



FROM GEO/LEO ENVIRONMENT DATA TO THE NUMERICAL ESTIMATION OF SPACECRAFT SURFACE CHARGING AT MEO

6th of April 2016, SCTC, Noordwijk, The Netherlands

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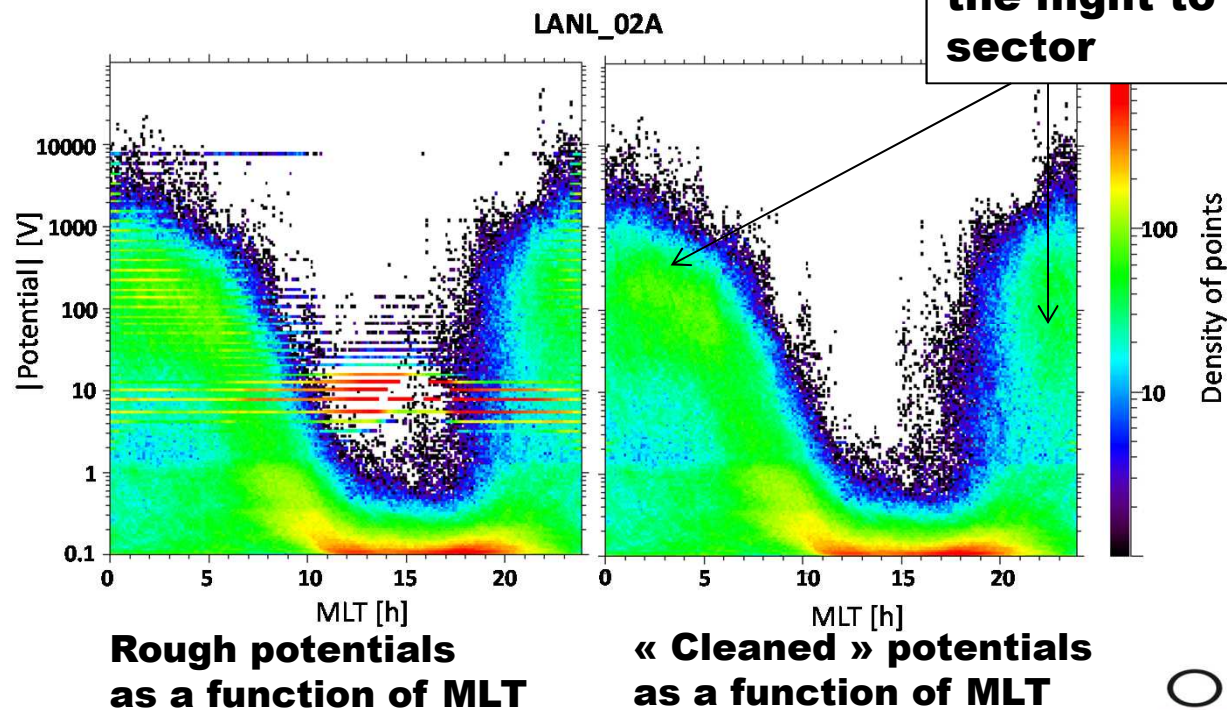


Introduction

- Space industry guidelines with specifications of **worst case environments** for surface charging at GEO and PEO based on events measured in orbit
- What about MEO ?
- Van Allen Probes (RBSP): see Sarno et al. [2016] negative charging at daylight of totally conductive spacecraft !
- Complementary approach:
 - Get measurements at GEO and LEO
 - Extract severe environments
 - Check whether we can rely on them
 - Try to predict MEO

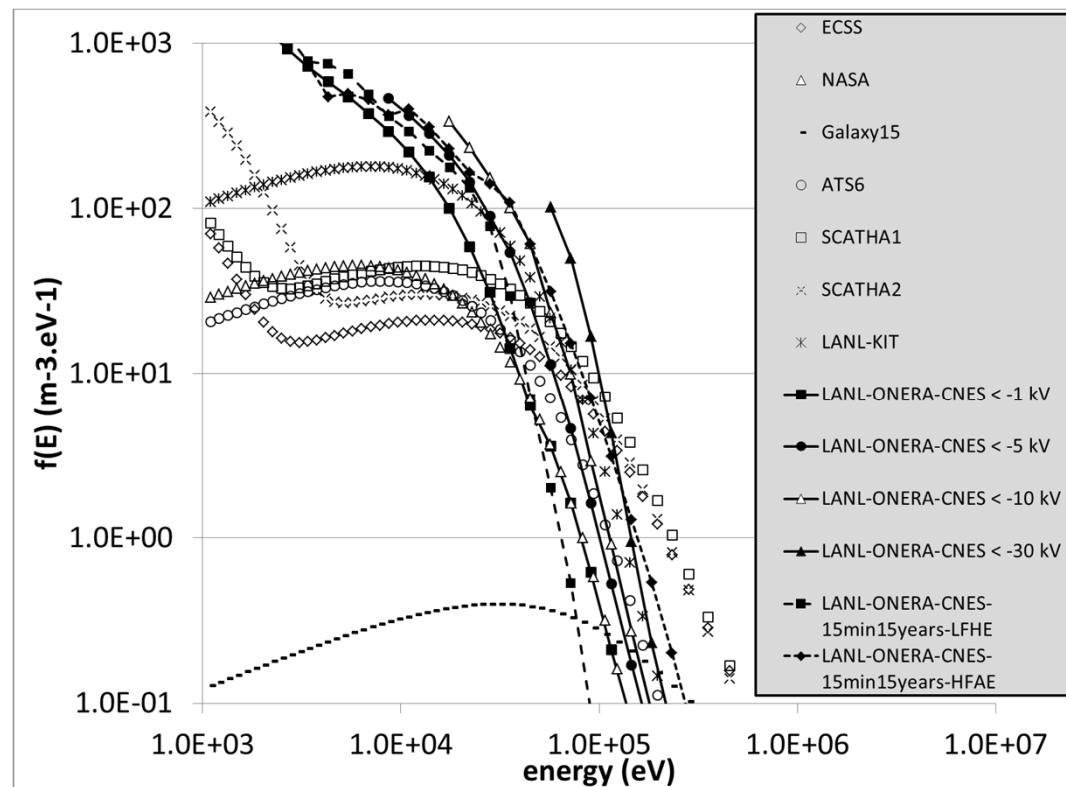
LANL spacecraft at GEO

- 7 GEO LANL satellites from 1994 to 2008
 - 1989-049, 1990-095, 1991-080, 1994-084, LANL-97A, LANL-01A, LANL-02A
 - Electron and proton detectors 1 keV to some MeV
 - Spacecraft potential routinely provided
- Remove all « easy to remove » data



Classify LANL data

- Sort the remaining events in « Top 100 » series
 - Top 100 longest durations with large negative potentials
 - Top 100 largest integrated fluxes 15 min
 - Top 100 largest fluxes at low energy 15 min
- Apply Liouville's theorem for part. distribution distortion by spacecraft ϕ_{SC}



Shall we rely only on fluxes and spacecraft potentials?

