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 bv the European Union's Horizon 2020 research and innovation programme under grant agreement No 637302 PROGRESS

Isradynamics 2016, April 3-10, 2016, Ein Bokek, Israel

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.

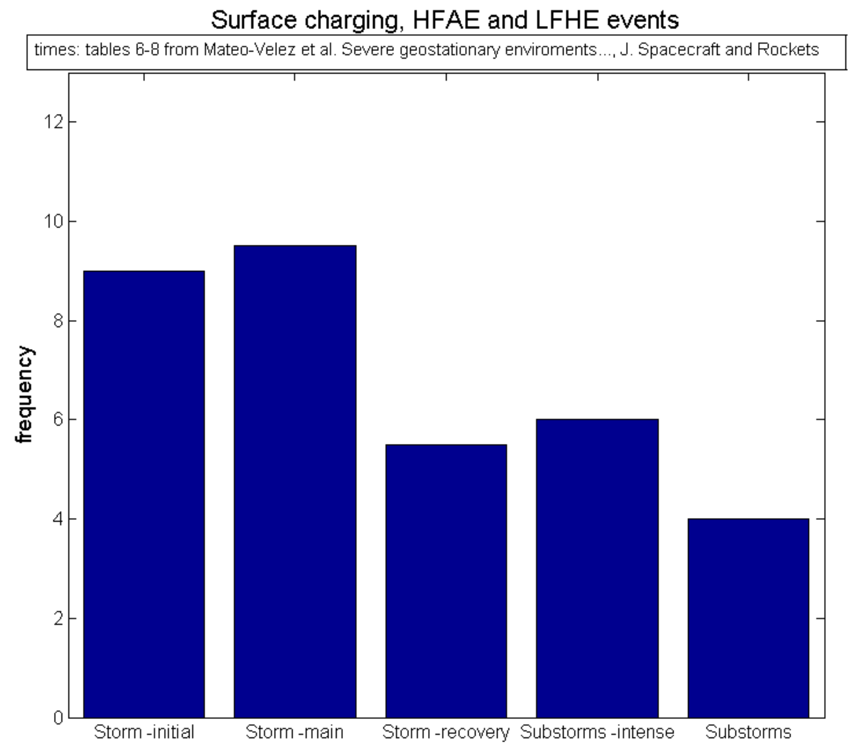
- Chorus emissions (intense whistler mode waves) excited in the low-density region outside the plasmapause are associated with the injection of keV plasma sheet electrons into the inner magnetosphere.

- 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

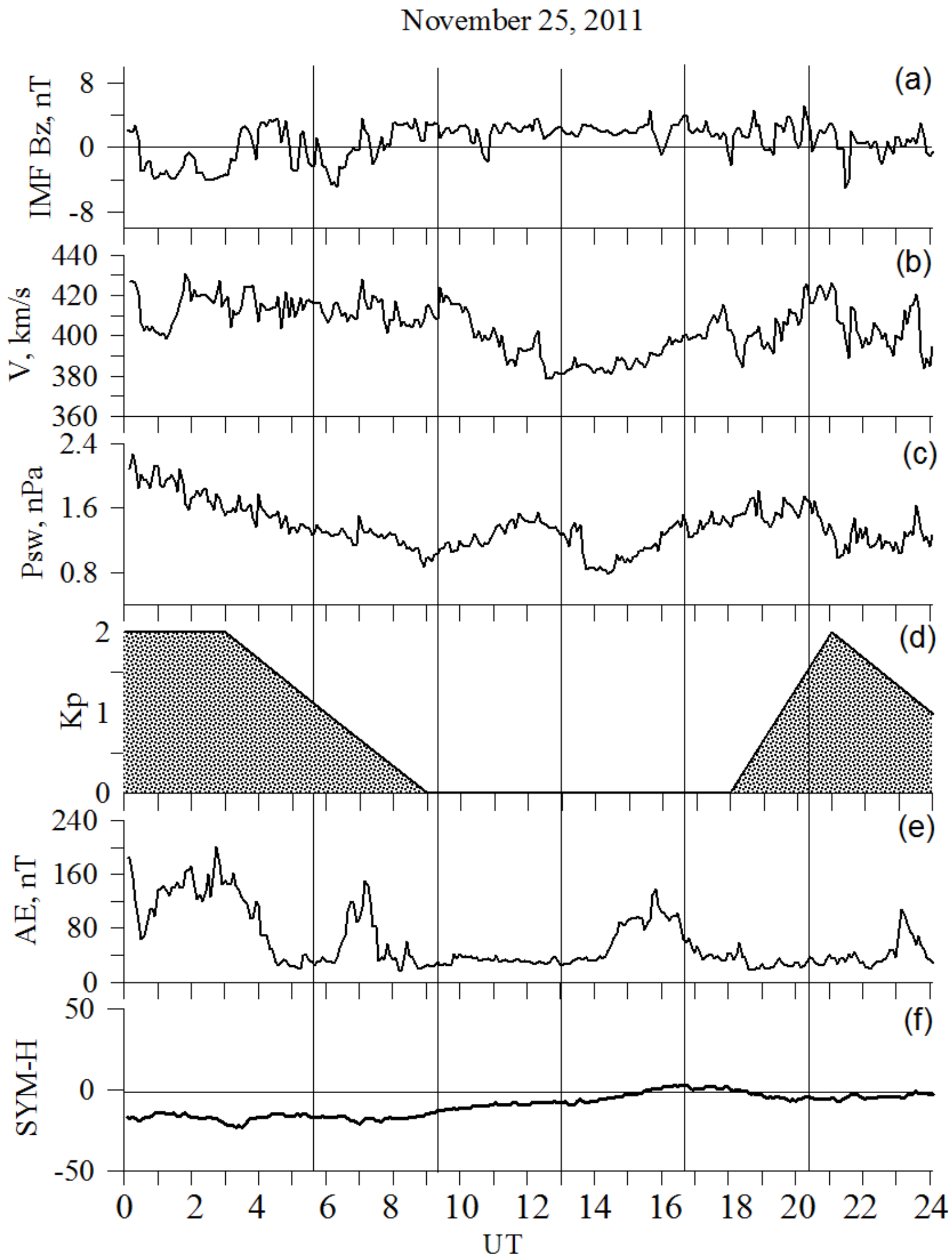
It is NOT necessary to have even a moderate storm for significant surface charging event to happen



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

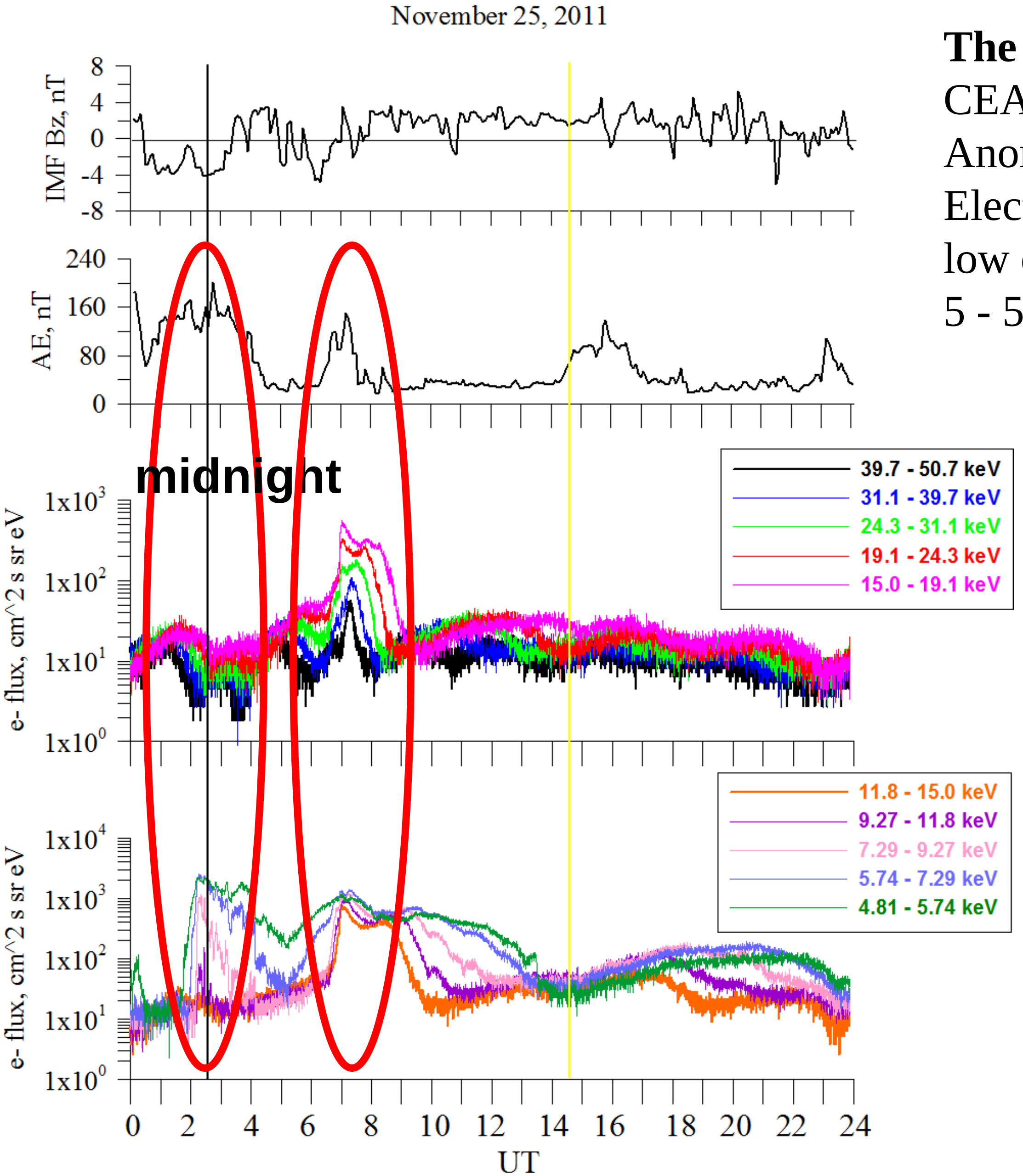
Matéo Vélez et al., Severe geostationary environments: from flight data to numerical estimation of spacecraft surface charging, *Journal of Spacecraft and Rockets, submitted, 2015*



No storm is needed for 2-3 orders of magnitude increase of low energy electron fluxes at geostationary orbit

Rather quiet event

5-50 keV electrons during quiet event



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.

