From GEO/LEO environment data to the numerical estimation of spacecraft surface charging at MEO

J.C. Mateo-Velez (1), A. Sicard-Piet (1), V. Maget (1), N. Ganushkina (2) , I. Sillanpaa (2), S. Dubyagin (2), N. P. Meredith (3), D. Payan (4)

(1) ONERA, France

(2) FMI, Finland

(3) BAS, UK

(4) CNES, France

The research leading to these results funded in part by the European Union Seventh Framework Programme (FP7) under grant agreement No 606716 SPACESTORM

Spacecraft Charging and Technology Conference, Noordwijk, The NL, 4-8 April 2016

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 !

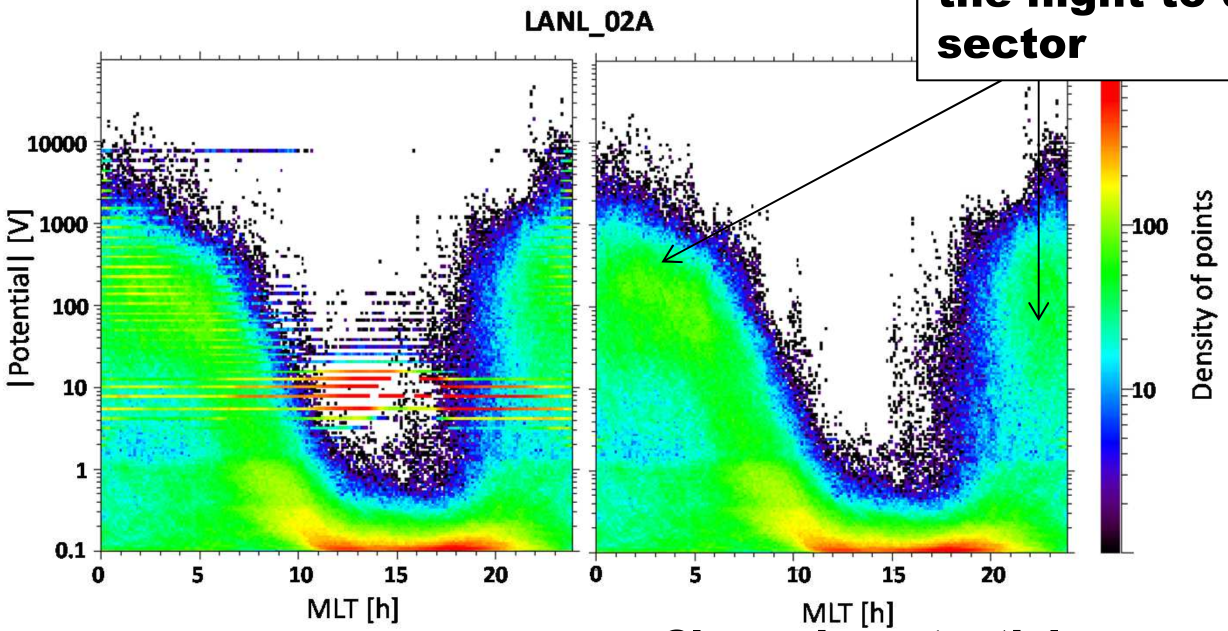
- <u>Complementary approach</u>: Get measurements at GEO and LEO
  Extract severe environments
  Check whether we can rely on them
  Try to predict MEO

