Transport and acceleration of plasma sheet electrons to geostationary orbit

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Special thanks for Dave Pitchford (SES) for AMC 12 CEASE electron data, Lois Smith (Univ of Michigan) for Van Allen Probes ECT HOPE data plots

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

European Geosciences Union, General Assembly 2014, Vienna, Austria, 27 April – 02 May 2014

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Low energy electrons in the inner magnetosphere

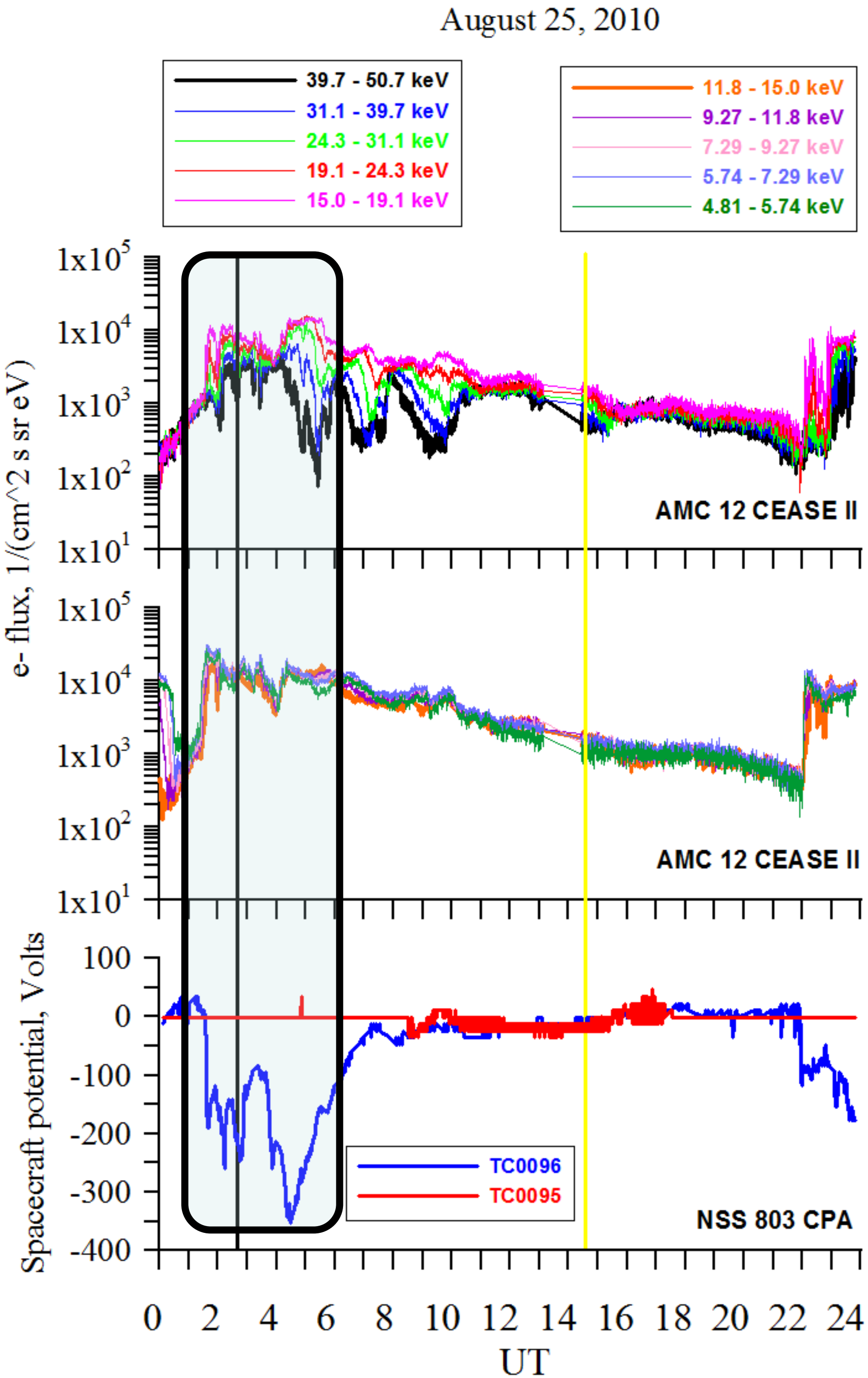
- The distribution of low energy electrons, the seed population (10 to few hundreds of keV), is critically important for radiation belt dynamics.

- Surface charging by electrons with < 100 keV can lead to discharges within and on the surface of the outer spacecraft layers that can cause significant damage and spacecraft anomalies.