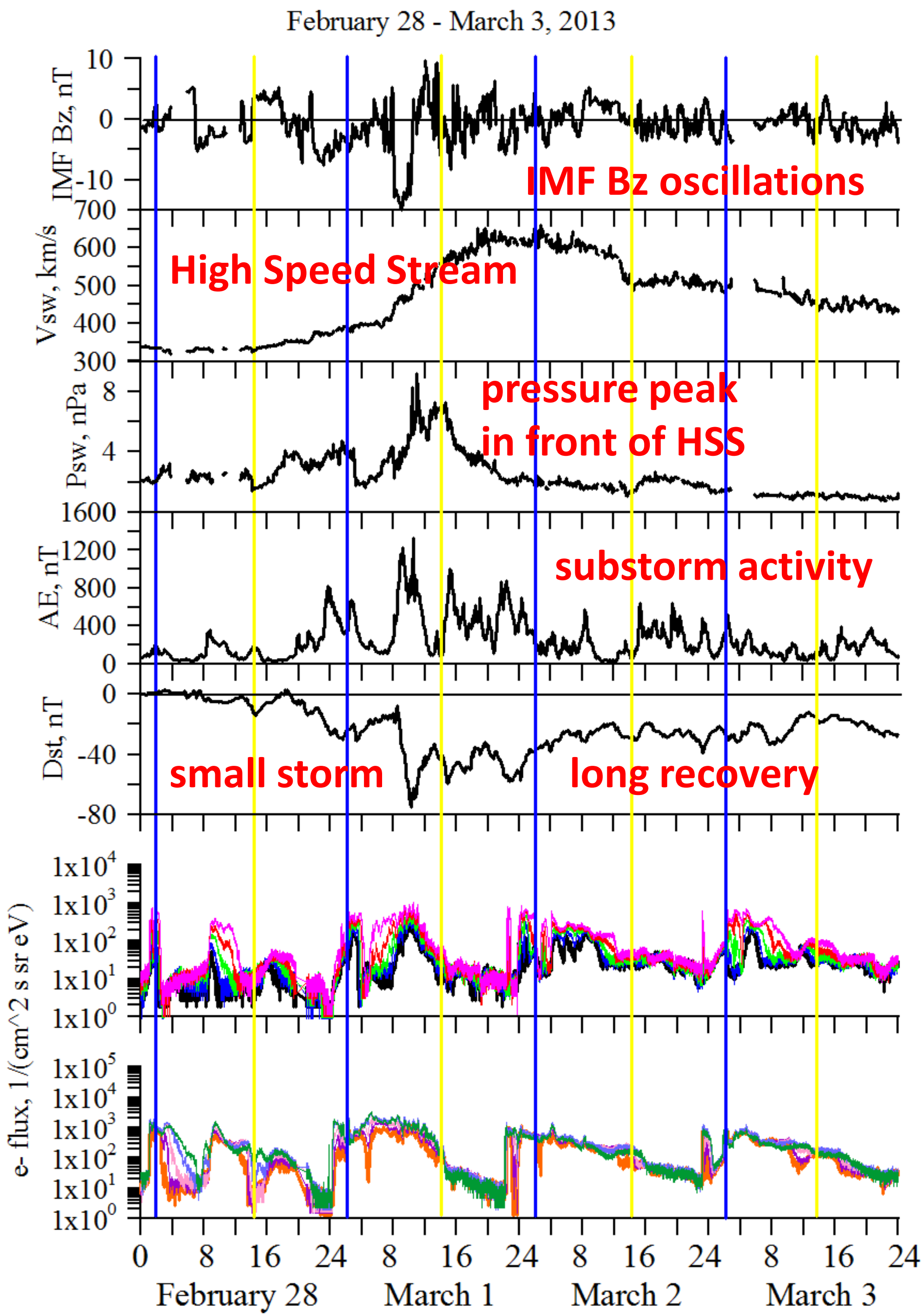
- **Flux increases** are related to **AE peaks** only (less than 200 nT, small, isolated substorms)

- The lower the energy, the large the flux

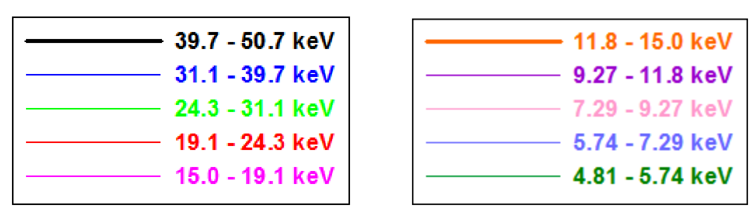
- Electrons of different channels behaves differently:
- 1st peak (AE=200 nT) at midnight seen for energies > 11 keV
- 2nd peak (AE=120 nT) at dawn, increase in all energies