ONERA
THE FRENCH AEROSPACE LAB

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

Negative charging in the night to dawn sector

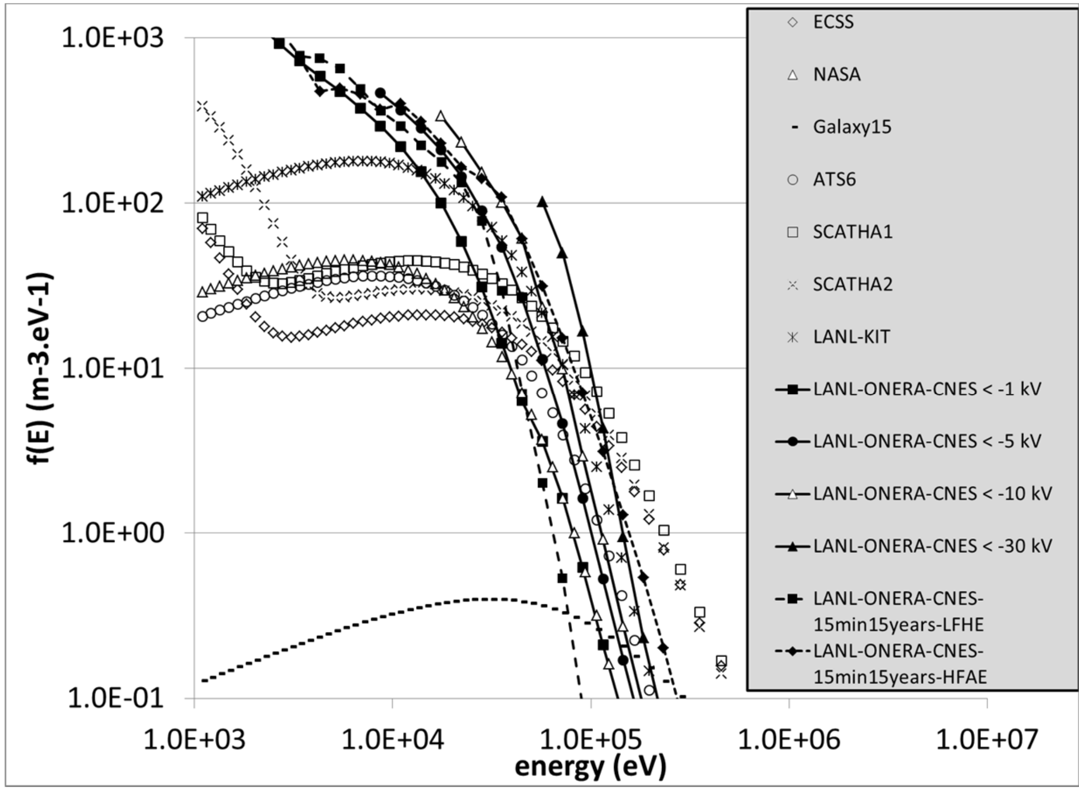


Rough potentials as a function of MLT

« Cleaned » potentials as a function of MLT

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}



ONERA
THE FRENCH AEROSPACE LAB

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

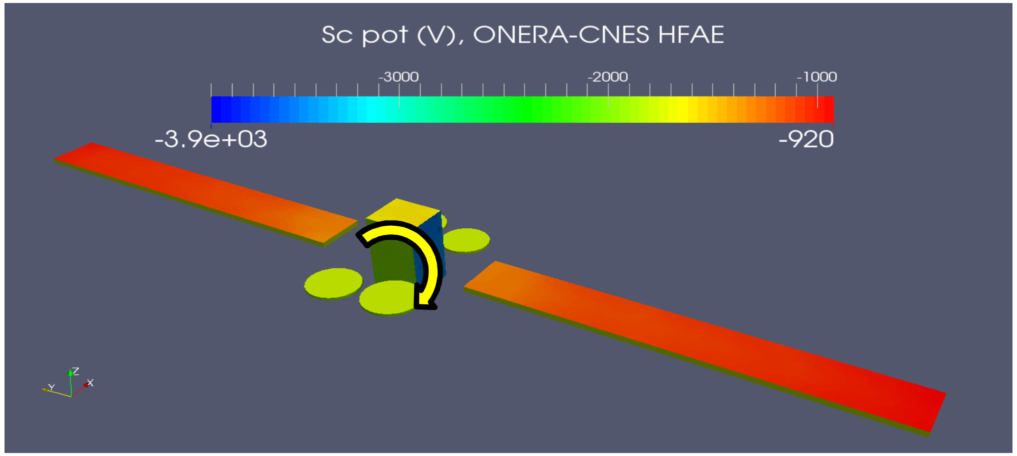
→ **Thanks to photoemission**

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 ?

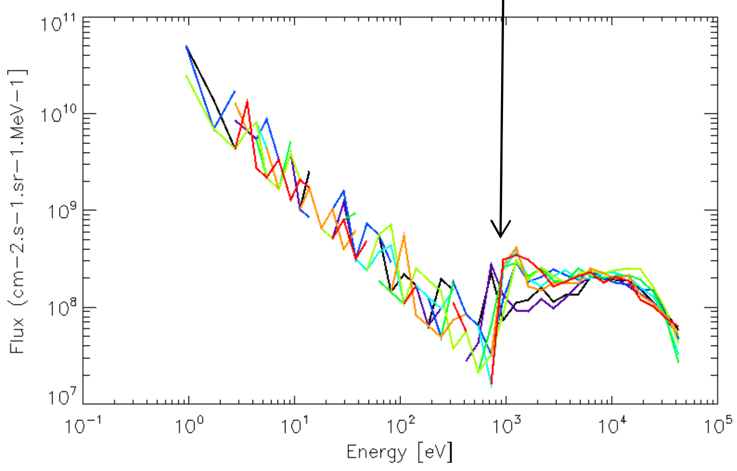
Instruments or algorithm errors

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

→ **Removing « easy to remove » data is not enough**

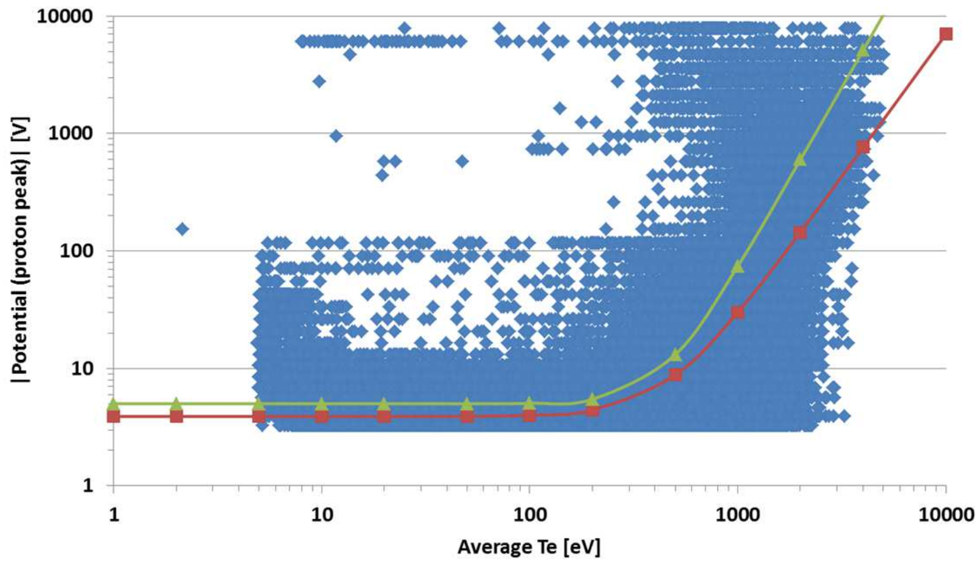
Cross-compare two methods to obtain the potentials