Seasonal effects

the same spacecraft under the same plasma conditions may charge very differently if at sunlight (positive to negative), in eclipse (very negative) or at eclipse exit

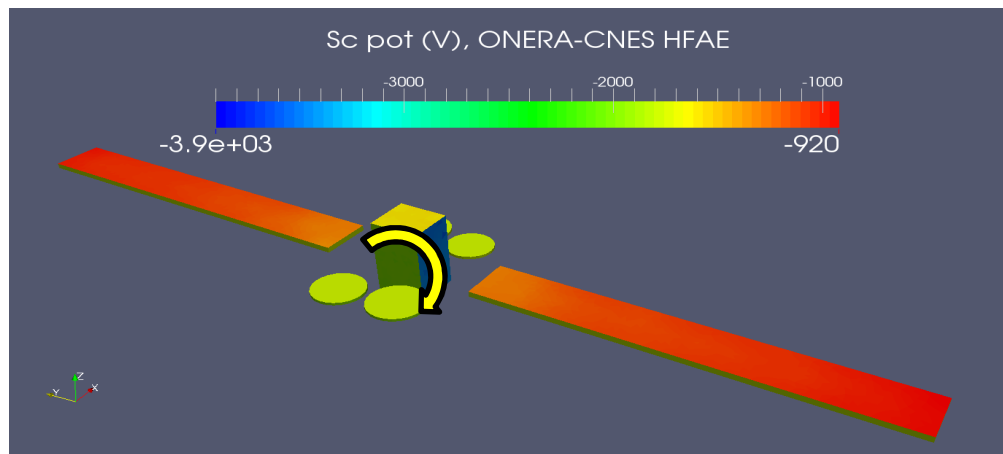
→ Thanks to photoemission

Spacecraft attitude

the same spacecraft under the same plasma conditions may charge very differently for different MLT locations

→ Thanks to photoemission

→ Because sunlit conductors area change with spacecraft orientation



No charging does not necessarily mean no hazardous environment

Not forgetting material properties (BOL, EOL)...

Can we rely on measurements ?

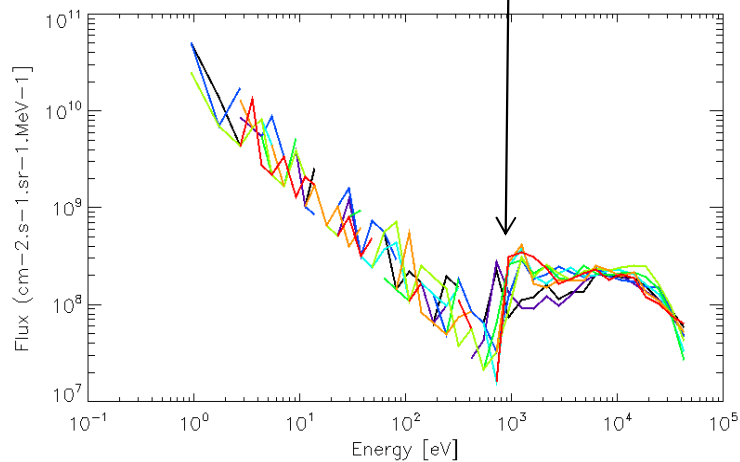
Instruments or algorithm errors

LANL acknowledged algorithms errors leading spacecraft potential uncertainties (sometimes very large)

→ Removing « easy to remove » data is not enough

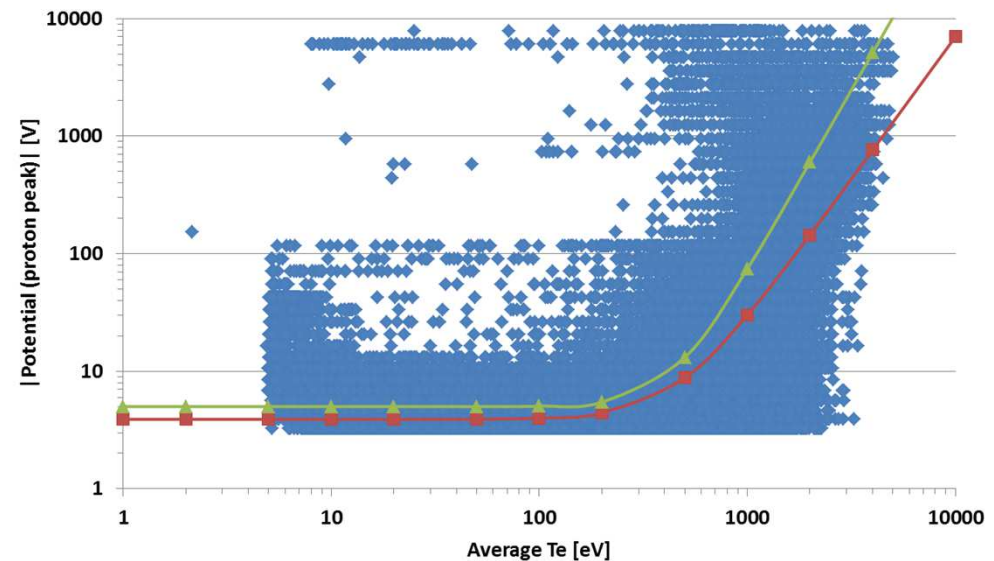
Cross-compare two methods to obtain the potentials

