



SPACESTORM



# Low energy electrons in the inner Earth's magnetosphere

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The research leading to these results was partly funded by the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement No 606716 SPACESTORM and by the European Union's Horizon 2020 research and innovation programme under grant agreement No 637302 PROGRESS

**EGU Assembly 2016, April 18-22, 2016, Vienna, Austria**



# Why are we interested in low energy electrons (< 200 keV) in the inner magnetosphere?

- Surface charging by electrons with < 100 keV can cause significant damage and spacecraft anomalies.
- The distribution of low energy electrons, the seed population (10 to few hundreds of keV), is critically important for radiation belt dynamics.
- Chorus emissions (intense whistler mode waves) excited in the low-density region outside the plasmapause are associated with the injection of keV plasma sheet electrons into the inner magnetosphere.
- The electron flux at the keV energies is largely determined by convective and **substorm-associated** electric fields and varies significantly with geomagnetic activity driven by the solar wind – **variations on time scales of minutes!**  
**No averaging over an hour/day/orbit!**

# It is challenging to nowcast and forecast low energy electrons

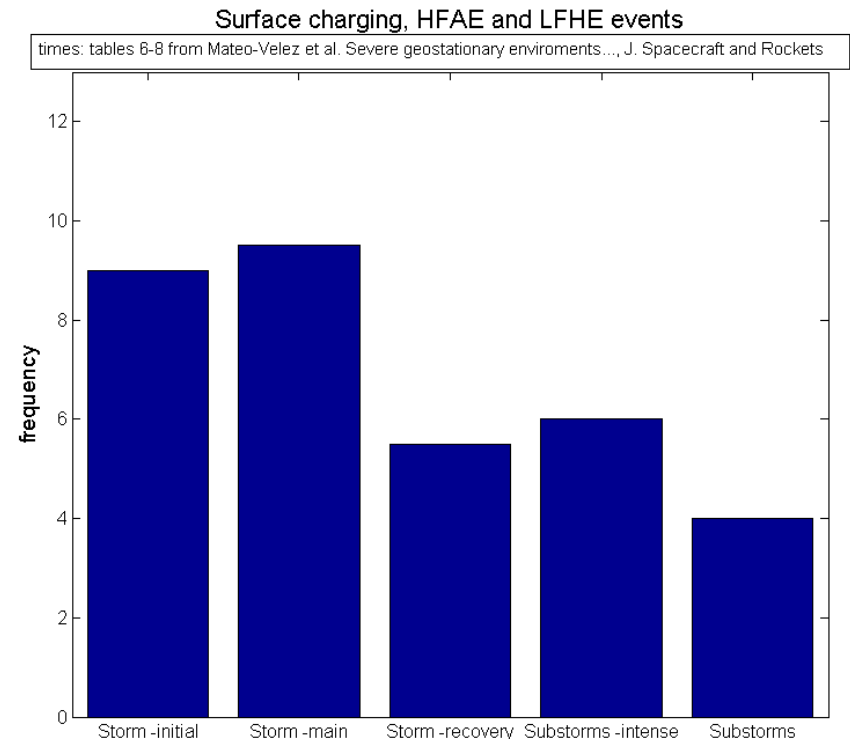
## Surface charging events vs. geomagnetic conditions

It is **NOT** necessary to have even a moderate storm for significant surface charging event to happen

The keV electron flux is largely determined by convective and substorm-associated electric fields and varies significantly with geomagnetic activity – variations on time scales of minutes!

No averaging over an hour/day/orbit!

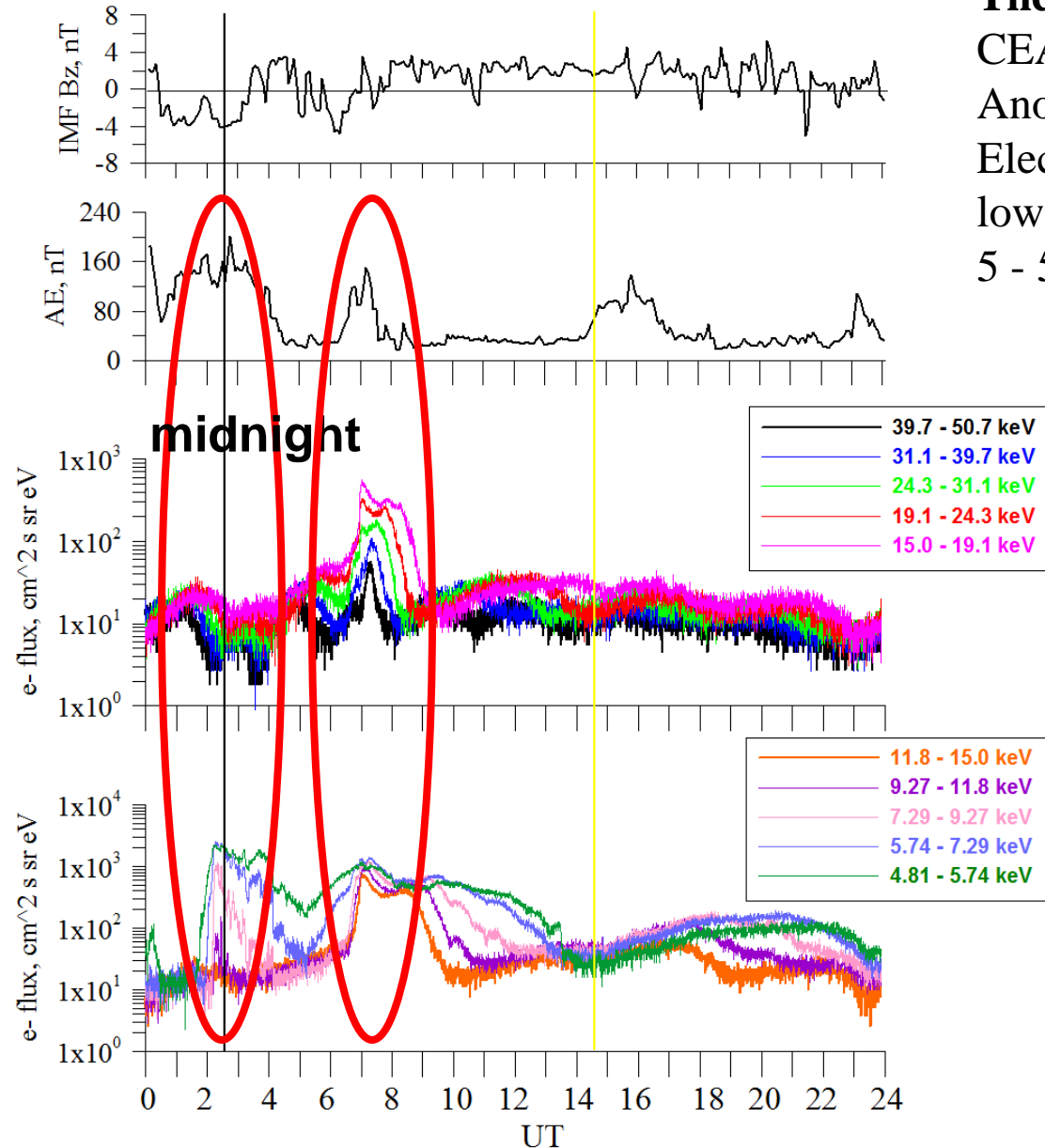
Correct models for electromagnetic fields, boundary conditions, losses are extremely hard to develop