ϕ_{SC} = - ion « peak » energy



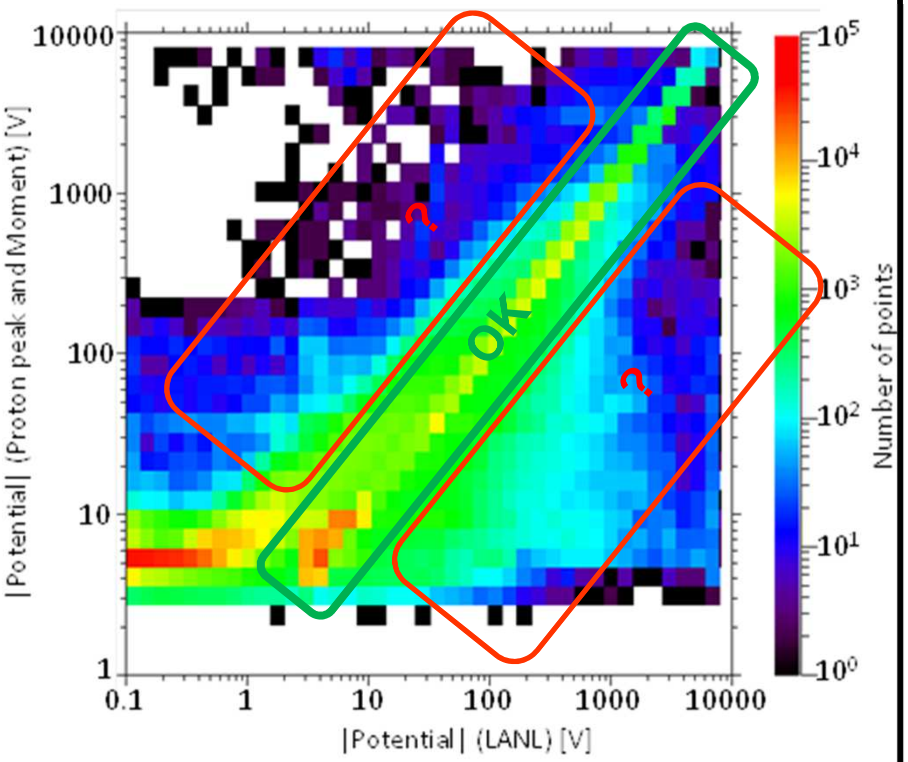
$$-\Phi_{sc} = A + B \times \left(T_{e,ave}/T_0\right)^D$$

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



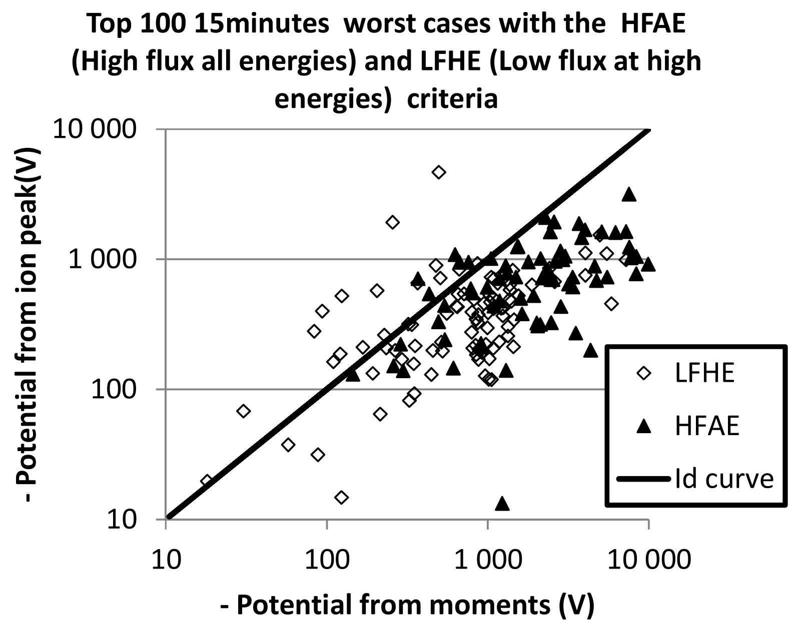
Can we rely on measurements ?

Global agreement in average



Top 200 largest flux events

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

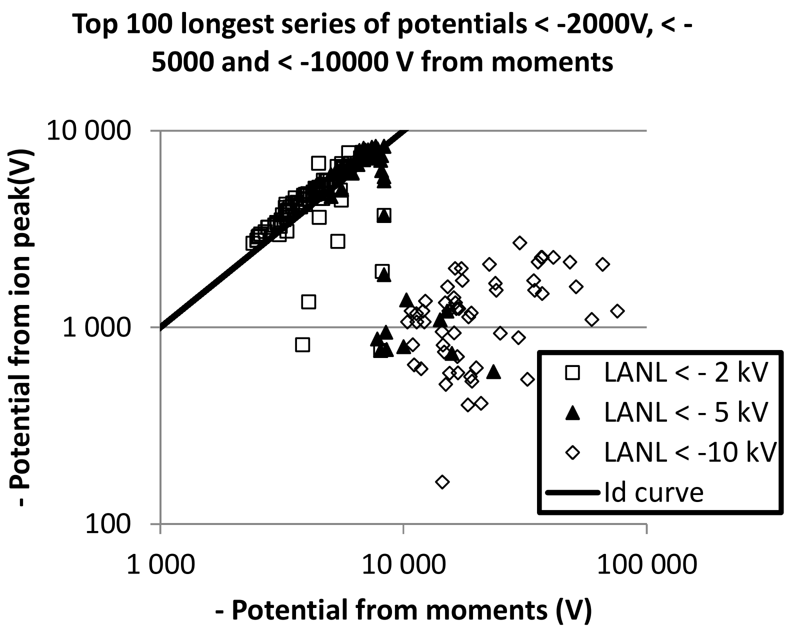


ONERA
THE FRENCH AEROSPACE LAB

Can we rely on measurements ?