Not a unique case

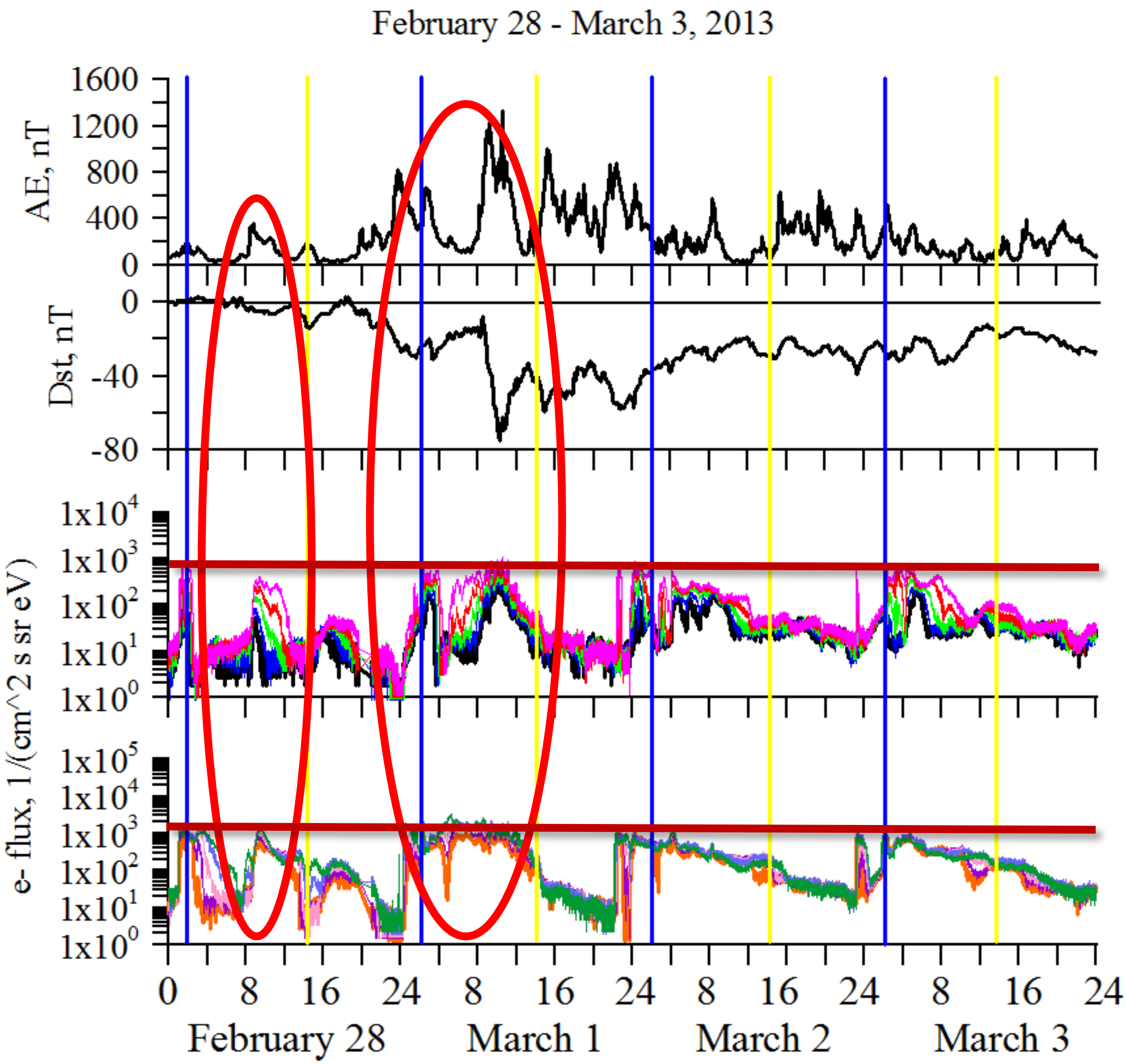
CIR-driven storm



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



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



AMC12 electron data

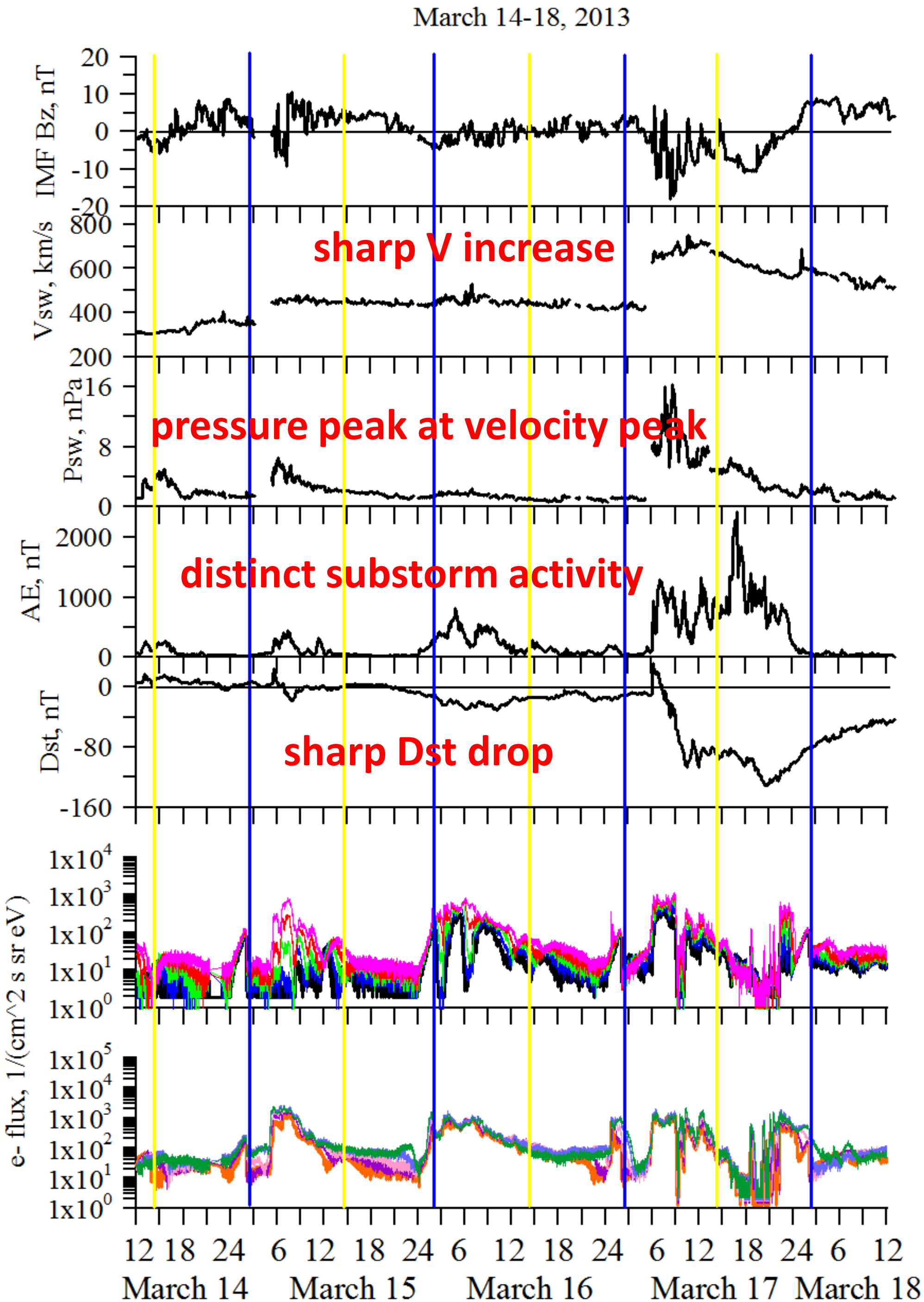
- peaks in both 15-50 keV and 5-15 keV electron fluxes show correlation with AE

- 2 orders of magnitude increase

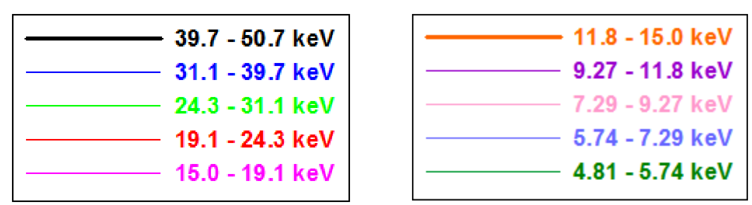
- all energies increase at midnight, when AE is only 200 nT

- same order of increase for AE = 800 nT and even for 1200 nT

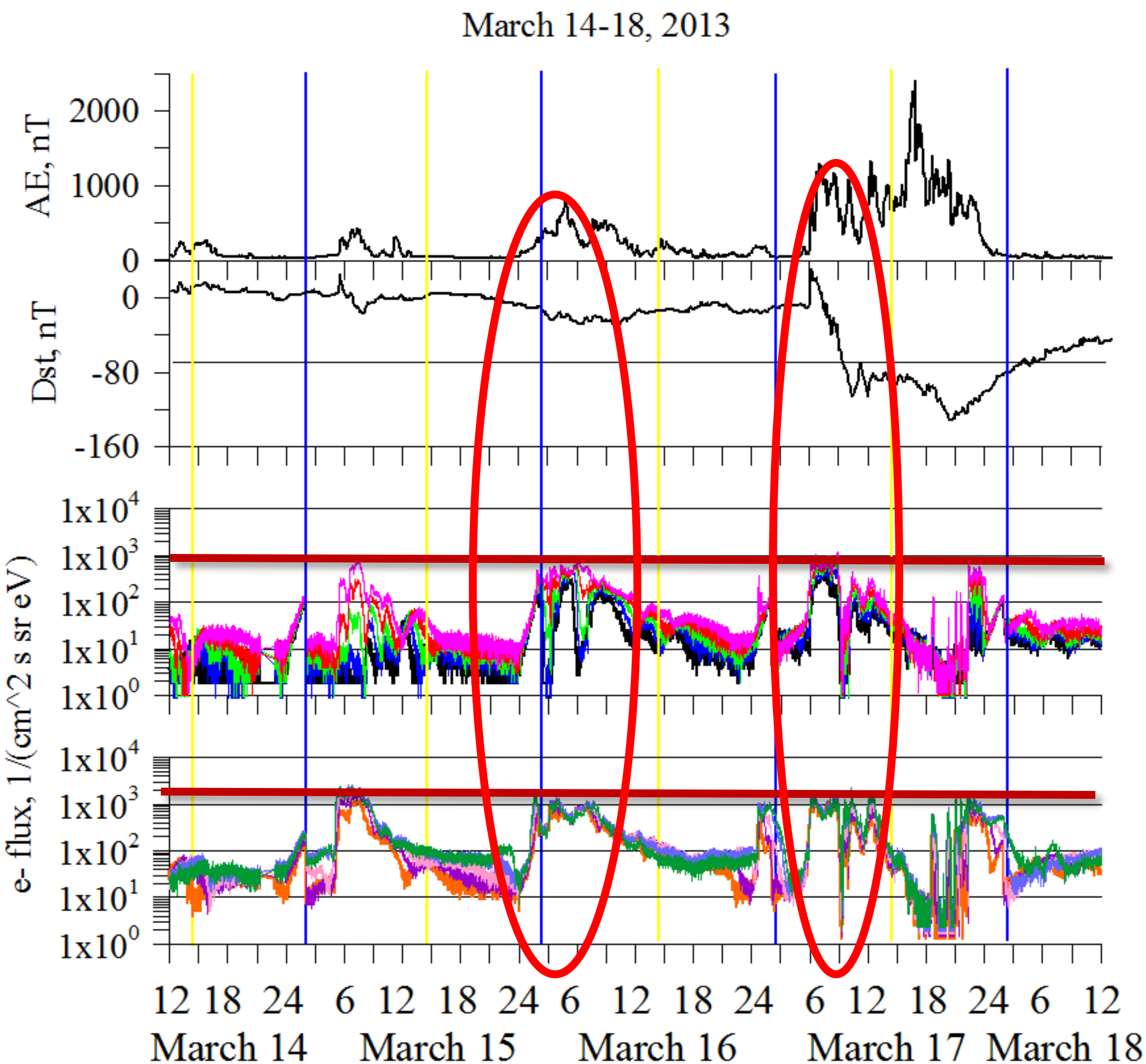
CME-driven storm



Moderate, CME-driven storm with **Dst of 130 nT,**
IMF Bz reaching -20 nT,
Vsw from 400 to 700,
Psw peak at 16 nPa,
AE peaks of 1000-2500 nT