Matéo Véléz et al., Severe geostationary environments: from flight data to numerical estimation of spacecraft surface charging, *Journal of Spacecraft and Rockets*, submitted, 2015

# 5-50 keV electrons during quiet event

November 25, 2011



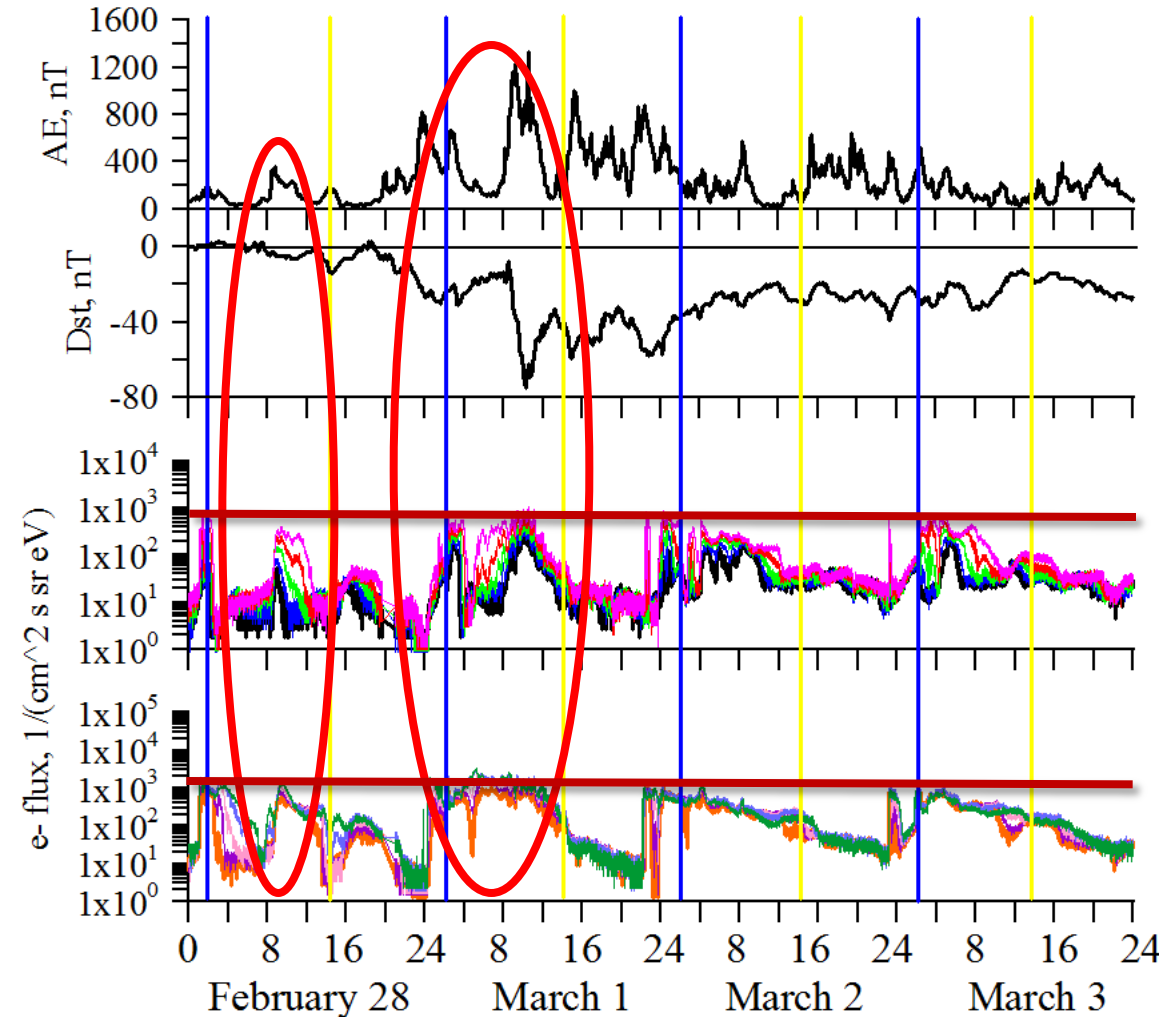
**The data:** AMC 12 geostationary satellite, CEASE-II (Compact Environmental Anomaly Sensor) instrument with Electrostatic Analyzer (ESA) for measuring low energy electron fluxes in 10 channels, 5 - 50 keV.

- **Flux increases** are related to **AE peaks** only (less than 200 nT, small, isolated substorms)
- The lower the energy, the larger the flux
- Electrons of different channels behaves differently:
- 1st peak (AE=200 nT) at midnight seen for energies  $> 11$  keV
- 2nd peak (AE=120 nT) at dawn, increase in all energies

**Not a unique case**

# Similar increase in electron fluxes during AE = 400 nT and AE=1200 nT

February 28 - March 3, 2013



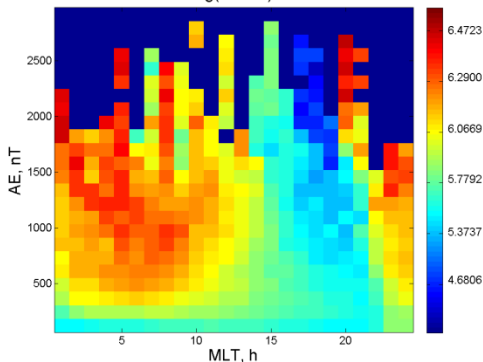
Small, CIR-driven storm with  
**Dst of 75 nT**,  
**IMF Bz** of -5 -10 nT,  
**Vsw** from 350 to 650 km/s,  
**Psw** peak at 8 nPa,  
AE peaks of 800-1200 nT

