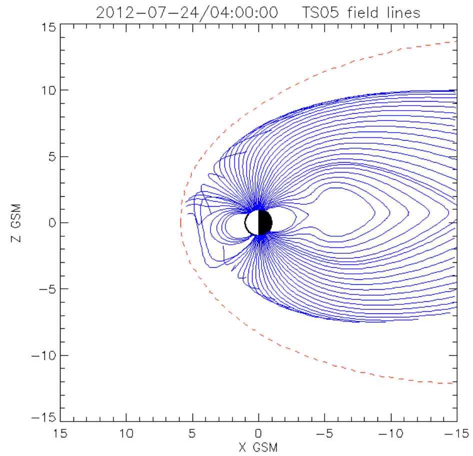


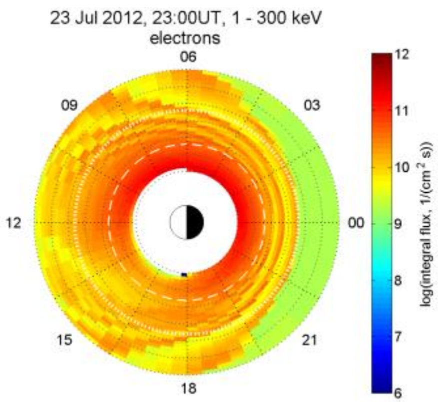
Dst = -500 nT, Psw=300 nPa, Vsw = 3000 km/s

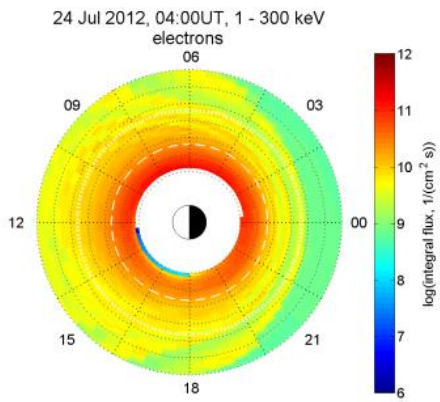
1st Dst drop

Dst min







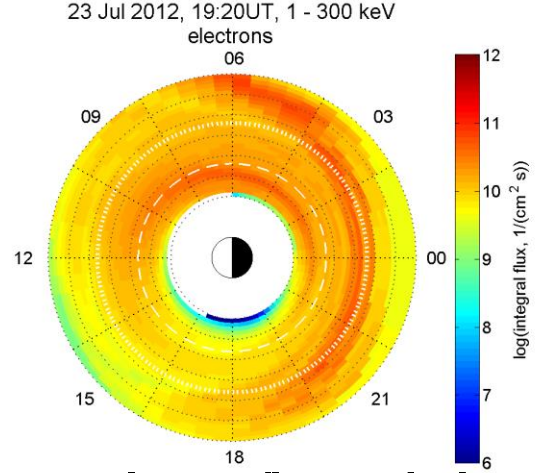


STEREO-A observations,
Wang-Sheerley-Arge, ENLIL model,
Temerin and Li (2006) Dst predictive model

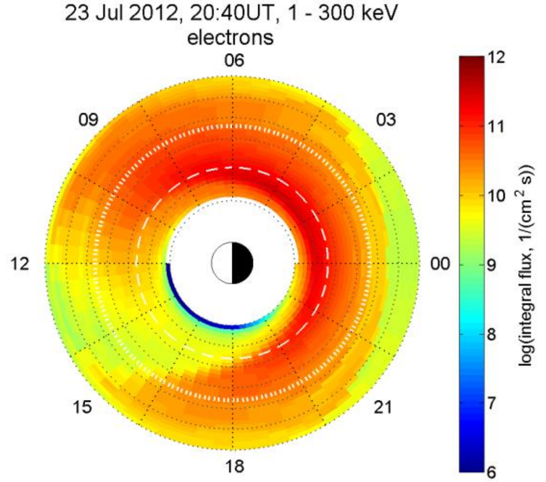
Magnetosphere becomes so compressed on the dayside and so stretched on the nightside that electrons are lost, they happen to be on larger L-shells.

Extreme Events for Surface Charging: July 23-24, 2012

In the beginning of the storm IMPTAM was able to output reasonable electron fluxes at closed magnetic field lines in the inner magnetosphere.



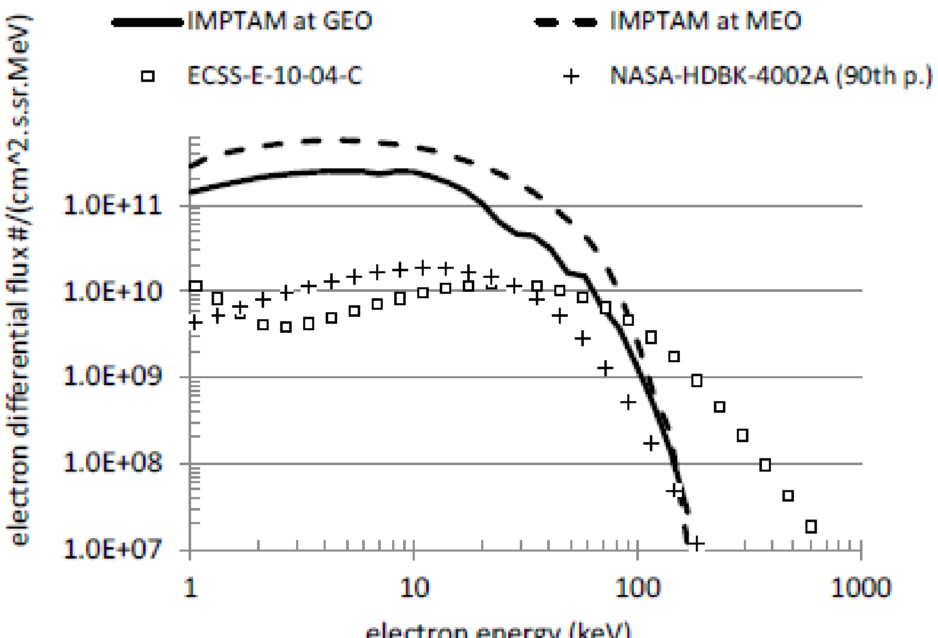
The maximum electron flux reached at GEO: July 23, 2012, at 1920 UT at MLT 2.4.



The maximum electron flux reached at MEO: July 23, 2012, at 2040 UT, 6.4 MLT.

Max IMPTAM electron flux at MEO is 6 times higher than that for the similar type of the event (beginning of the storm main phase on April 5, 2004).

The flux is also well above the ECSS and NASA worst-cases.



Summary

- ✓ Based on the analysis of LANL particle data at GEO, **four criteria for defining severe surface charging conditions** were developed based on integral fluxes and measured spacecraft potential and 400 events with worst-case environments were identified

- ✓ All types of the worst-case surface charging events were modeled using IMPTAM for electrons within 1-100 keV

- ✓ IMPTAM electron fluxes are comparable to the observed fluxes by LANL at GEO

- ✓ Max IMPTAM electron flux at MEO exceeds the GEO flux and the ECSS and NASA standards for worst-cases by a factor of 2 to 10.

- ✓ The event that missed the Earth on July 23-24, 2012 is the kind of space weather extreme conditions that could significantly overpass the ECSS and NASA standards. Caution is advised due to the difficulty of modeling of such events.