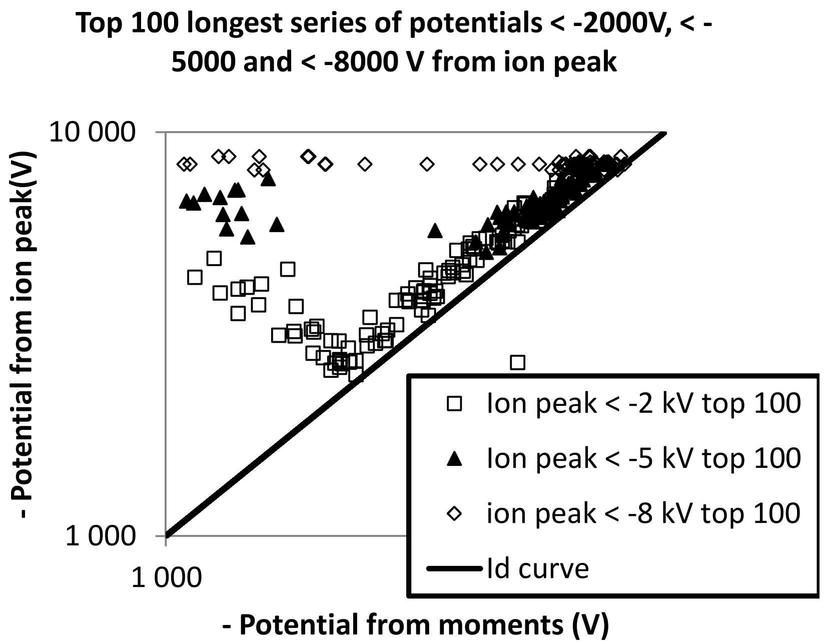
Top 100 largest potentials from the algorithm

Range of validity [-8 kV; 0 Volts]



Top 100 largest potentials from the ion peak

→ Algorithm still miss some events…



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

ONERA
THE FRENCH AEROSPACE LAB

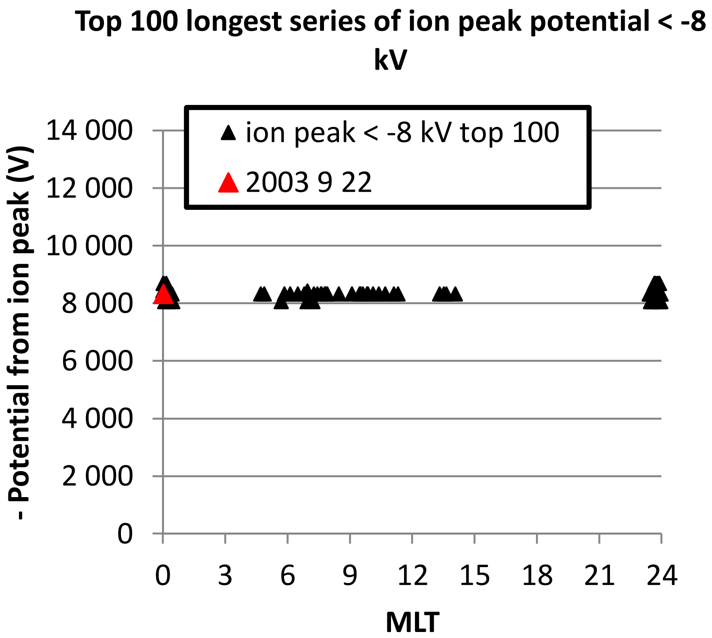
Inspection of ion peak potentials
Top 100 potentials < -8 kV

Longest events with ϕ_{SC} < -8kV

UNCERTAIN

ϕ_{SC} concentrated around -8kV → Instrument saturation close to -8 kV ?!

Too much uncertainty again



Inspection of ion peak potentials
Top 100 potentials < -5 kV

CLEAN

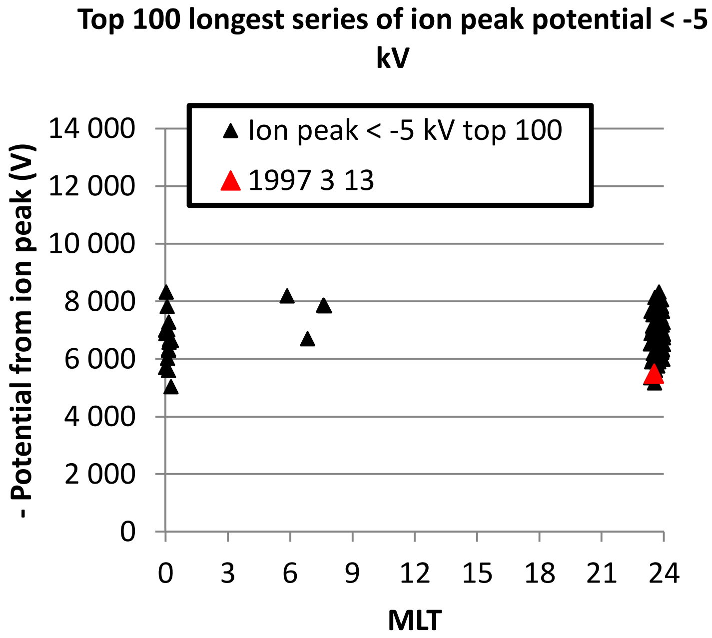
Longest events with ϕ_{SC} < -5kV

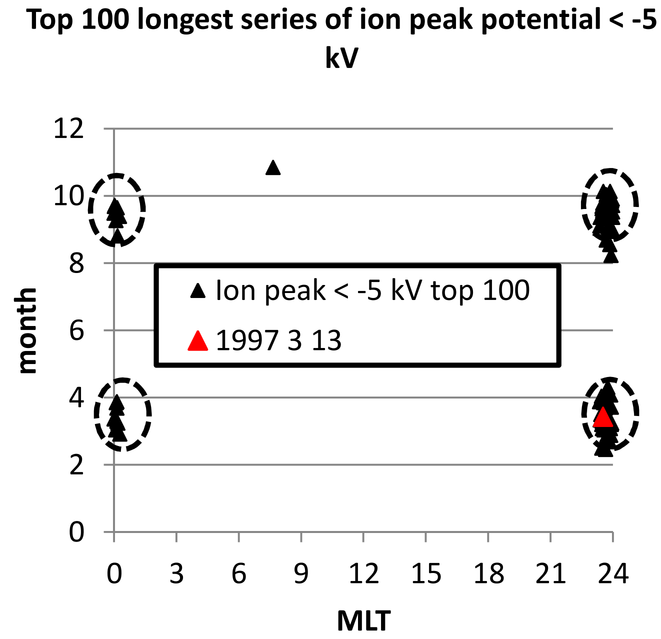
ϕ_{SC} nicely spread between -5 kV and -8kV