Similar increase in electron fluxes during AE = 500 nT and AE=1500 nT

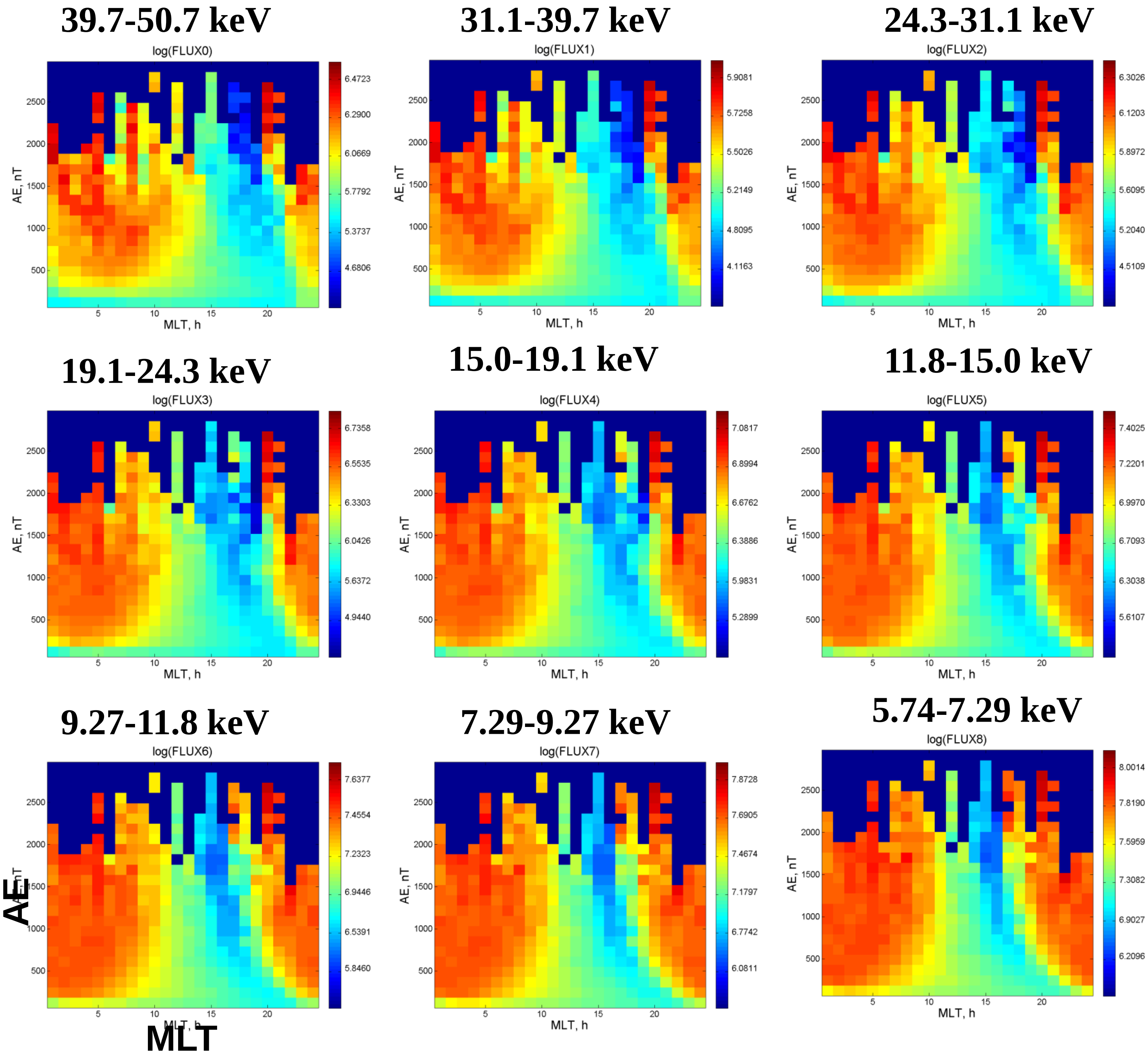


AMC12 electron data

- peaks in both 15-50 keV and 5-15 keV electron fluxes show clear correlation with AE peaks
- 2 orders of magnitude increase
- during quiet period before storm peaks with AE =500 nT similar to peaks with AE over 1000 nT at storm time

Log(flux)

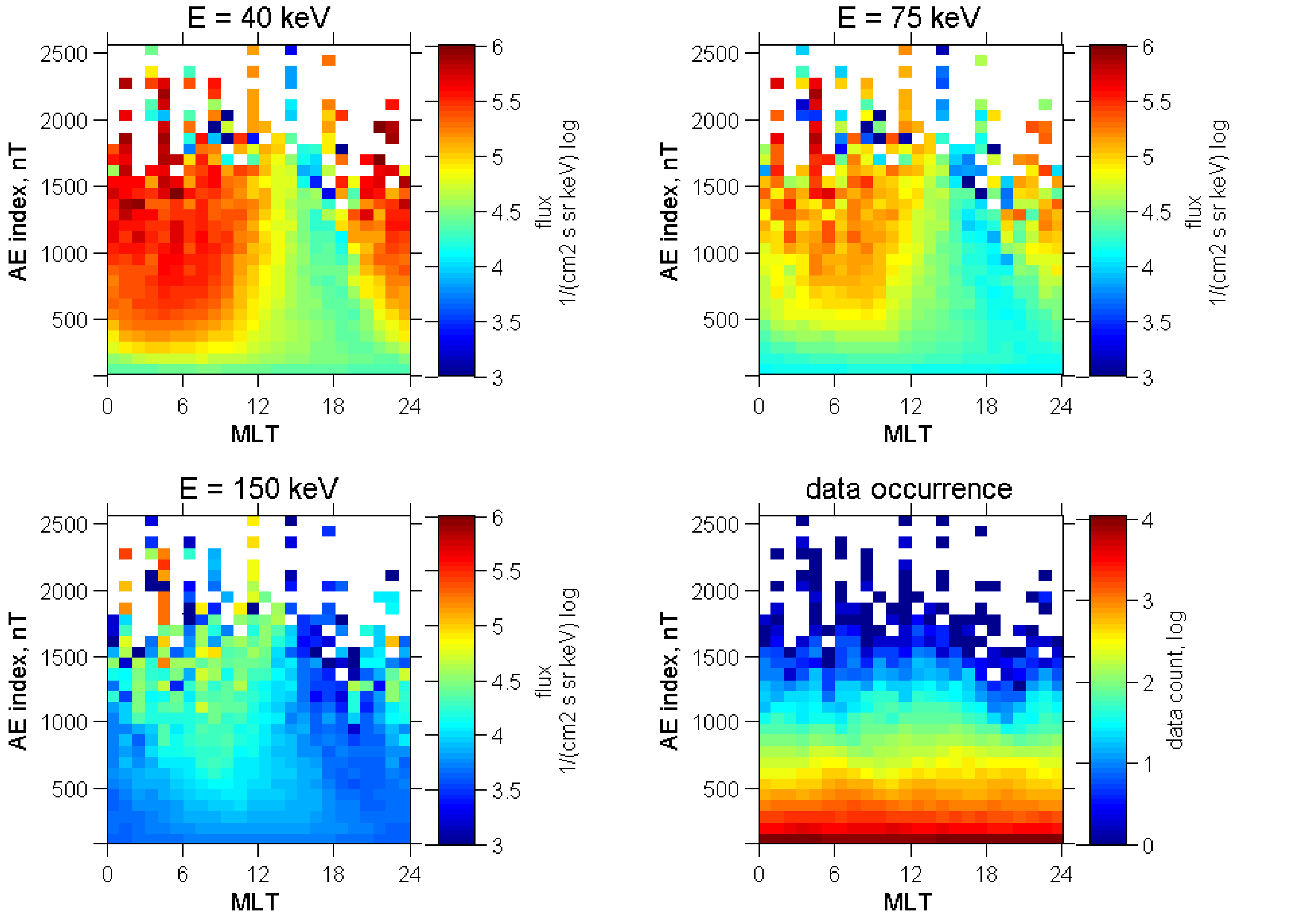
Flux(MLT, AE



The higher the energy, the less distributed the flux peak

No distinct dependence on AE strength

GOES 13 MAGED electron fluxes (MLT, AE)



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^{nd} 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 and imptam.fmi.fi

Near-real time IMPTAM model for low energy electrons (*Ganushkina et al., 2013, 2014, 2015*)