## AMC12 electron data

- peaks in both 15-50 keV and 5-15 keV electron fluxes show correlation with AE
- 2 orders of magnitude increase
- all energies increase at midnight, when AE is only 200 nT
- same order of increase for AE = 800 nT and even for 1200 nT

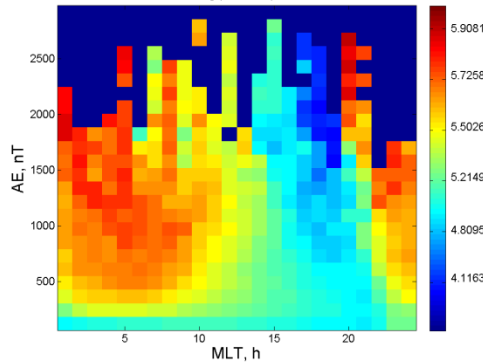
**39.7-50.7 keV**

log(FLUX0)



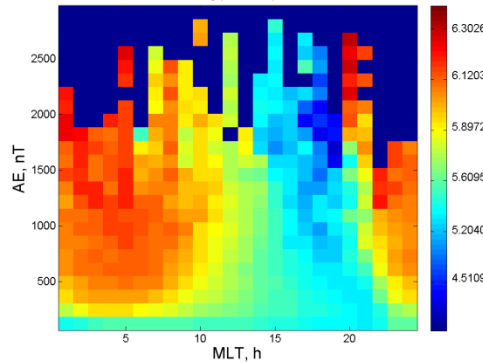
**31.1-39.7 keV**

log(FLUX1)



**24.3-31.1 keV**

log(FLUX2)



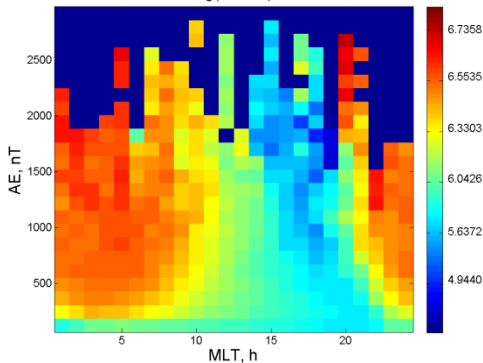
**Log(flux)**

**Flux(MLT, AE)**

**AMC 12  
CEASE-II  
ESA data,  
2010-2014**

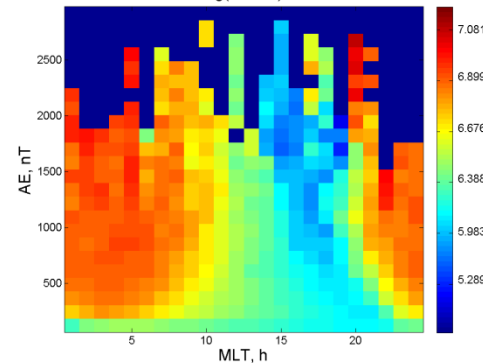
**19.1-24.3 keV**

log(FLUX3)



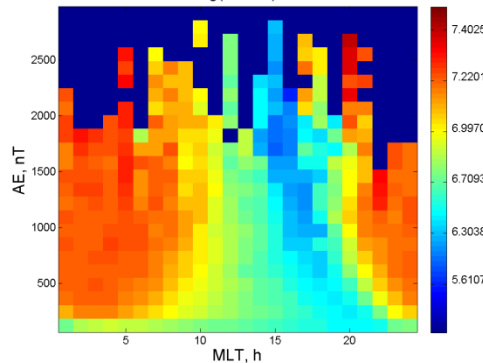
**15.0-19.1 keV**

log(FLUX4)



**11.8-15.0 keV**

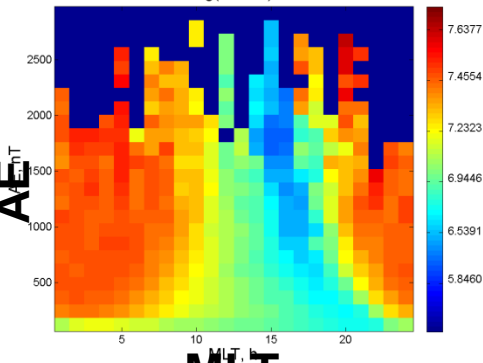
log(FLUX5)



The higher  
the energy,  
the less  
distributed  
the flux peak

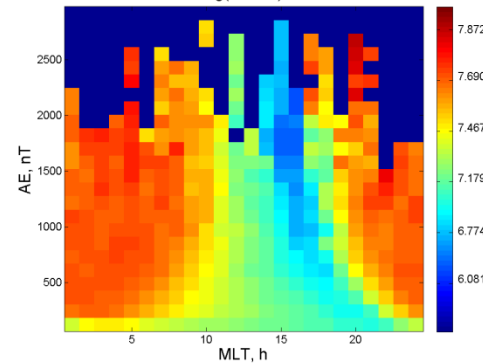
**9.27-11.8 keV**

log(FLUX6)



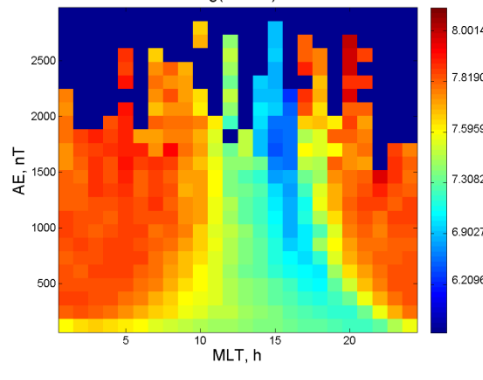
**7.29-9.27 keV**

log(FLUX7)



**5.74-7.29 keV**

log(FLUX8)