97% events centered around midnight

Longest durations all occur in eclipse

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





Inspection of High Flux at All Energy
Top 100 HFAE

CLEAN

Top 100 HFAE

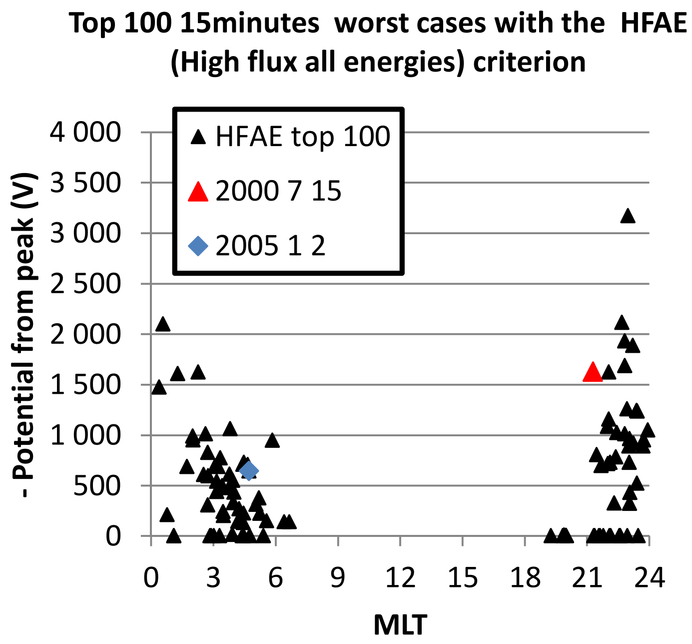
ϕ_{SC} spread between 0 and – 3500 V

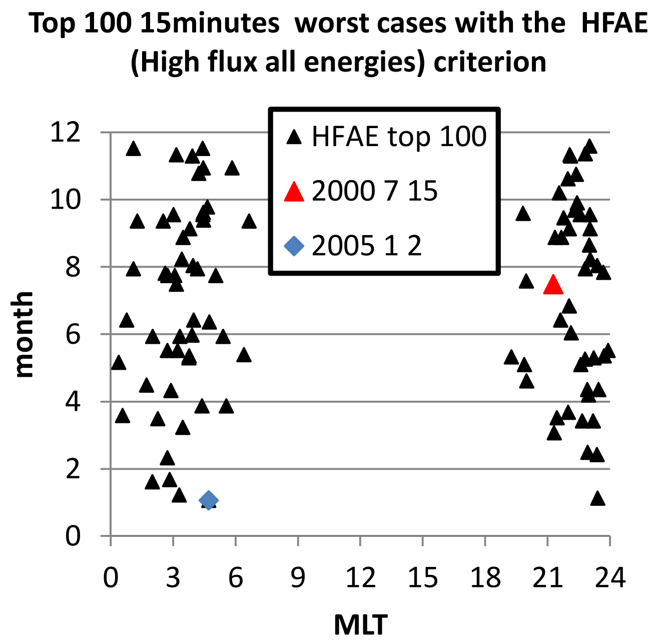
Between night and dawn as expected

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





Focus on one specific day … at LEO
HFAE #2

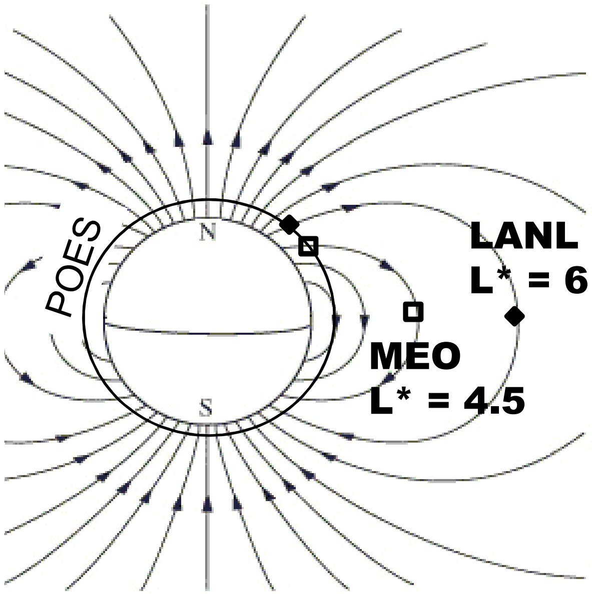
POES data during "LANL_1994_084 on 2005/01/02 at 15h46min12s at MLT 04 47"