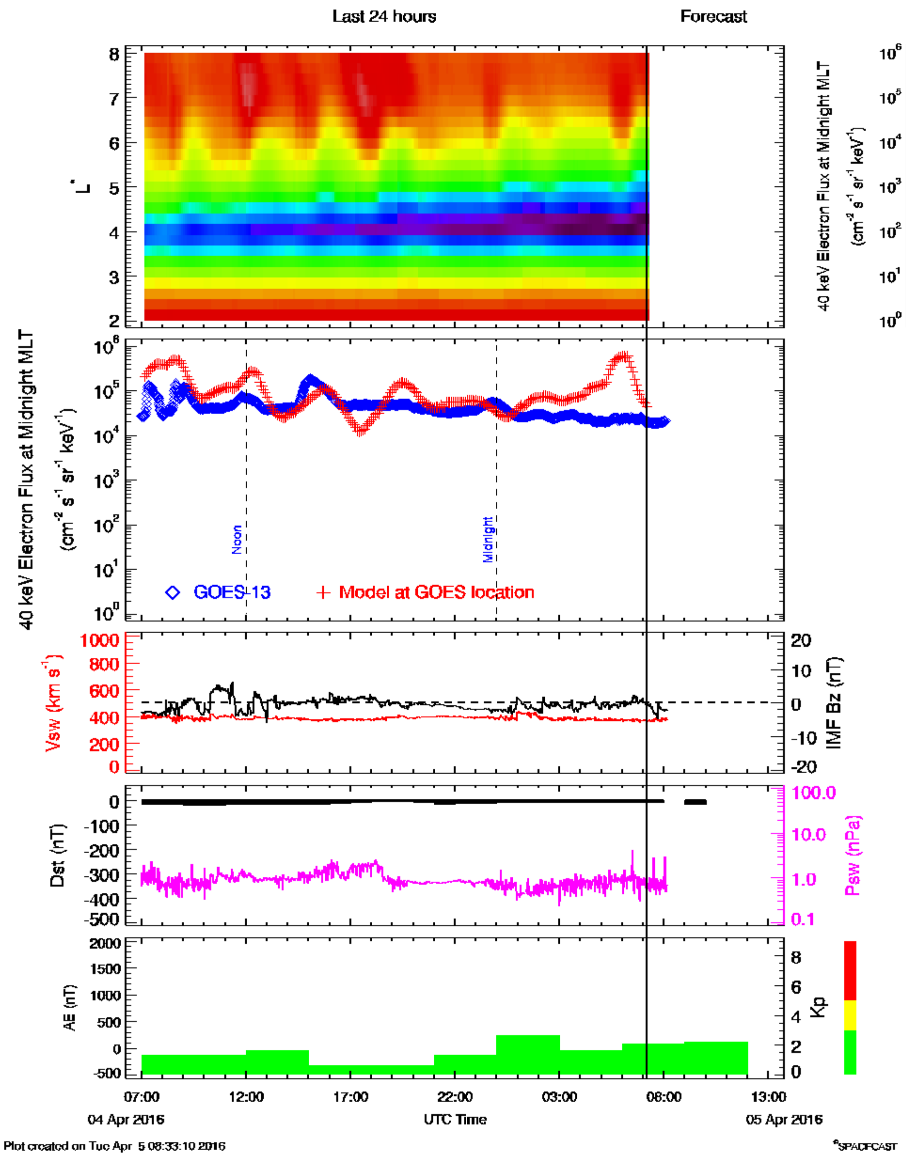
What do we present?
IMPTAM (Inner Magnetosphere Particle Transport and Acceleration model): nowcast model for low energy (< 200 keV) electrons in the near-Earth geospace, operating online at **http://fp7-spacecast.eu** and **imptam.fmi.fi**

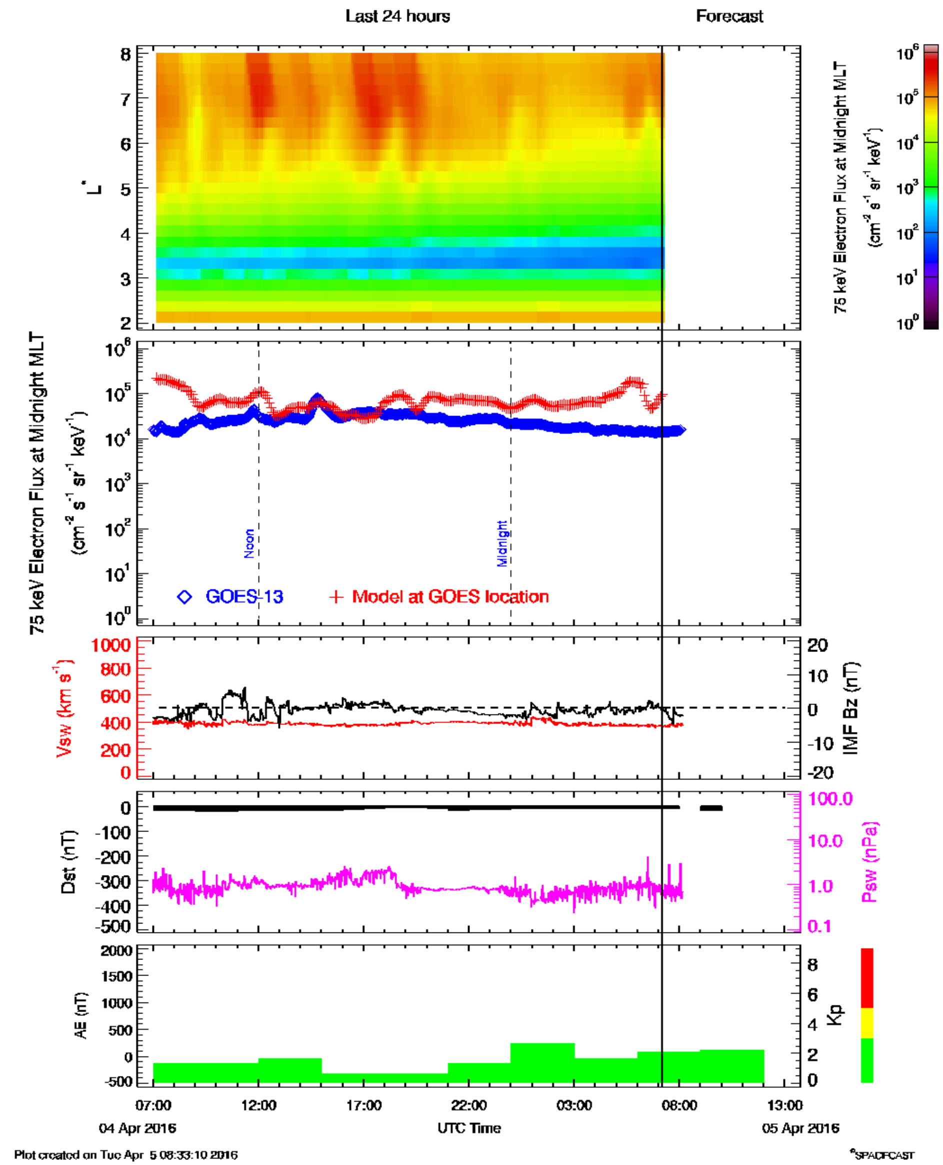
Why this model is important?
Low energy electron fluxes are very important to specify when hazardous satellite **surface charging** phenomena are considered.
They constitute the low energy part of the seed population for the high energy MeV particles in the **radiation belts**

What does the model provide?
The presented model provides the low energy electron flux at all locations and at all satellite orbits, when necessary, in the near-Earth space.

What are the drivers of the model?
The model is driven by the real time solar wind and Interplanetary Magnetic Field parameters with 1 hour time shift for propagation to the Earth's magnetopause, and by the real time geomagnetic activity index Dst.

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 angl**e , it is necessary to specify:

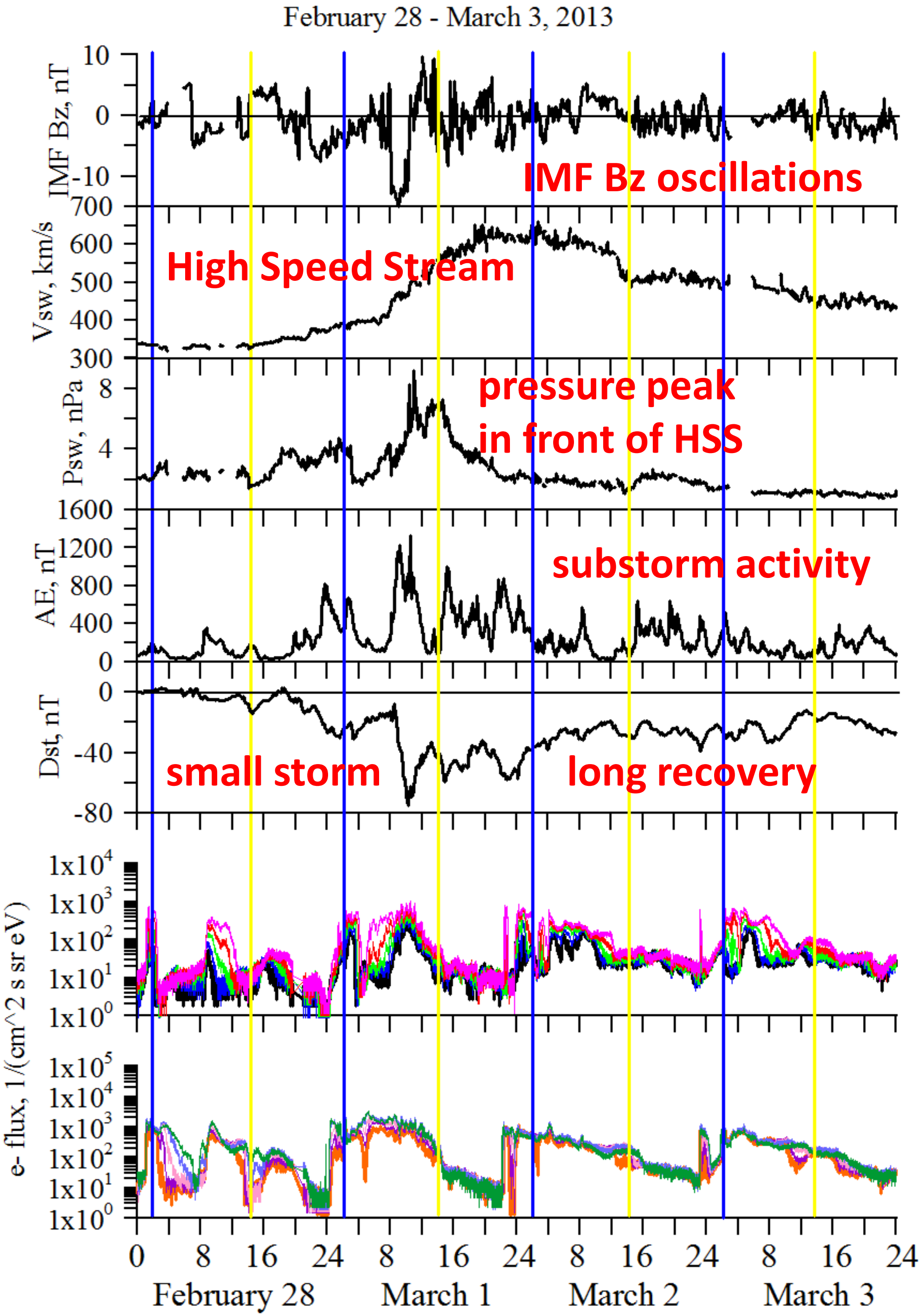
(1) **particle distribution** at initial time **at the model boundary**;
Model boundary at 10 *Re* with kappa electron distribution function. Parameters are the number density *n* and temperature *T* in the plasma sheet given by the empirical model derived from a new empirical model at L=6-11 dependent 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 θ_{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].

CIR-driven storm



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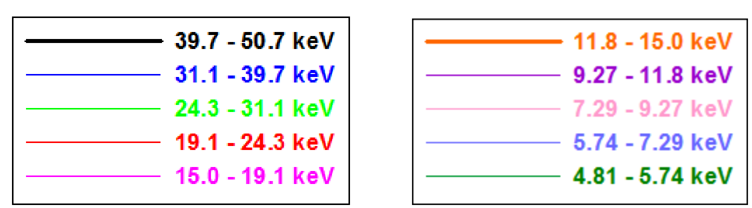
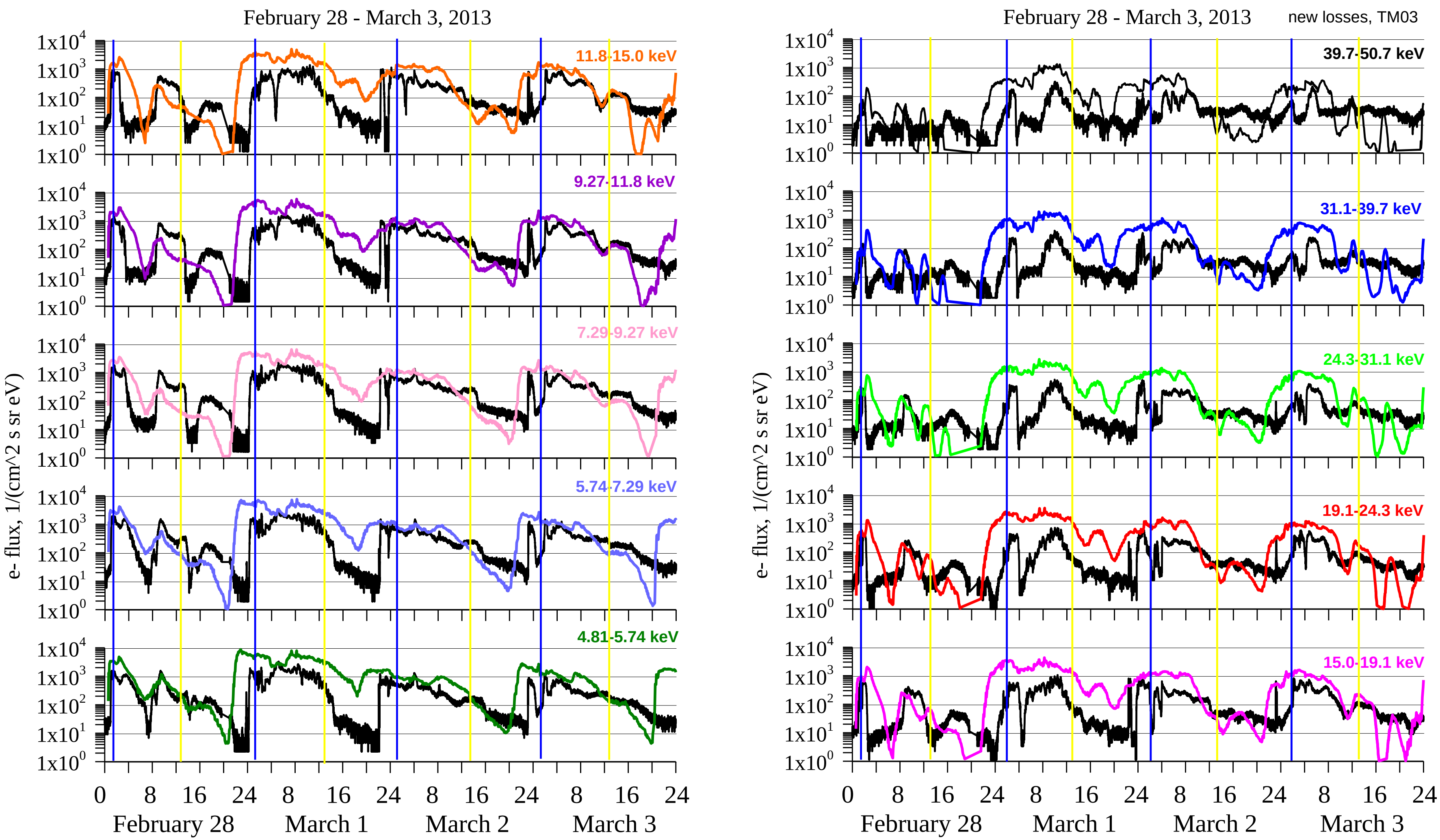


Electron fluxes observed by AMC 12 CEASE II ESA instrument for 15-50 keV energies and modeled

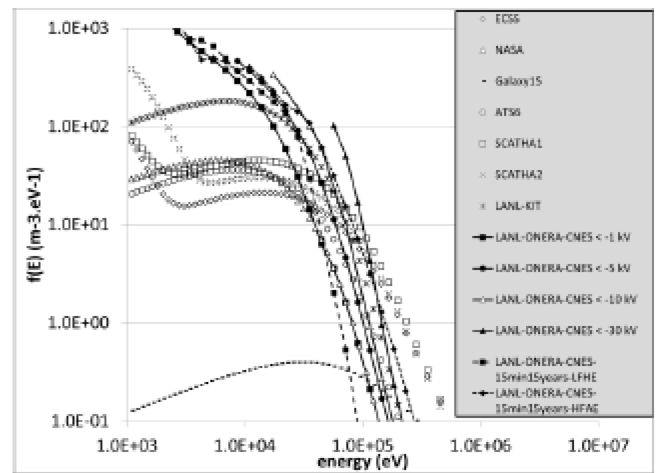
With **THEMIS** model and ***Orlova and Shprits* [2014] and *Orlova et al.* [2014]** electron lifetimes



LANL data in GEO

- 15 years of plasma measurements including electrons and protons
- 7 GEO LANL satellites
  - 1989-049, 1990-095, 1991-080, 1994-084, LANL-97A, ~~LANL-01A~~, LANL-02A
  - Electron detectors
    - MPA : 1keV – 40 keV
    - SOPA : 50 keV – 1.3 MeV
    - EPD : 1 MeV – some MeV
    - 15 years of data every 86 seconds

To be published, Mateo-Velez et al. 2016



- List of worst cases to be published 2016
  - Literature
  - High fluxes at all energies
  - Low fluxes at high energies
  - Large potentials on long durations