$\phi_{SC} = -$ ion « peak » energy

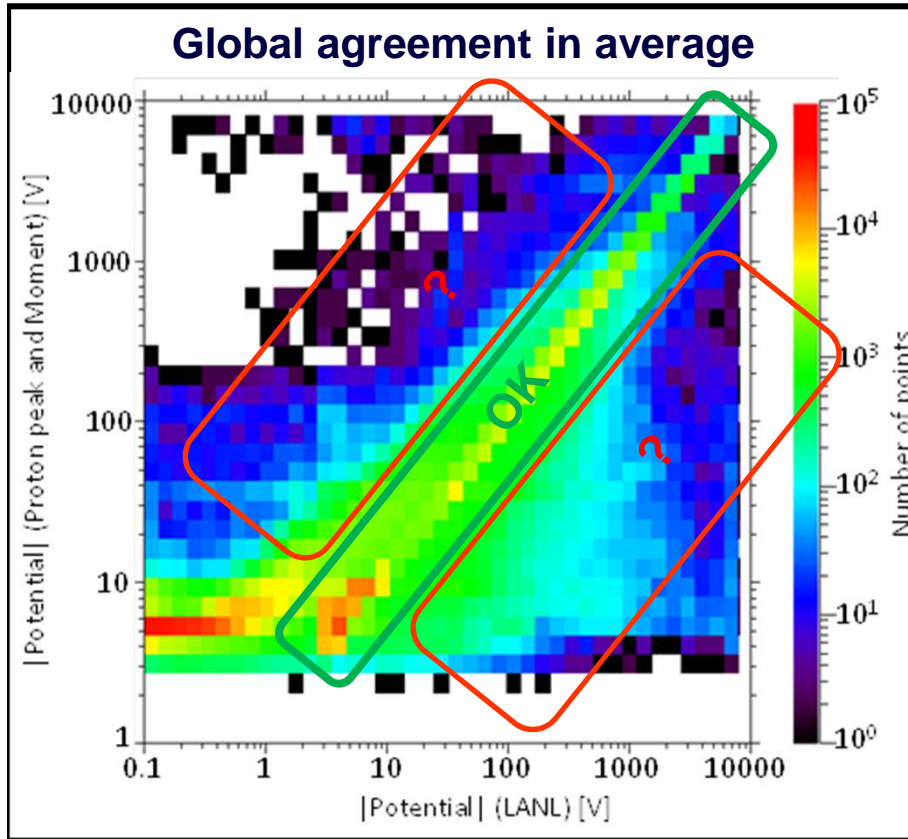


$$-\Phi_{sc} = A + B \times (T_{e,ave}/T_0)^D$$

$$T_{e,ave} = [(n_{lp} \times 5.0eV) + (n_{he} \times T_{he})] / (n_{lp} + n_{he})$$



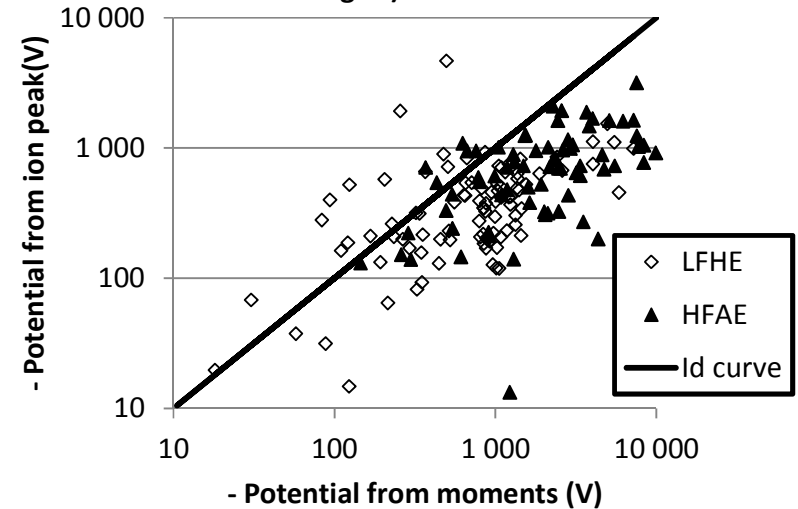
Can we rely on measurements ?



Top 200 largest flux events

→ Algorithm often overestimates ϕ_{SC} by factor of 2 to 4

Top 100 15minutes worst cases with the HF AE (High flux all energies) and LF AE (Low flux at high energies) criteria

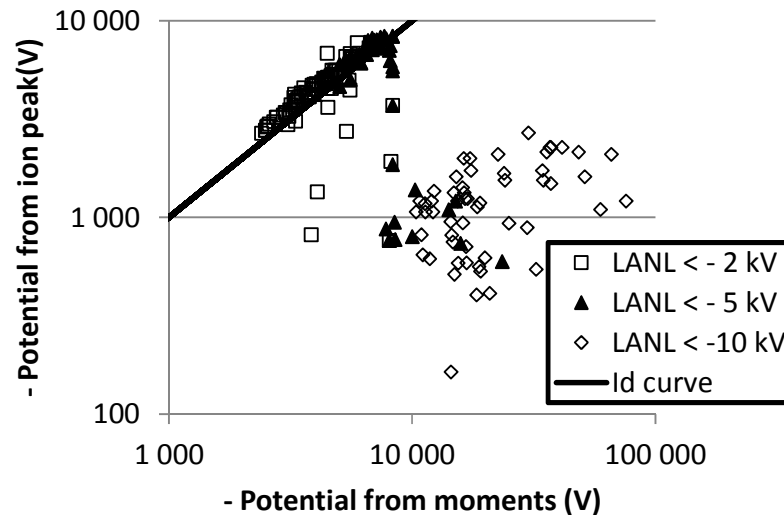


Can we rely on measurements ?

Top 100 largest potentials from the algorithm

Range of validity [-8 kV; 0 Volts]

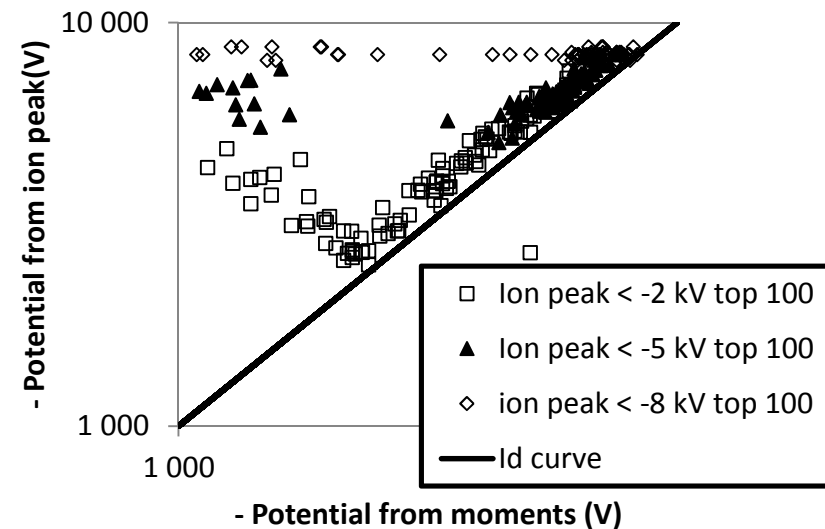
Top 100 longest series of potentials < -2000V, < -5000 and < -10000 V from moments



Top 100 largest potentials from the ion peak

→ Algorithm still miss some events...