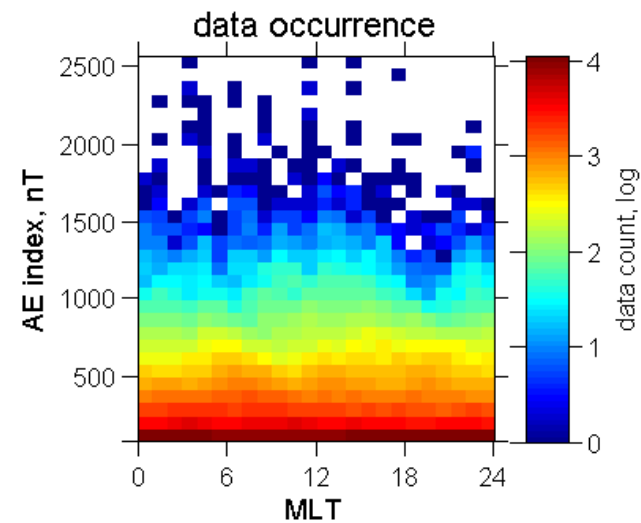
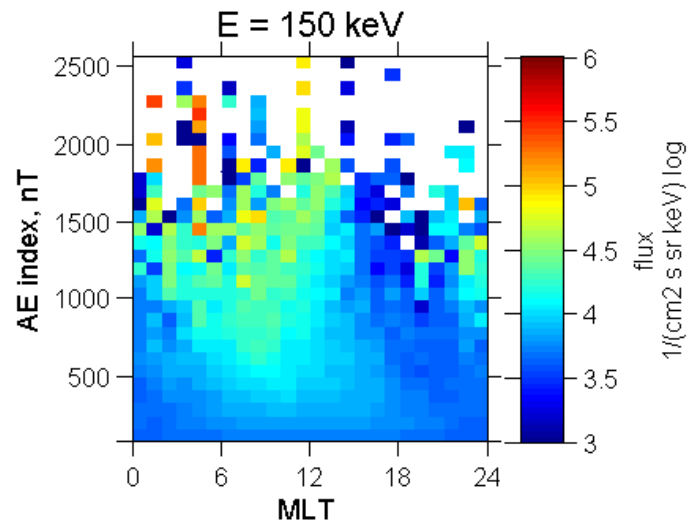
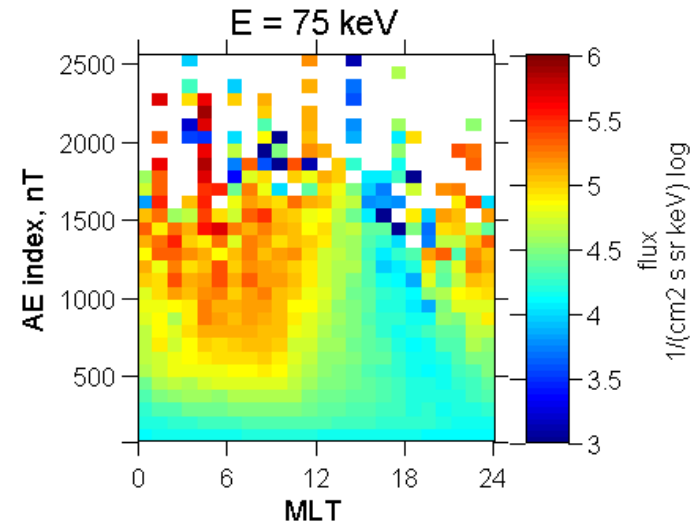
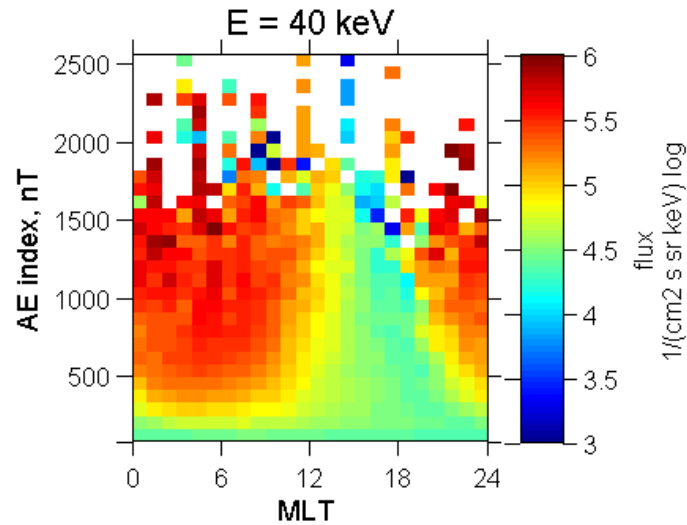