- We selected four LANL events out of 400

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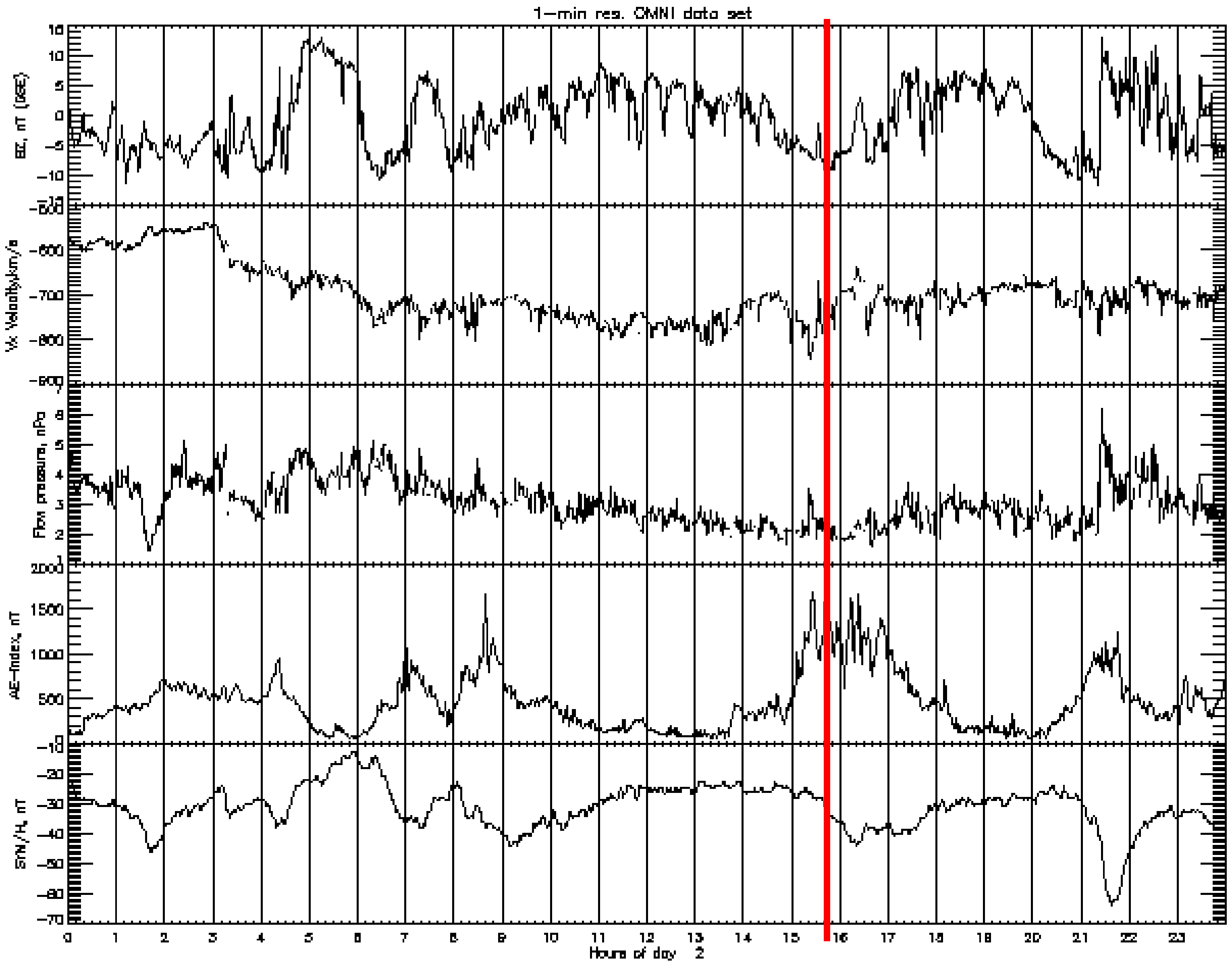
From presentation at **SCTC 2016, April 4-8, Noordwijk, The Netherlands: "**From GEO/LEO environment data to the numerical estimation of spacecraft surface charging at MEO" by J.C. Mateo-Velez et al.

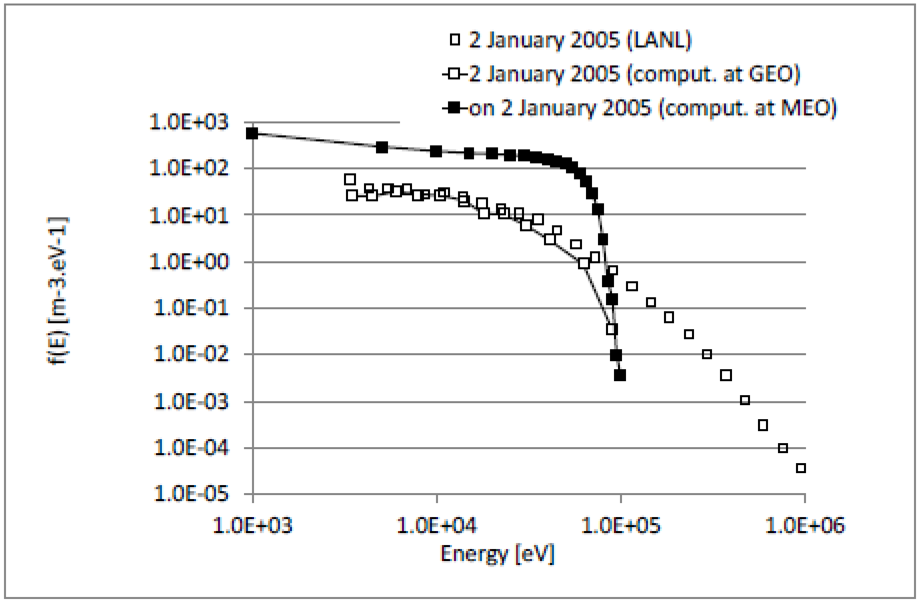
January 2, 2005, surface charging event



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

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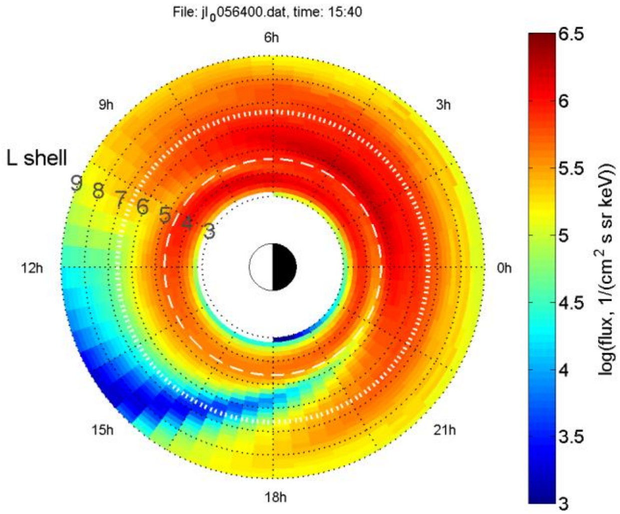
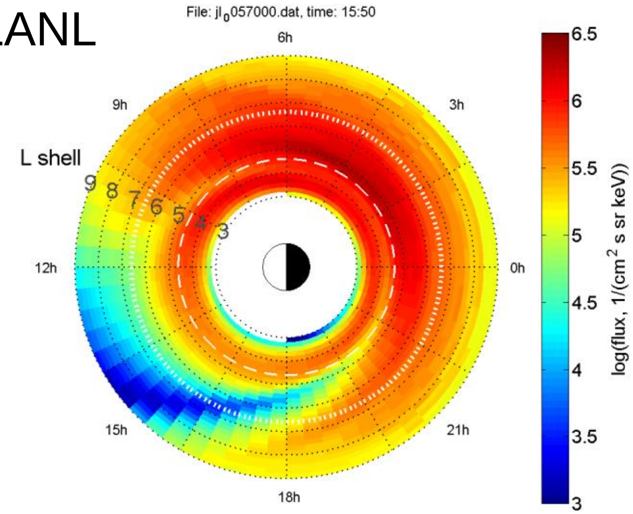
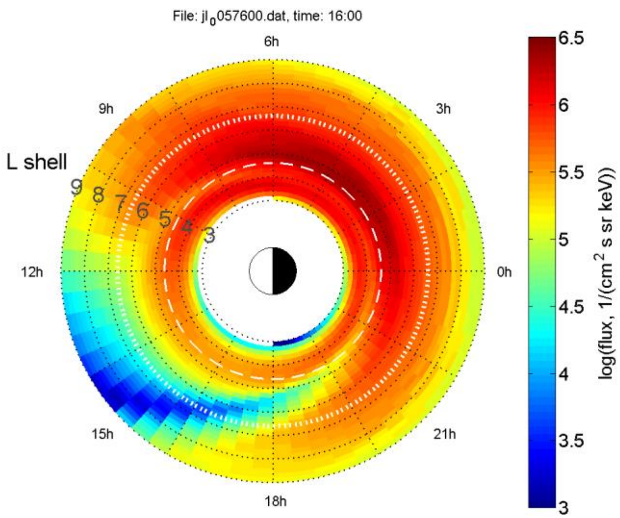
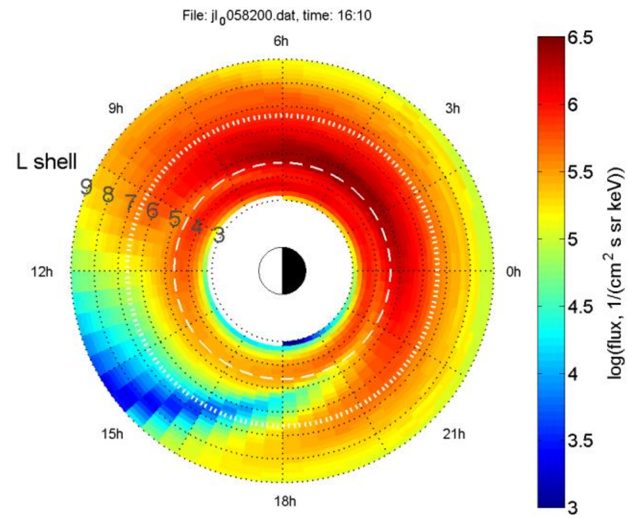
January 2, 2005, 1540 -1610 UT