- Satellite measurements cannot provide continuous measurements.

- With the development of the Inner Magnetosphere Particle Transport and Acceleration model (IMPTAM) for low energy particles in the inner magnetosphere [*Ganushkina et al.*, AnnGeo, *2005*, *JGR*, *2006*, AnnGeo, *2012*, *JGR*, *2013*, *2014*], the computational view on the low energy electron fluxes important for radiation belts at L=2-10 is now feasible.

AMC 12 CEASE II ESA data

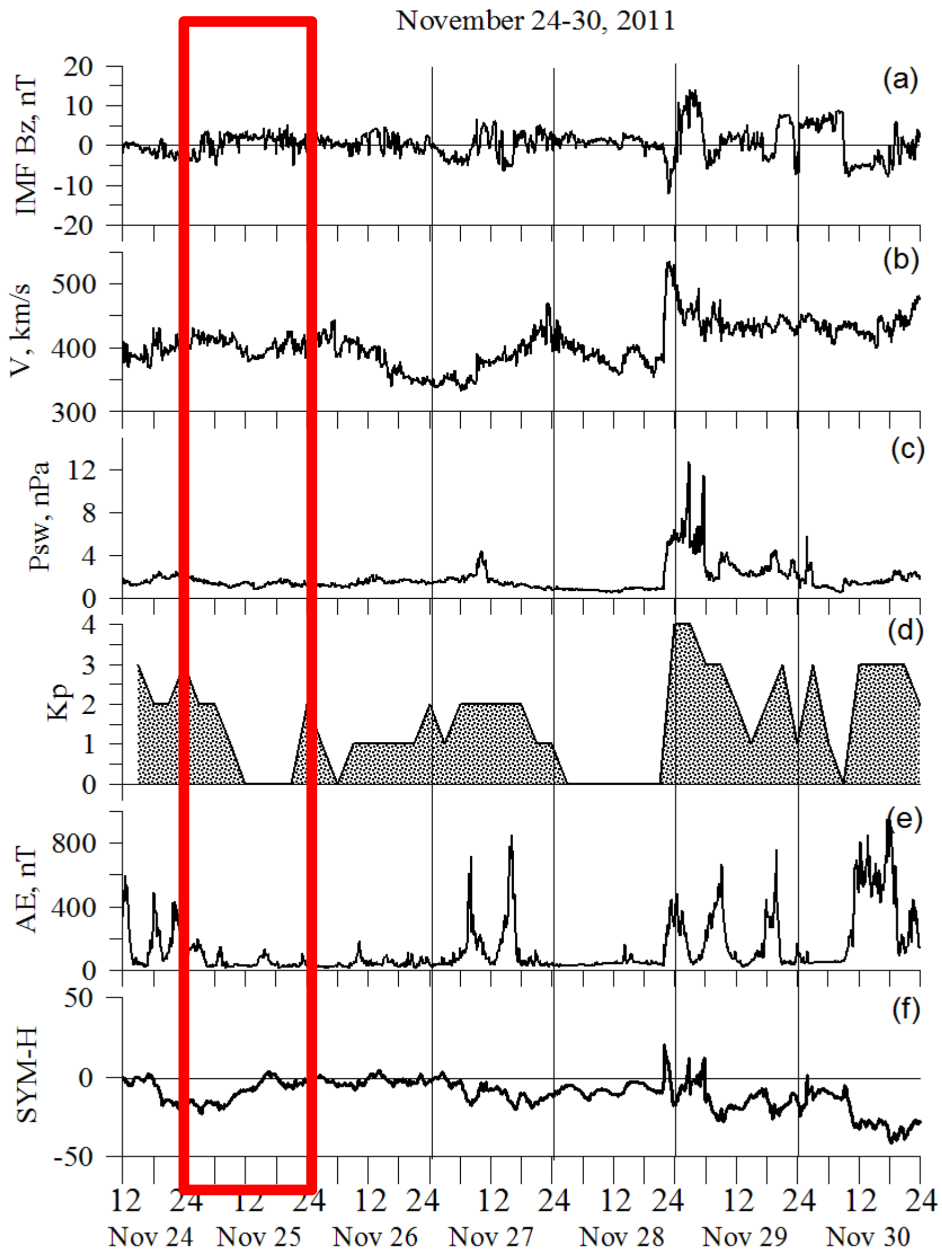


The data come from the AMC 12 geost. satellite at 322.5 Deg E.
CEASE-II (Compact Environmental Anomaly Sensor) instrument contains an Electrostatic Analyzer (ESA) for measuring low energy electron fluxes in 10 channels, 5 - 50 keV.