**No distinct  
dependence  
on AE  
strength**

**AE  
nT**  
**MLT**

# GOES 13 MAGED electron fluxes (MLT, AE)

## 2011-2015



**No distinct dependence of electron fluxes on AE strength**

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

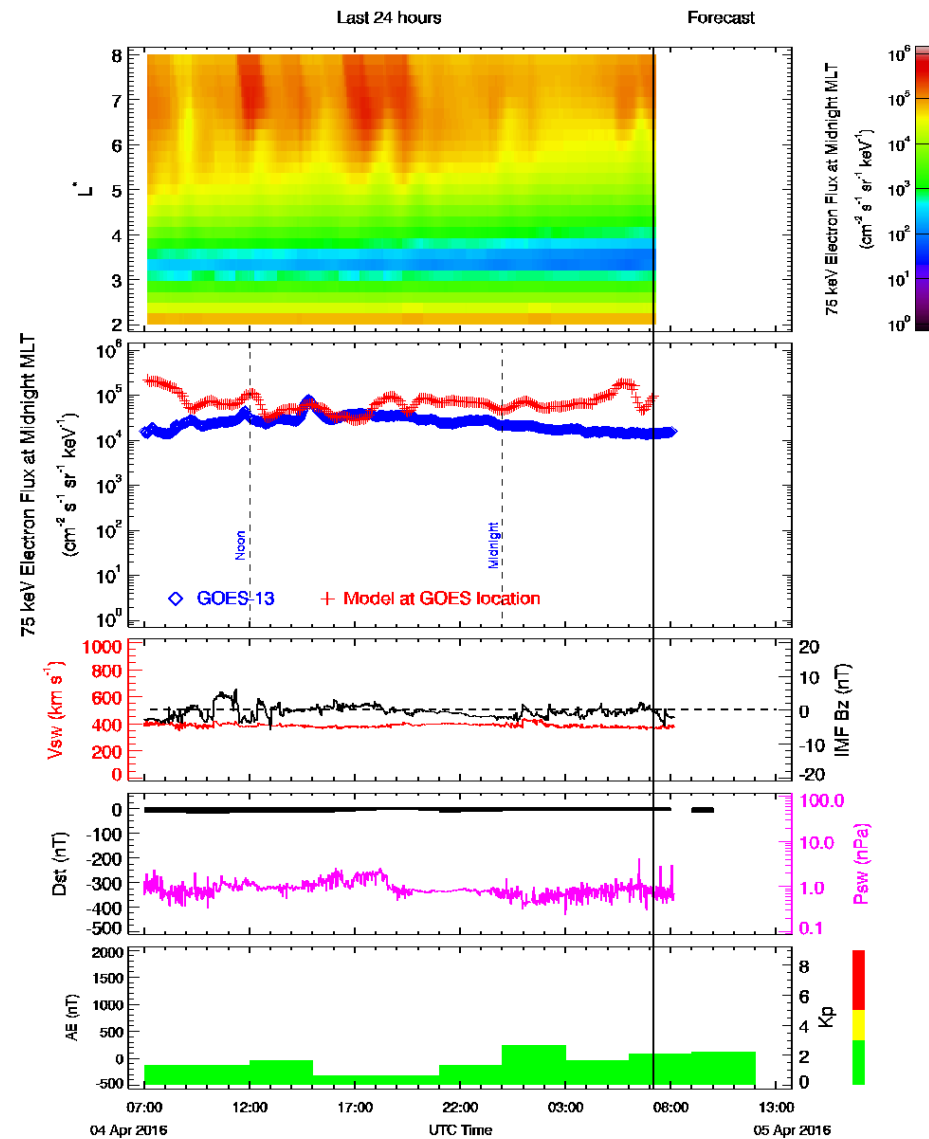
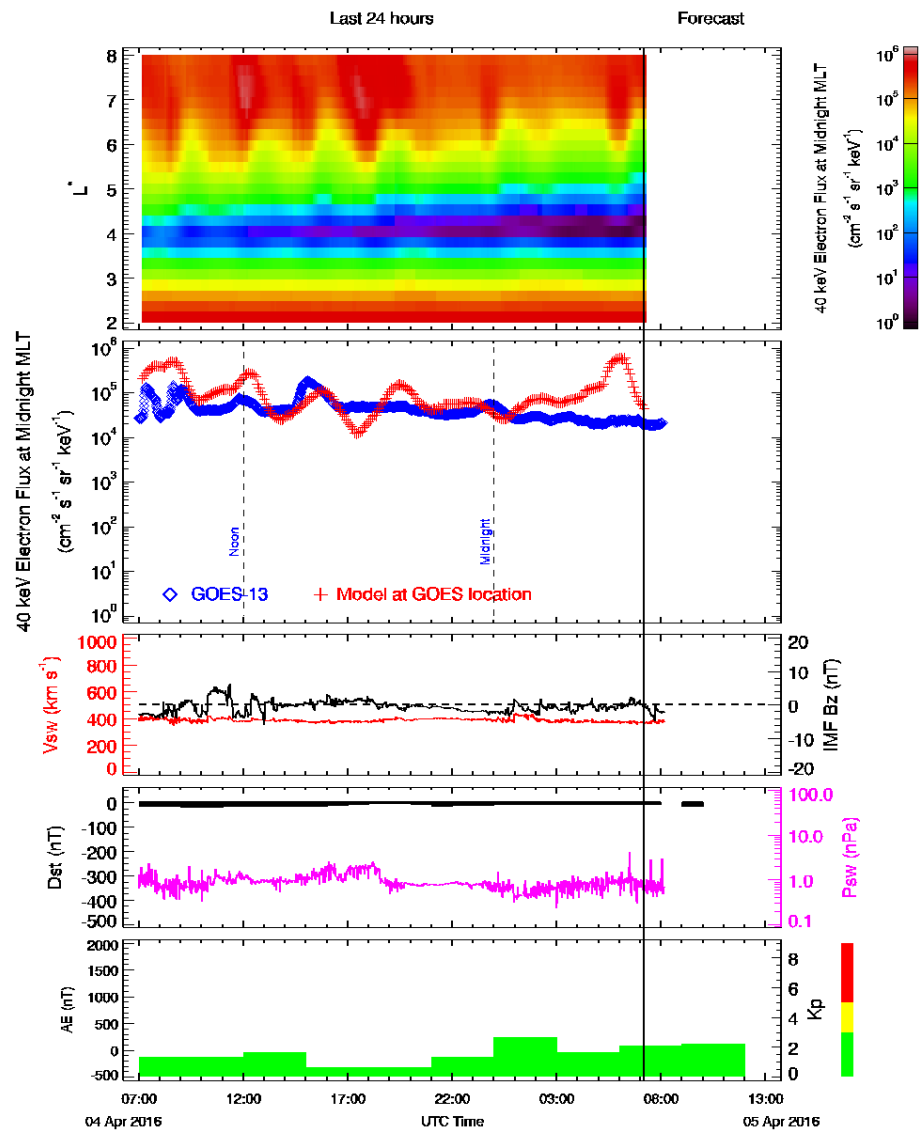
*(Ganushkina et al., 2013, 2014, 2015)*

- ◆ traces **electrons** with arbitrary pitch angles from the plasma sheet to the inner L-shell regions with energies up to **300 keV** in time-dependent magnetic and electric fields
- ◆ traces a distribution of particles in the **drift approximation** under the conservation of the 1st and 2<sup>nd</sup> adiabatic invariants. Liouville theorem is used to gain information of the entire distribution function
- ◆ for the obtained distribution function, we apply **radial diffusion** by solving the radial diffusion equation
- ◆ electron losses: convection outflow and pitch angle diffusion by the **electron lifetimes**
- ◆ advantage of IMPTAM: can utilize any magnetic or electric field model, including self-consistent magnetic field and substorm-associated electromagnetic fields.

**Run online in real time:** <http://fp7-spacecast.eu>, [imptam.fmi.fi](http://imptam.fmi.fi),  
<http://csem.engin.umich.edu/tools/imptam/>



# Current IMPTAM output compared to GOES MAGED 40 and 75 keV electron fluxes



# Recent advances in IMPTAM for electrons

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 angle**, it is necessary to specify:

(1) **particle distribution** at initial time **at the model boundary**;

Model boundary at 10  $Re$  with kappa electron distribution function. Parameters are the number density  $n$  and temperature  $T$  in the plasma sheet given by **the new empirical model** at L=6-11 dependent on solar wind and IMF parameters **constructed using THEMIS** ESA (eV-30 keV) and SST (25 keV – 10 MeV) data during 2007-2013.