Top 100 longest series of potentials < -2000V, < -5000 and < -8000 V from ion peak



For strong charging events, the ion peak method is to be preferred

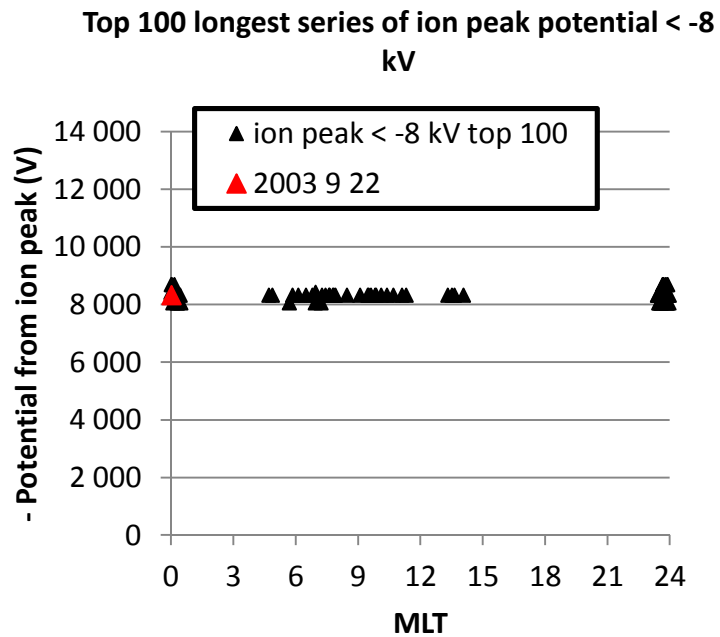
Inspection of ion peak potentials

Top 100 potentials < -8 kV

Longest events with $\phi_{SC} < -8\text{kV}$

ϕ_{SC} concentrated around -8kV \rightarrow Instrument saturation close to -8 kV ?!
Too much uncertainty again

UNCERTAIN



Inspection of ion peak potentials

Top 100 potentials < -5 kV



Longest events with $\phi_{SC} < -5\text{kV}$

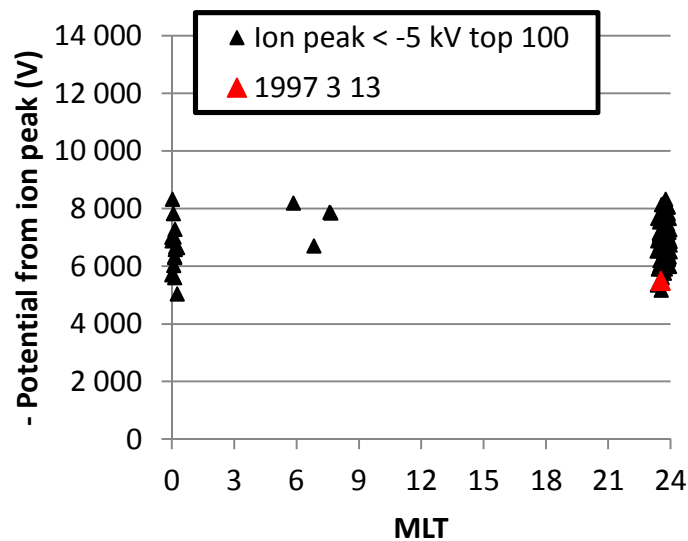
ϕ_{SC} nicely spread between -5 kV and -8kV

97% events centered around midnight

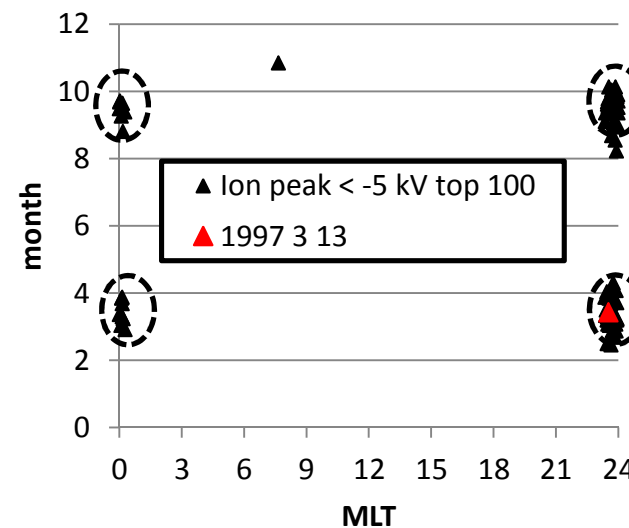
Longest durations all occur in eclipse

This less restrictive criterion is more appropriate for long duration with high potentials