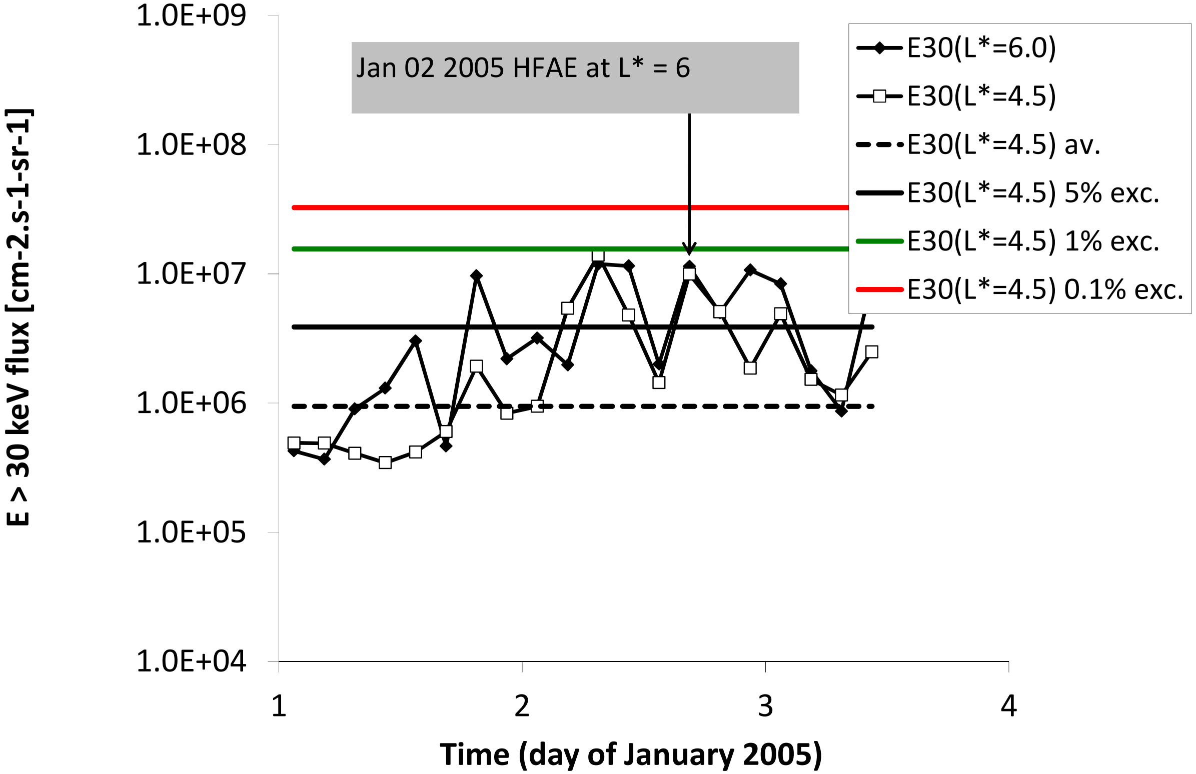
Maximal 2s electron flux E>30 keV each 3 hours

Fluxes at L*= 6.0 exceed the 5% excedence level → correlation with high fluxes at GEO

Fluxes at L*= 4.5 very close to the 1% excedence level → high fluxes at MEO too !

Fluxes at L* = 4.5 of same order as Fluxes at L* = 6.0 → same charging risks …





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”

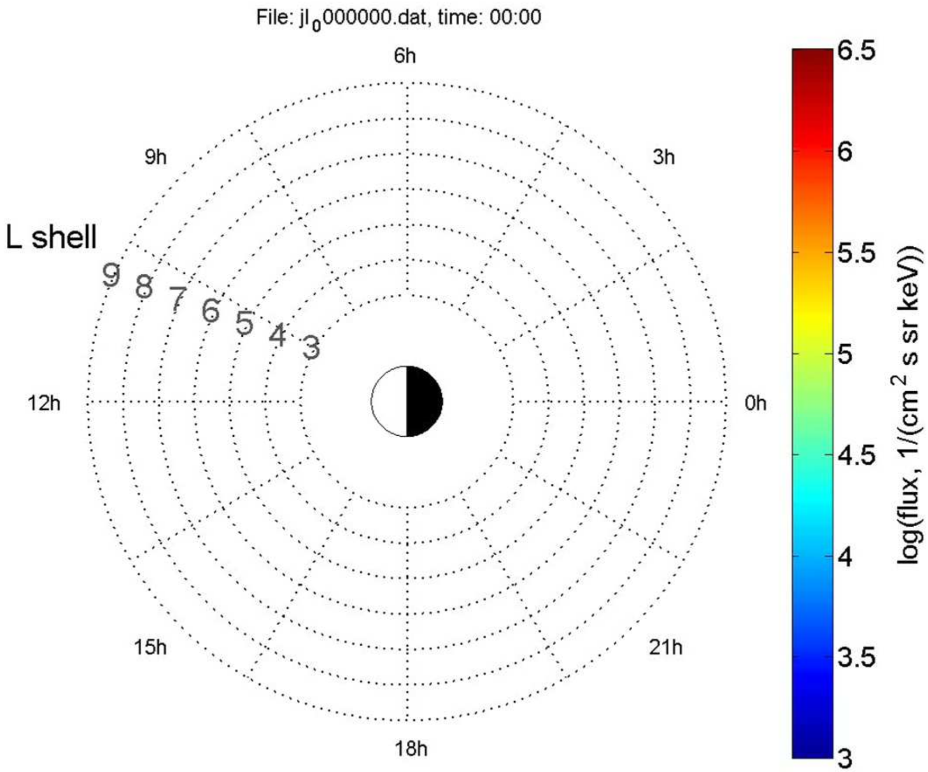
IMPTAM = Inner Magnetosphere Particle Transport and Acceleration model

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

We start our modeling with IMPTAM with empty magnetosphere.