(2) magnetic and electric fields everywhere dependent on time;

The **magnetic field model is Tsyganenko T96 model** [Tsyganenko, 1995] with Dst index, solar wind pressure  $P_{SW}$ , and IMF  $B_Y$  and  $B_Z$  as input parameters. The **electric field** is determined using the solar wind speed  $V_{SW}$ , the IMF strength  $B_{IMF}$  and its components  $B_Y$  and  $B_Z$  (via IMF clock angle  $\theta_{IMF}$ ) being the **Boyle et al. [1997] ionospheric potential**.

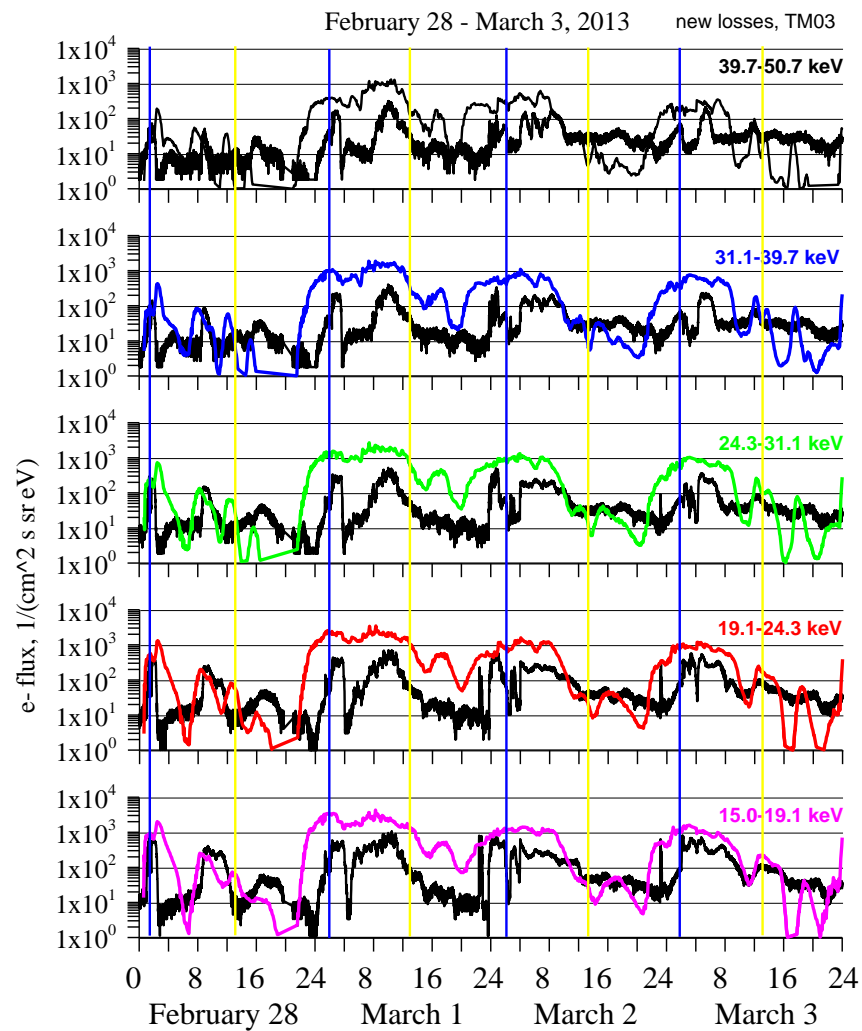
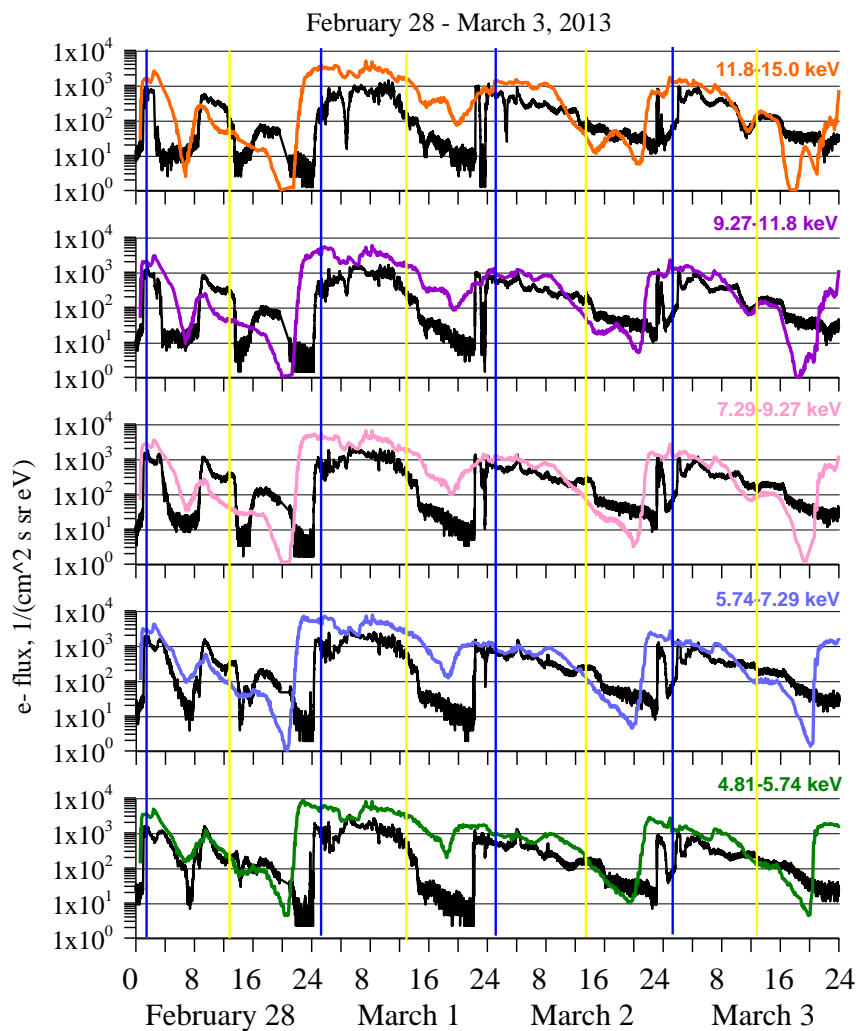
(3) drift velocities;

(4) all sources and **losses of particles**.