Top 100 longest series of ion peak potential < -5 kV



Top 100 longest series of ion peak potential < -5 kV



Inspection of High Flux at All Energy Top 100 HFAE

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Top 100 HFAE

ϕ_{SC} spread between 0 and – 3500 V

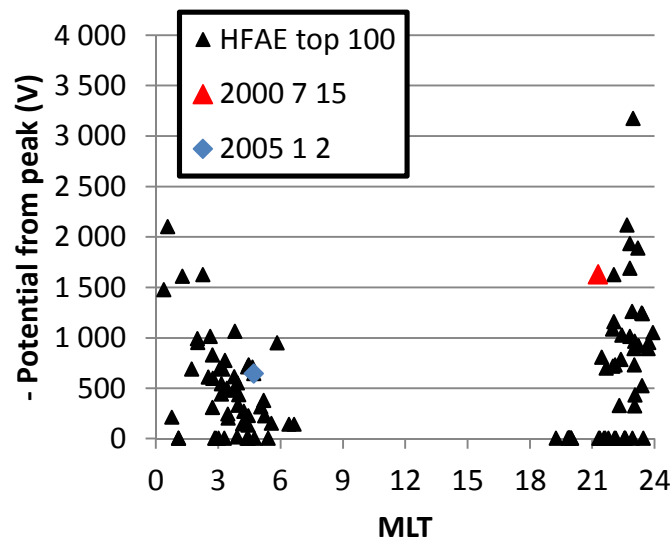
Between night and dawn as expected

No seasonal correlation as expected

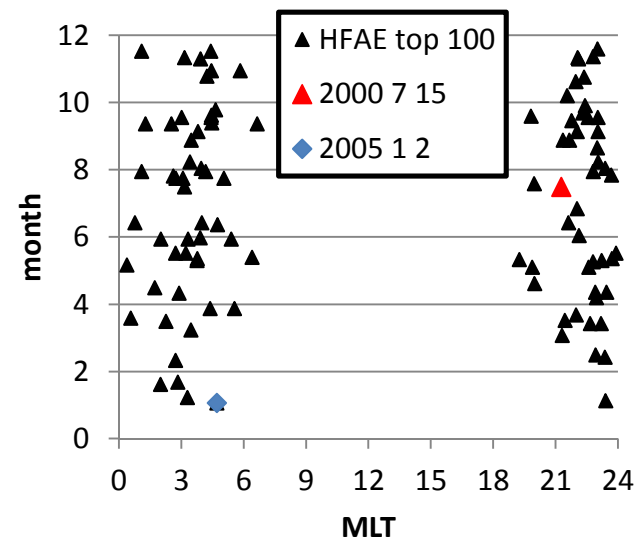
#1 on LANL_1994_084 on 2005/07/15 at 14h40min39s at MLT 21 18 [Bastille's day]

#2 on LANL_1994_084 on 2005/01/02 at 15h46min12s at MLT 04 47

Top 100 15minutes worst cases with the HFAE
(High flux all energies) criterion



Top 100 15minutes worst cases with the HFAE
(High flux all energies) criterion



Focus on one specific day ... at LEO

HFAE #2

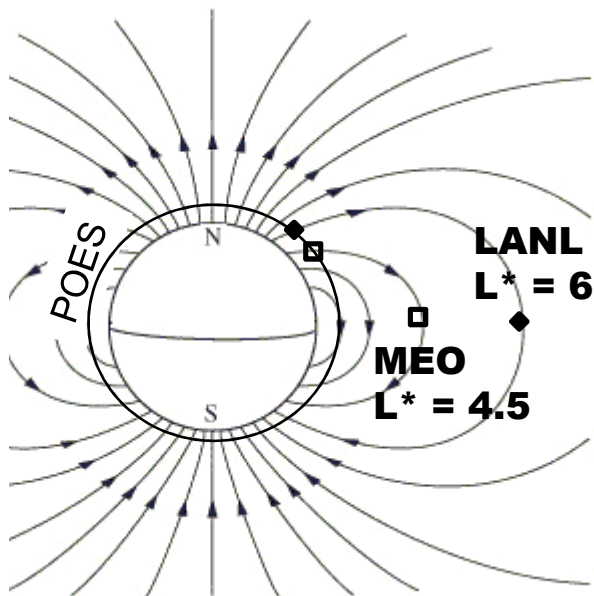
POES data during "LANL_1994_084 on 2005/01/02 at 15h46min12s at MLT 04 47"

Maximal 2s electron flux $E > 30$ keV each 3 hours

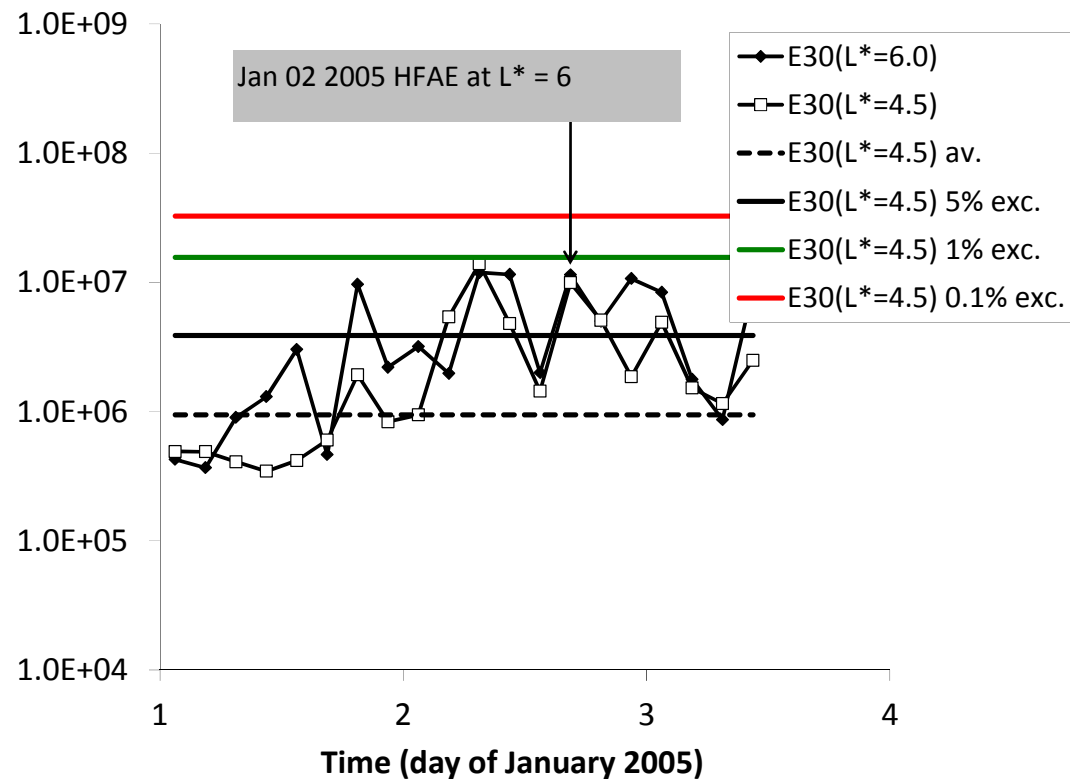
Fluxes at $L^* = 6.0$ exceed the 5% exceedence level \rightarrow correlation with high fluxes at GEO

Fluxes at $L^* = 4.5$ very close to the 1% exceedence level \rightarrow high fluxes at MEO too !