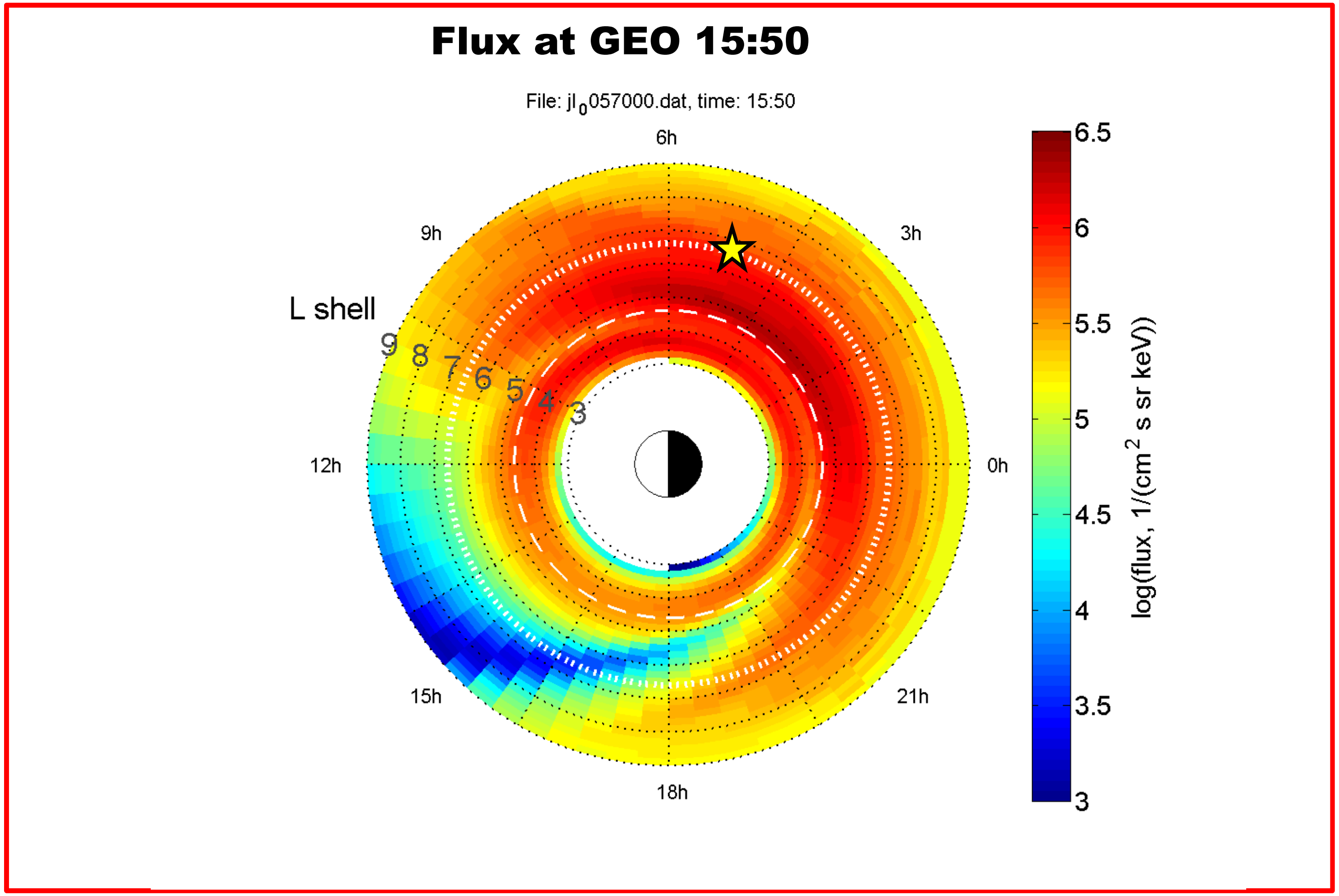
Electrons move from the plasma sheet to the inner regions.

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"



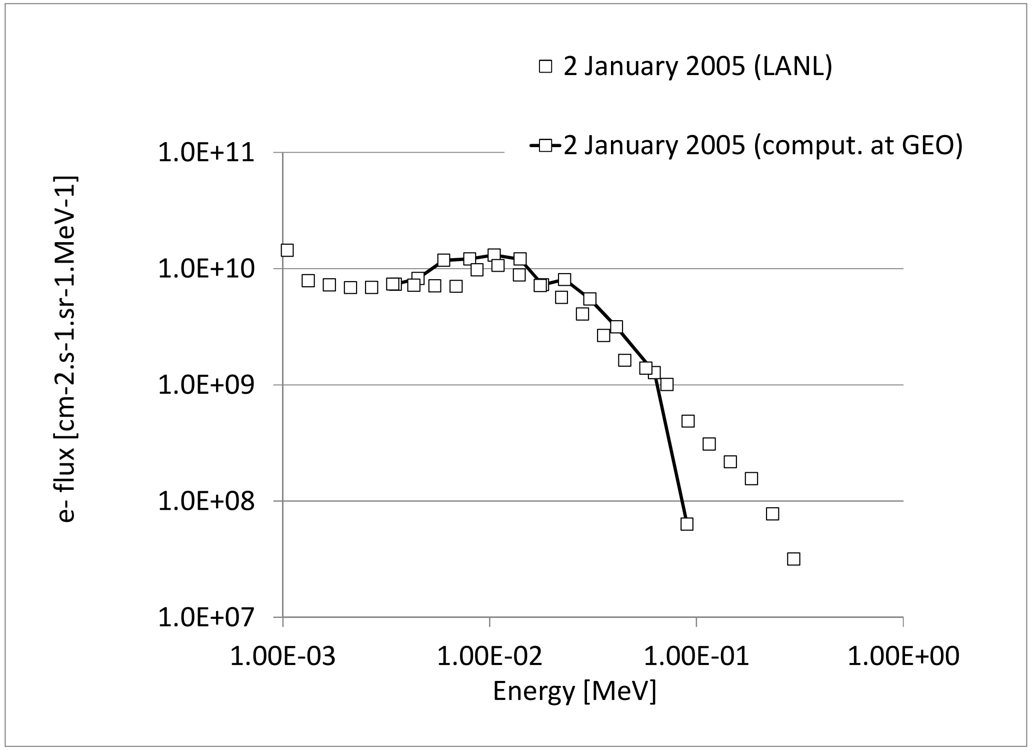
Can we predict severe environments at MEO ?
IMPTAM at GEO