Most recent and advanced parameterization of the **electron lifetimes** due to interactions with chorus and hiss waves obtained by *Orlova and Shprits* [2014] and *Orlova et al.* [2014].

# Electron fluxes observed by AMC 12 CEASE II ESA instrument for 15-50 keV energies and modeled

With THEMIS model and *Orlova and Shprits [2014]* and *Orlova et al. [2014]* electron lifetimes



# Selected GEO environments #1

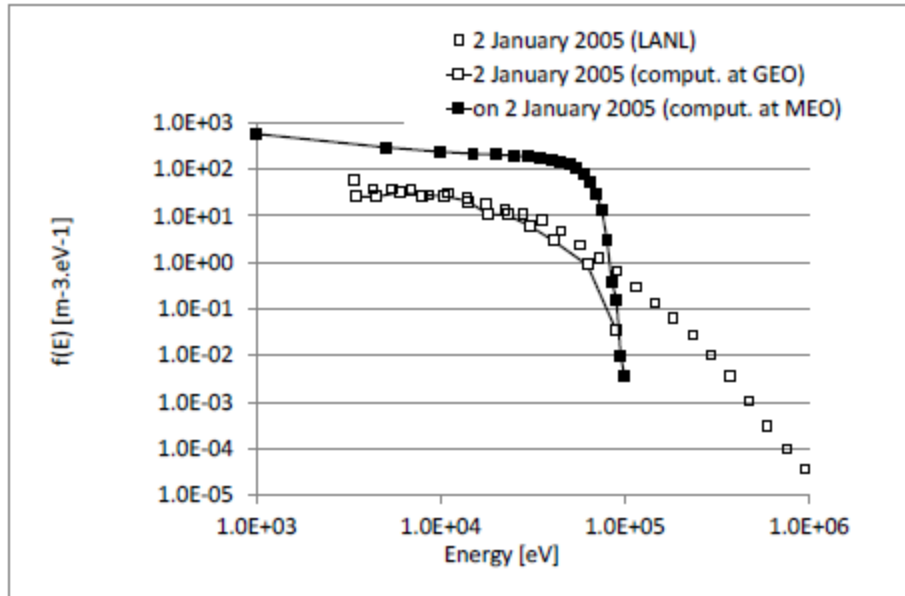
LANL\_1994\_084

2005/01/02

15h46min12s

MLT 04 47

## 3. IMPTAM computations



GEO

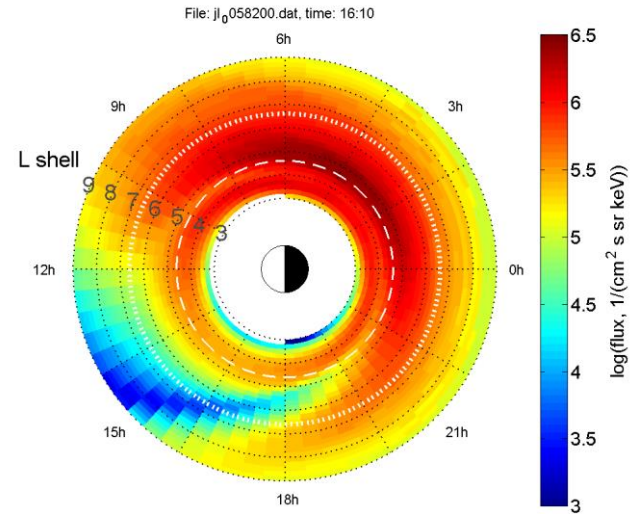
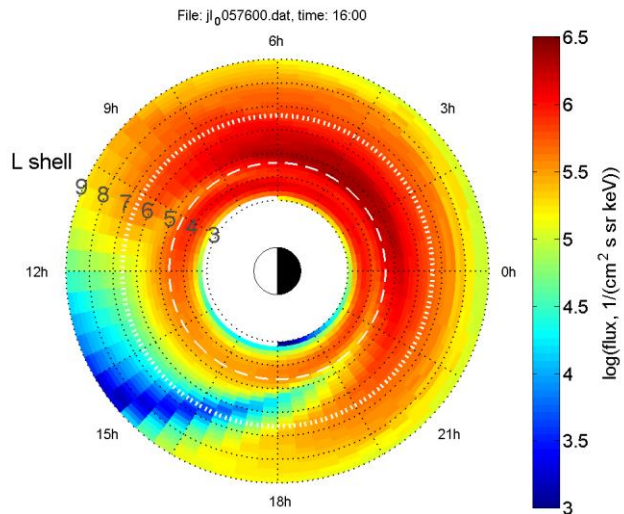
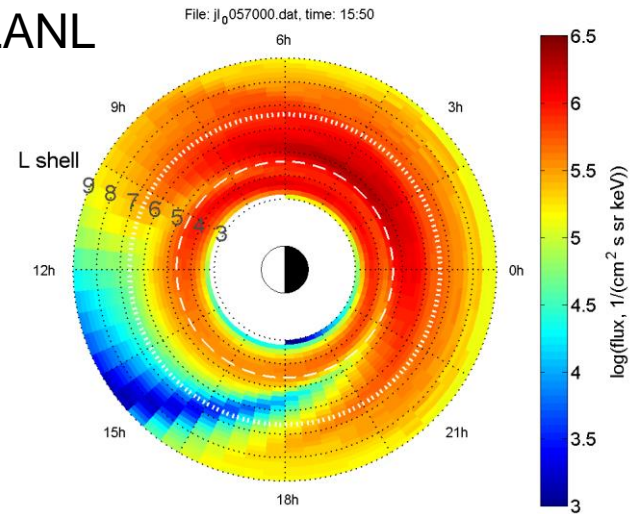
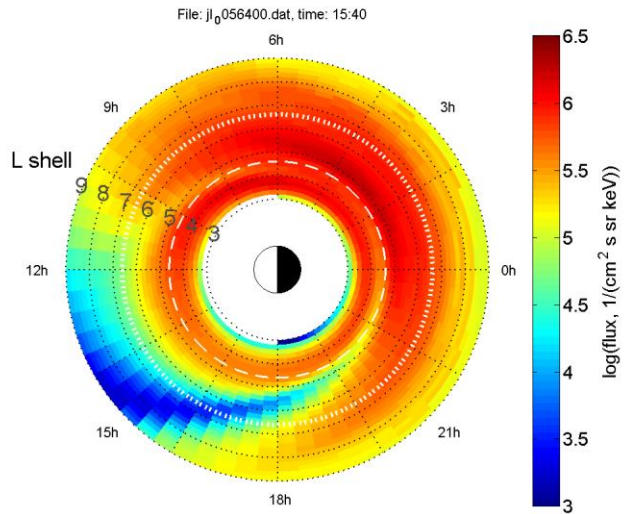
Very good agreement with LANL < 50keV  
Flux > 10 \* LANL @ 100 keV