Fluxes at $L^* = 4.5$ of same order as Fluxes at $L^* = 6.0$ \rightarrow same charging risks ...



$E > 30$ keV flux [$\text{cm}^{-2}\cdot\text{s}^{-1}\cdot\text{sr}^{-1}$]



Can we predict severe environments at MEO ?

IMPTAM simulations : 1 full day in rad belt

Simulation of “LANL_1994_084 on 2005/01/02 at 15h46min12s at MLT 04 47”

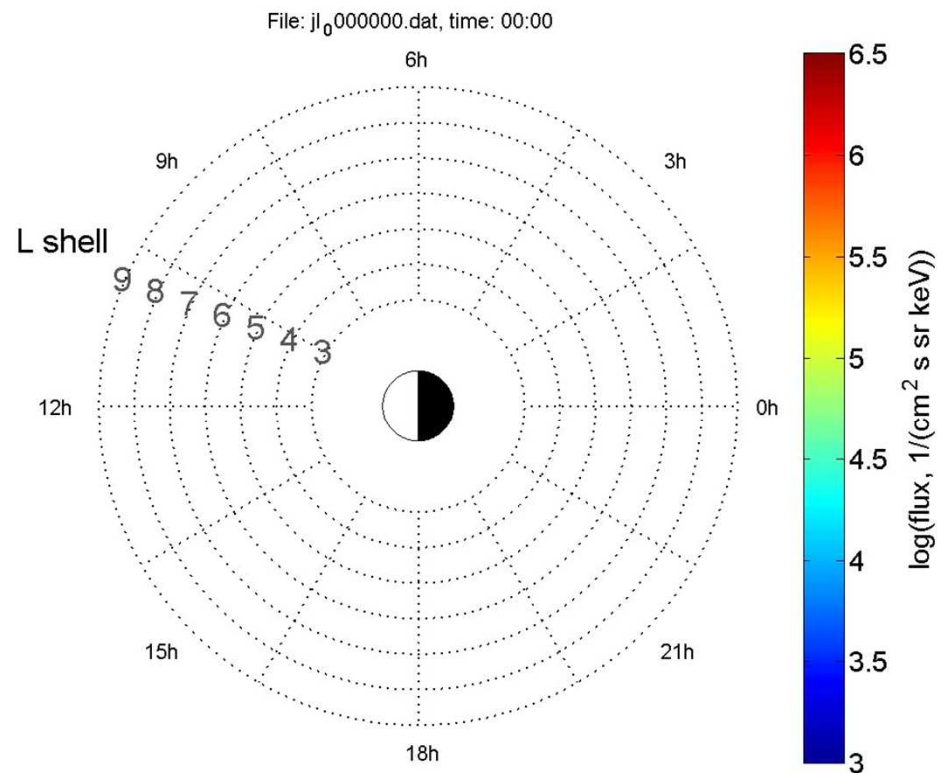
IMPTAM = Inner Magnetosphere Particle Transport and Acceleration model

Evolution of [1-100 keV] electron fluxes in the equatorial plane during the modeled period.

We start our modeling with IMPTAM with empty magnetosphere.

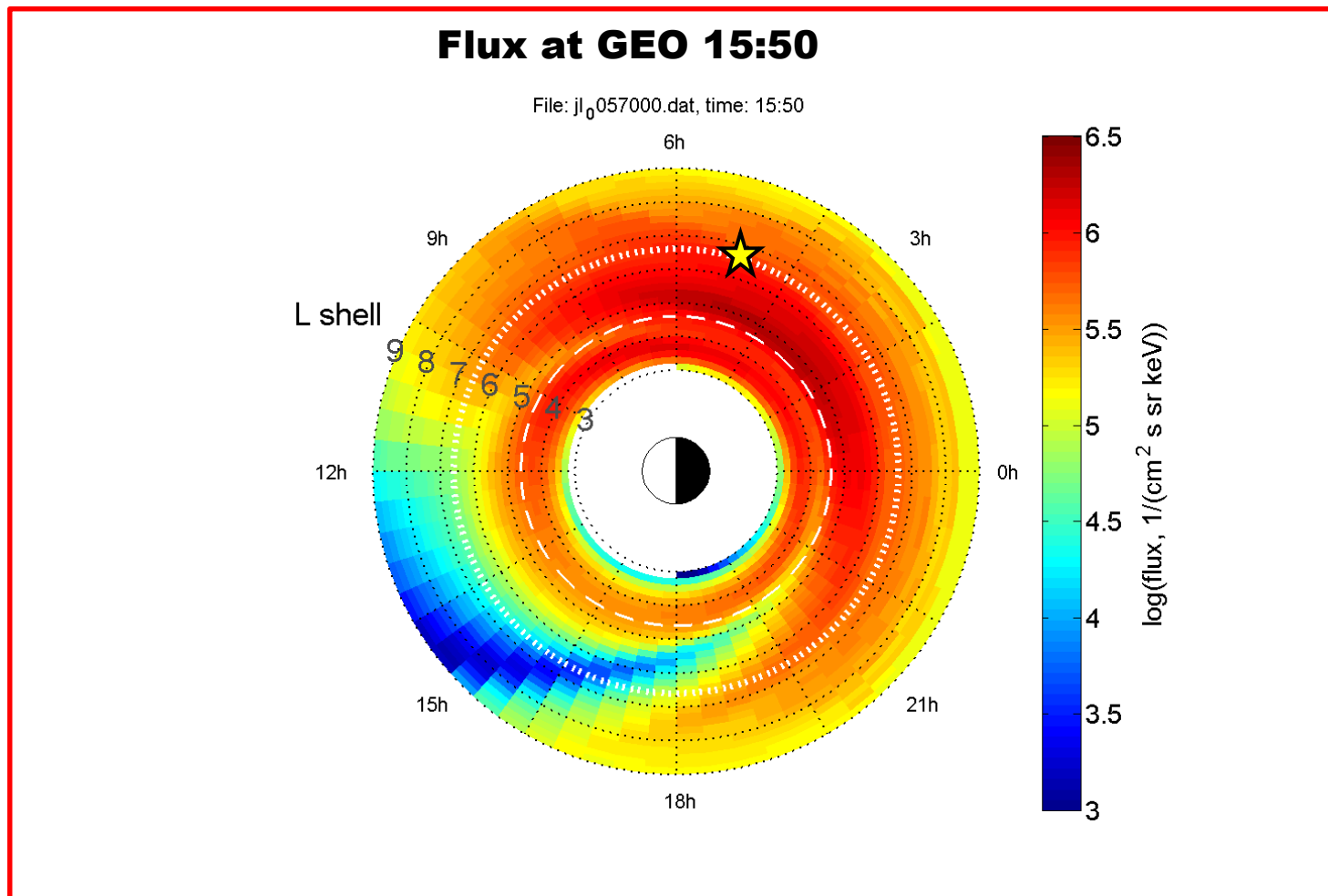
Electrons move from the plasma sheet to the inner regions.