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

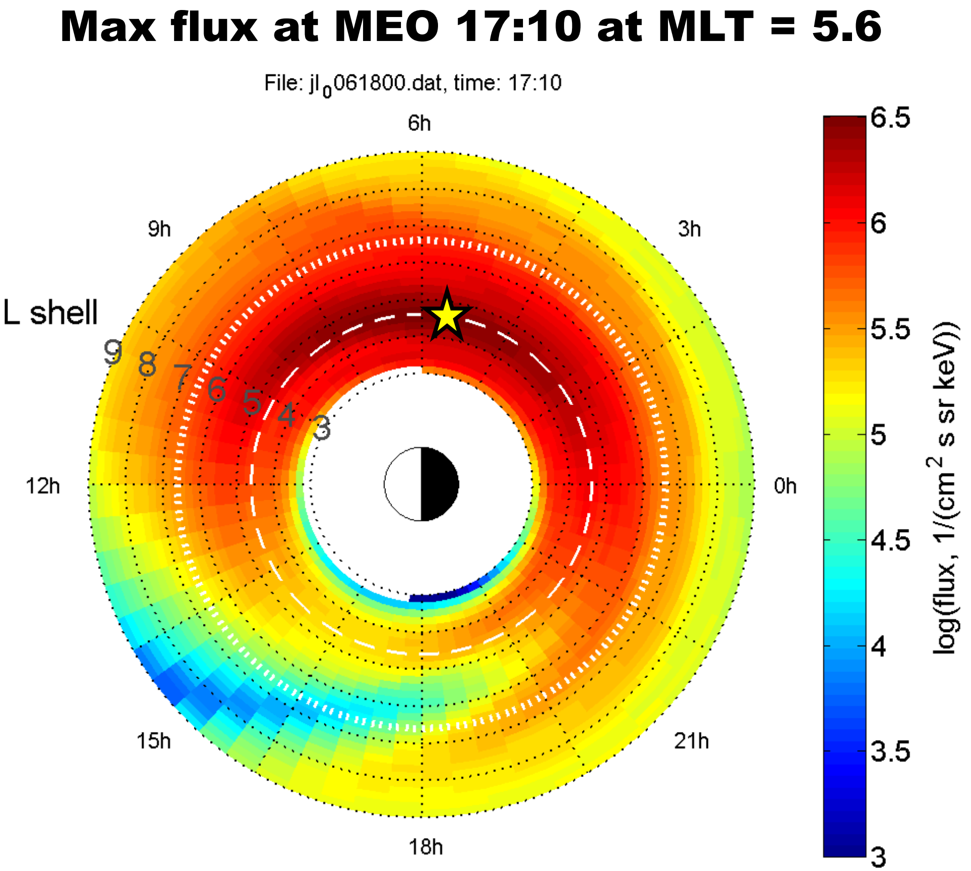
Matches LANL E< 90 keV

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”



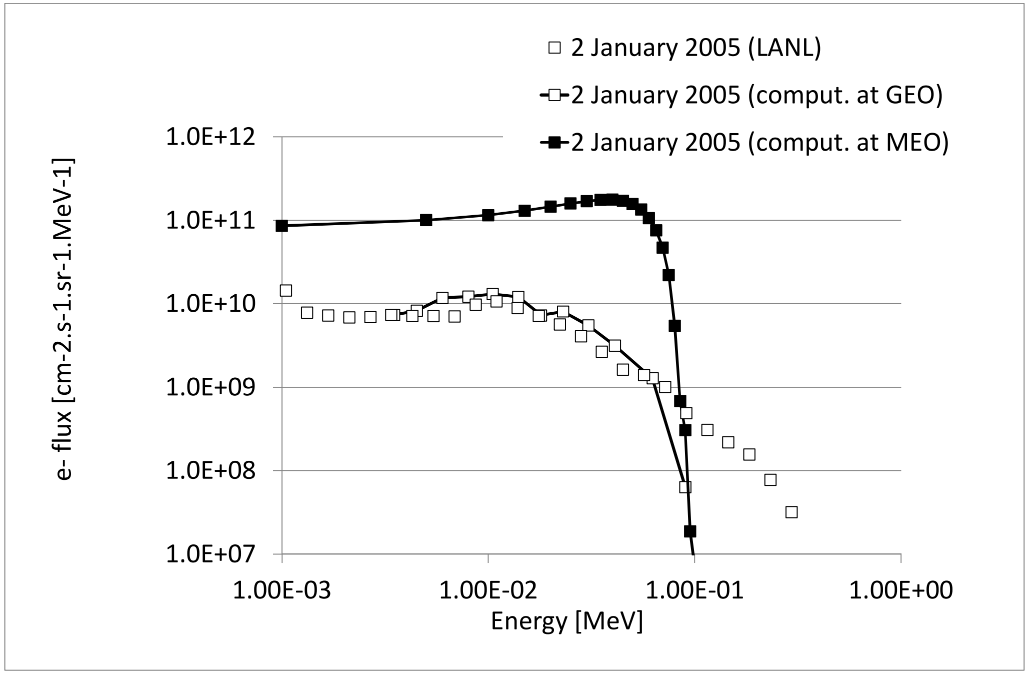
Can we predict severe environments at MEO ?
IMPTAM maximal flux at MEO

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: flux_MEO ≥ 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

THE FRENCH AEROSPACE LAB

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…

ONERA

THE FRENCH AEROSPACE LAB

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

ONERA

THE FRENCH AEROSPACE LAB

Acknowledgements

The Spacestorm project is funded in part by the European Union Seventh Framework Programme (FP7) under grant agreement no 606716