MEO L = 4.6

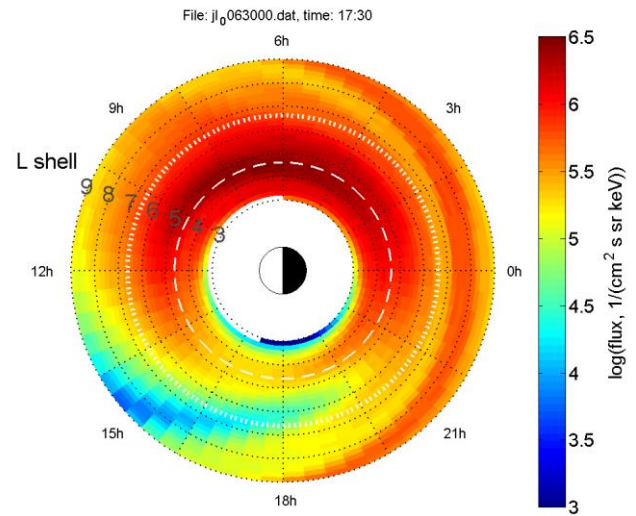
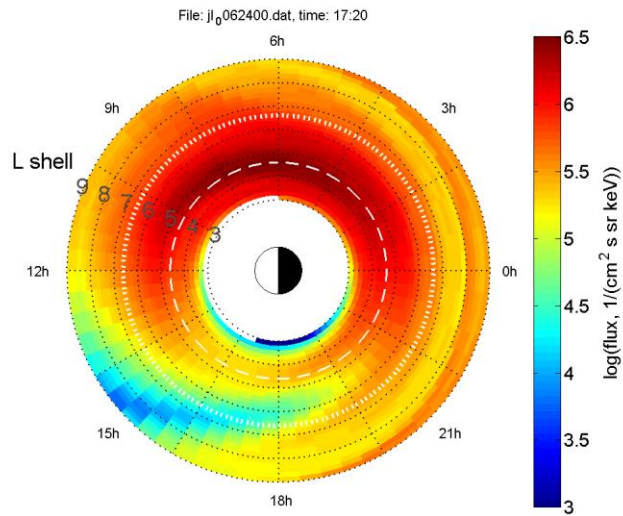
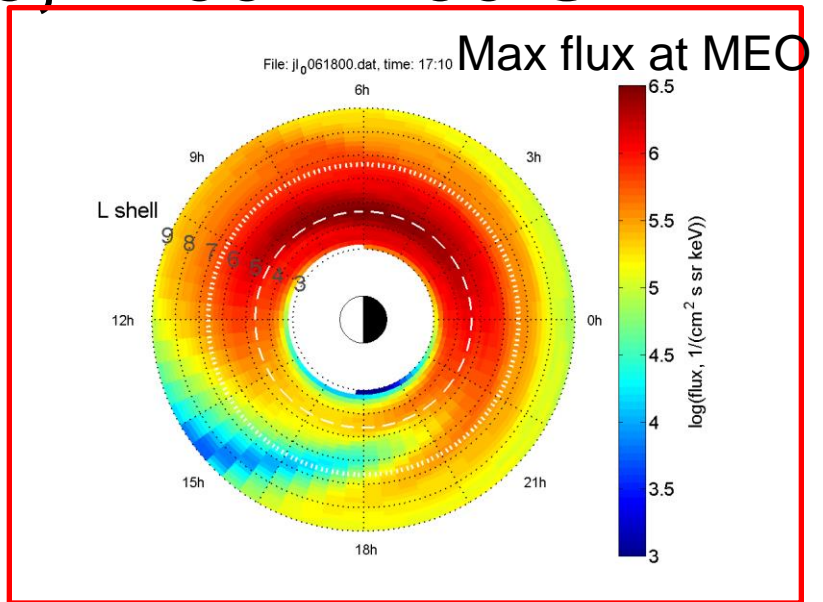
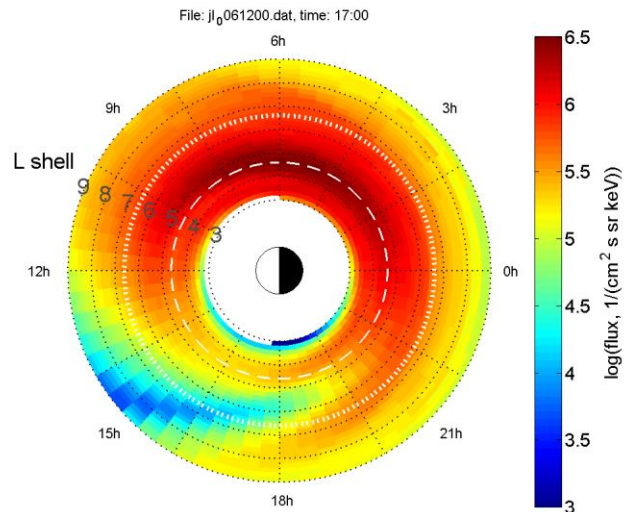
Flux \*5-10 at low energy  
Flux > 10-50 times the flux at GEO

# January 2, 2005, 1540 -1610 UT

## Event at LANL



# January 2, 2005, 1700 -1730 UT



# Summary

1. IMPTAM is very suitable for modeling of fluxes of low energy electrons ( $< 200$  keV) responsible for surface charging
2. It is NOT necessary to have even a moderate storm for significant surface charging event to happen. Substorms are important but low energy electrons (at geostationary) are not organized by AE index, for example.
3. It is a challenge to model low energy electrons with their important variations on 10 min scales. Advance made: A revision of the source model at 10 Re in the plasma sheet was done using the particle data from THEMIS ESA and SST instruments for years 2007-2013. Most advanced representation of loss processes for low energy electrons due to wave-particle interactions with chorus and hiss were incorporated using electron lifetimes following *Orlova and Shprits* [2014] and *Orlova et al.* [2014].
4. Modeling of documented surface charging events detected at LANL with further propagation to MEO: good agreement at GEO, reasonable values at MEO?
5. Still open issue: proper incorporation of substorm effects