Solar wind and IMF



Can we predict severe environments at MEO ? IMPTAM at GEO

IMPTAM simulation of “LANL_1994_084 on 2005/01/02 at 15h46min12s at MLT 04 47”



Can we predict severe environments at MEO ?

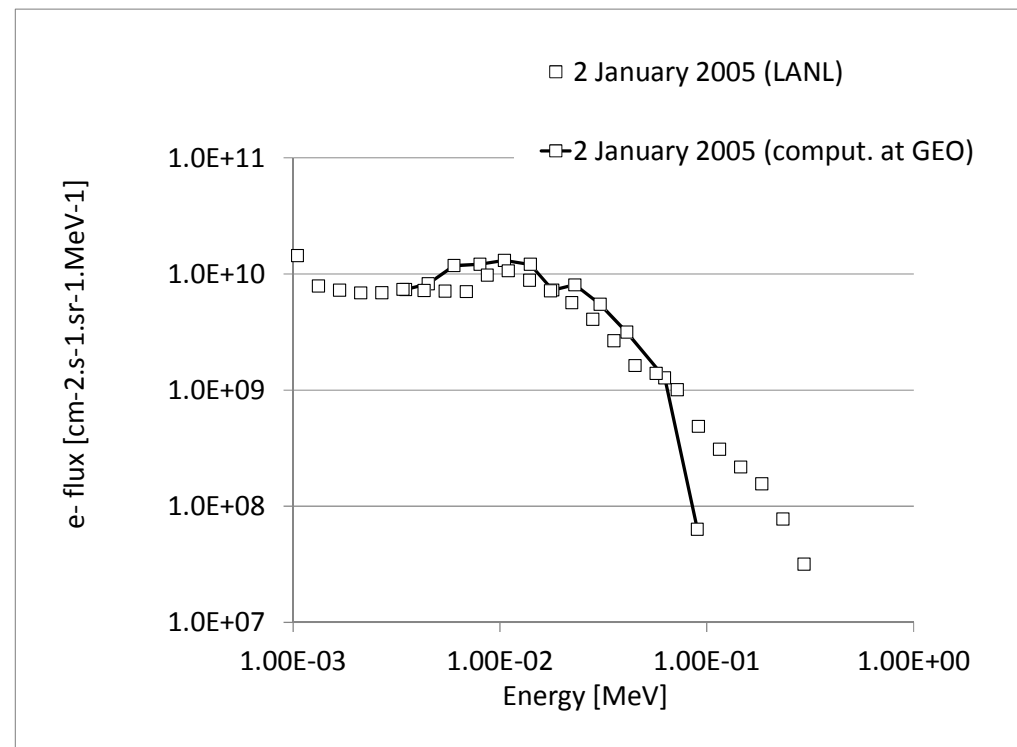
IMPTAM at GEO

IMPTAM simulation of “LANL_1994_084 on 2005/01/02 at 15h46min12s at MLT 04 47”

Flux compared at GEO LANL 15:46:12 at MLT = 4.47

Matches LANL E < 90 keV

IMPTAM limited to 100 keV

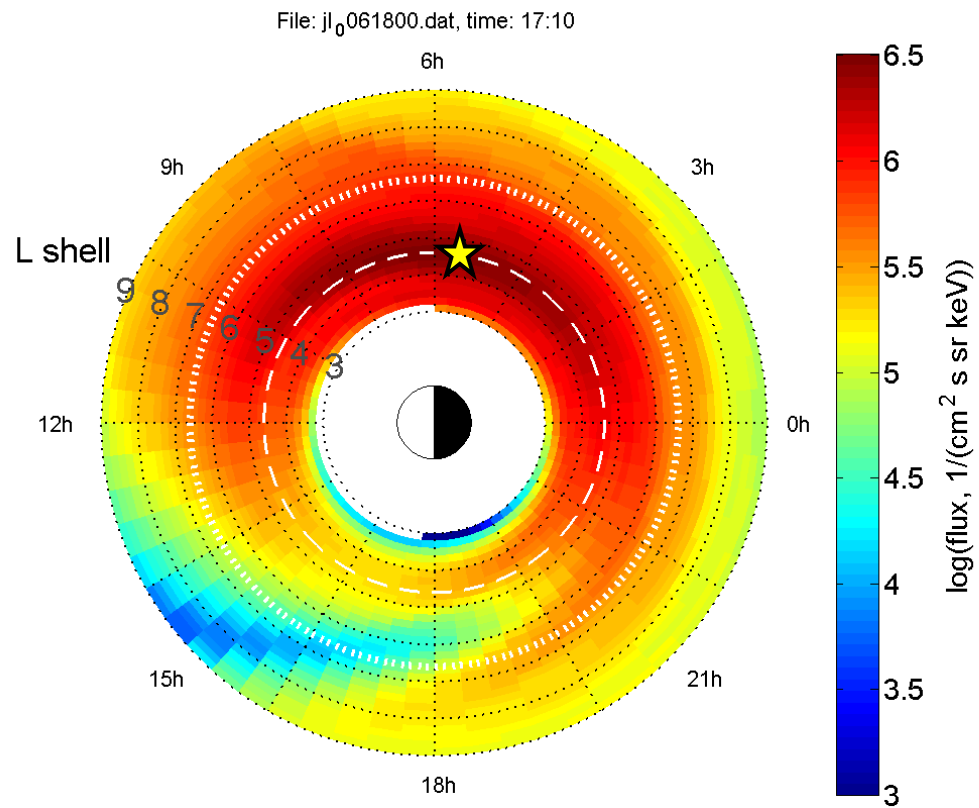


Can we predict severe environments at MEO ?