Event at LANL

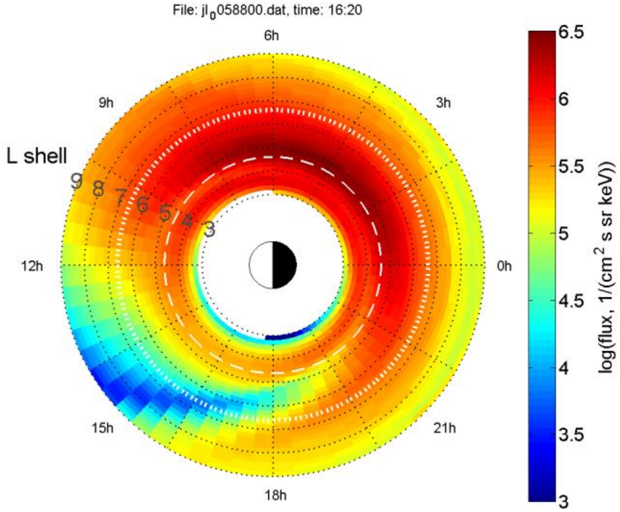


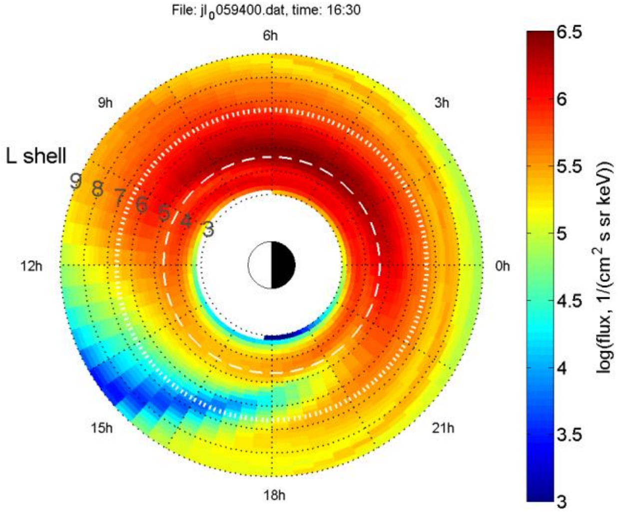


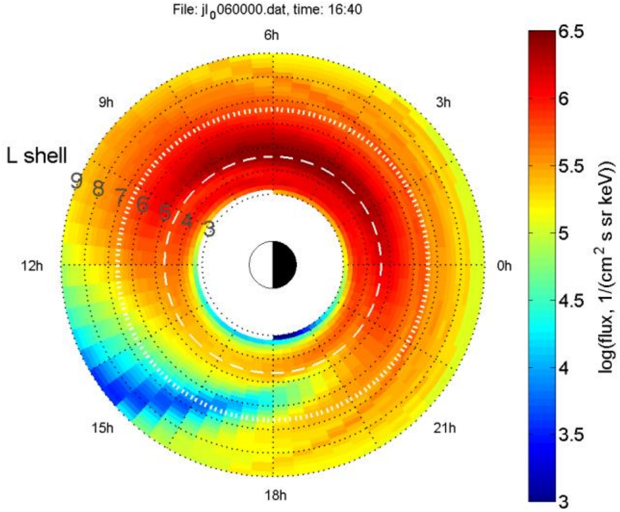


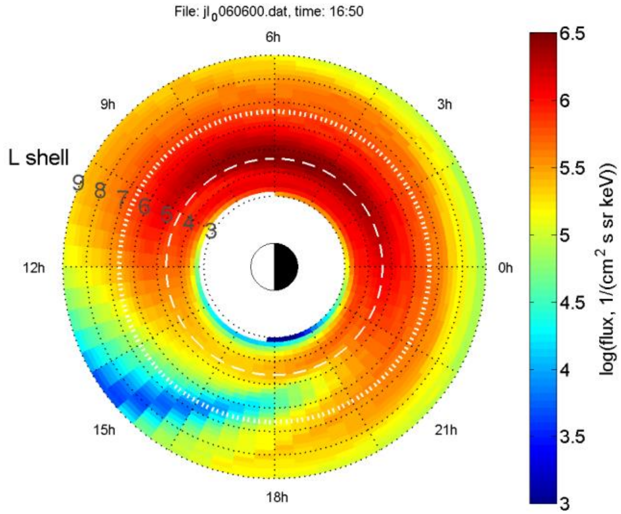


January 2, 2005, 1620 -1650 UT

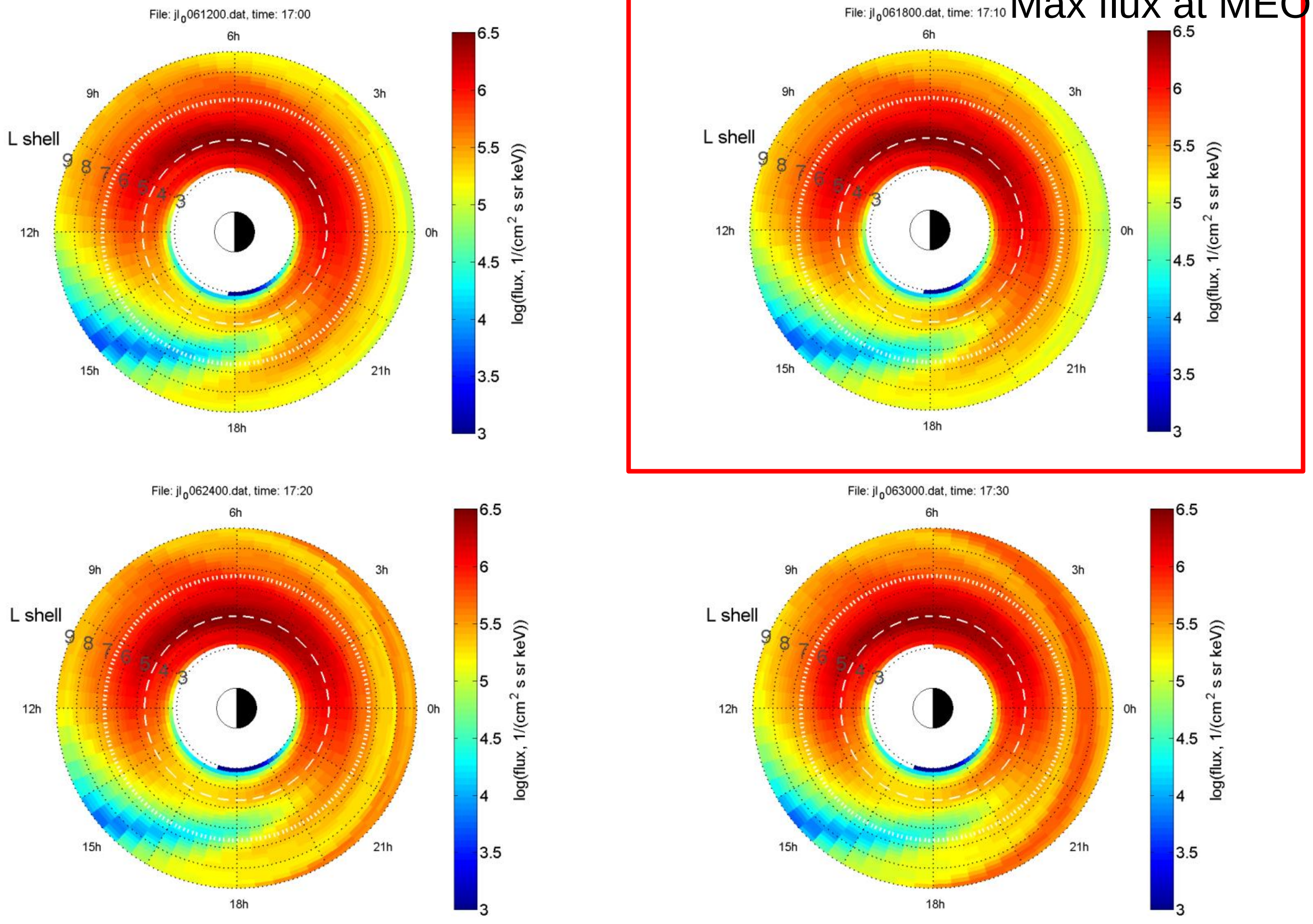








January 2, 2005, 1700 -1730 UT



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