IMPTAM maximal flux at MEO

IMPTAM simulation of “LANL_1994_084 on 2005/01/02 at 15h46min12s at MLT 04 47”

Max flux at MEO 17:10 at MLT = 5.6



Can we predict severe environments at MEO ?

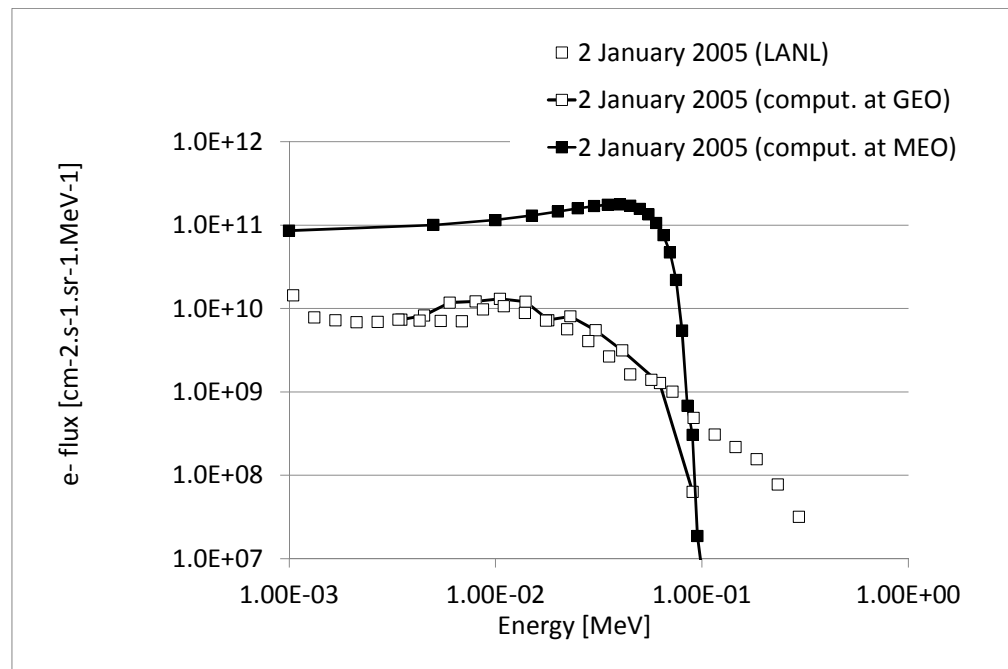
IMPTAM maximal flux at MEO

IMPTAM simulation of “LANL_1994_084 on 2005/01/02 at 15h46min12s at MLT 04 47”

Max flux at MEO 17:10 at MLT = 5.6

10 to 50 times larger than at GEO !

Correlates POES observations: $\text{flux_MEO} \geq \text{flux_GEO}$



Summary

- LANL data have been fully reprocessed
- Top 100 worst environments examined with care concerning the potential
- POES data and IMPTAM program both suggest that low-energy electron fluxes at MEO are at least of the same order of magnitude as at GEO during particle injections
 - at least use the same design margins and mitigation techniques to avoid secondary arcing

Perspectives

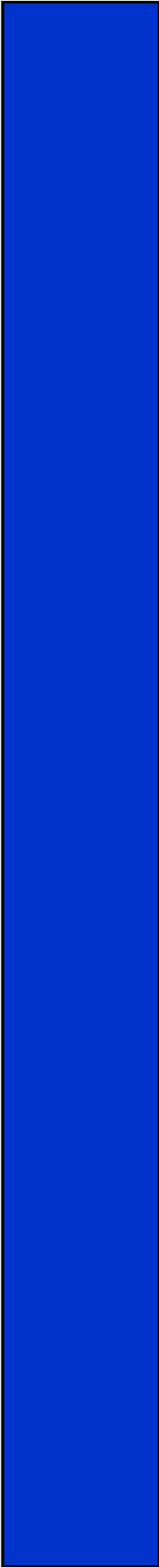
- Model other LANL events with IMPTAM and cross compare with POES
- Examine also $E > 100$ keV and $E > 300$ keV fluxes
- Cross-compare with GTO/MEO data: RBSP

- Guideline, standards
 - SCATHA-Mullen-1 good candidate for WC at GEO
 - Needs more investigations ?
 - Include MEO

- Need for combined plasma sensors and ESD monitors in-flight because ESD also depends on material properties, spacecraft geometry, attitude, season...

Acknowledgments

- Part of this work was funded by the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement no 606716 (Spacestorm)
- Part of this work was funded by CNES R&D
- Thanks to R. Friedel, G. Reeves, M. Thomsen, M. Henderson from Los Alamos National Laboratory for sharing data



Inspection of Large Fluxes but not at High Energy Top 100 LFHE

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Top 100 LFHE

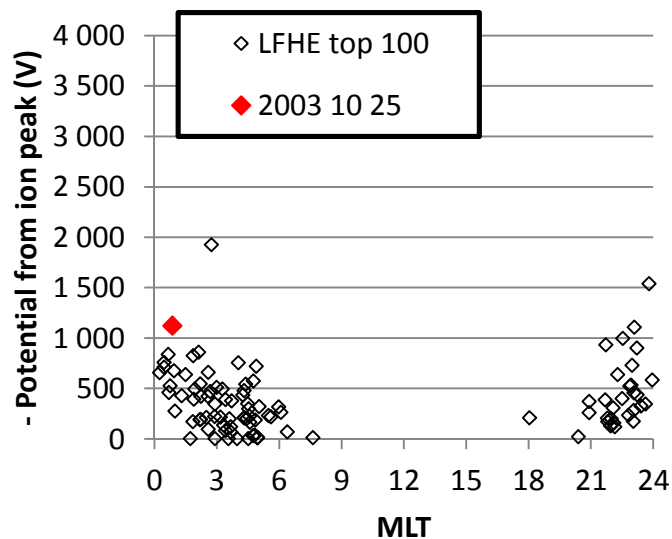
ϕ_{SC} spread nicely between 0 and -1500 V

Between night and dawn as expected

No seasonal correlation as expected

#1 on LANL_1994_084 on 2003/10/25 at 14h54min09s at MLT = 00 54 [Halloween event]

Top 100 15minutes worst cases with the LFHE
(Low flux at high energies) criterion



Top 100 15minutes worst cases with the LFHE
(Low flux at high energies) criterion