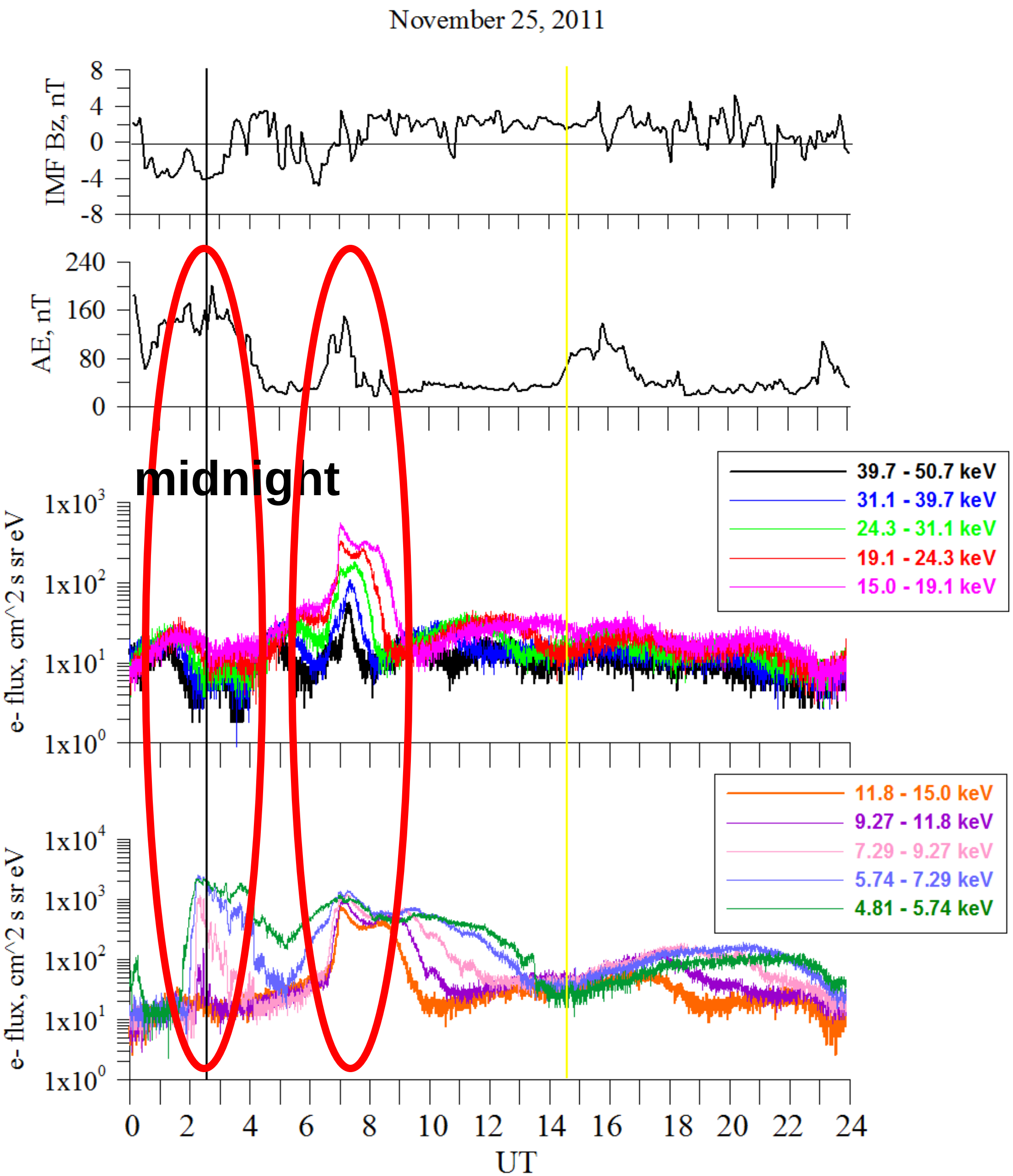
The measured low energy electrons are responsible for surface charging.
The CPA (Charge Plate Assembly) sensor is at geost. spacecraft NSS-803 at 340 Deg E.
Signatures from both CEASE II and CPA sensors can be compared.

The TC0095 and TC0096 are Charge Plates, one on either a North or South Panel (TC0095) and one on the anti-earth panel (TC0096).
During the periods of increased low energy electron fluxes, there exist the clear increase in the spacecraft potential magnitudes.

Quiet event example



5-50 keV electrons during quiet event



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

- The lower the energy, the large the flux

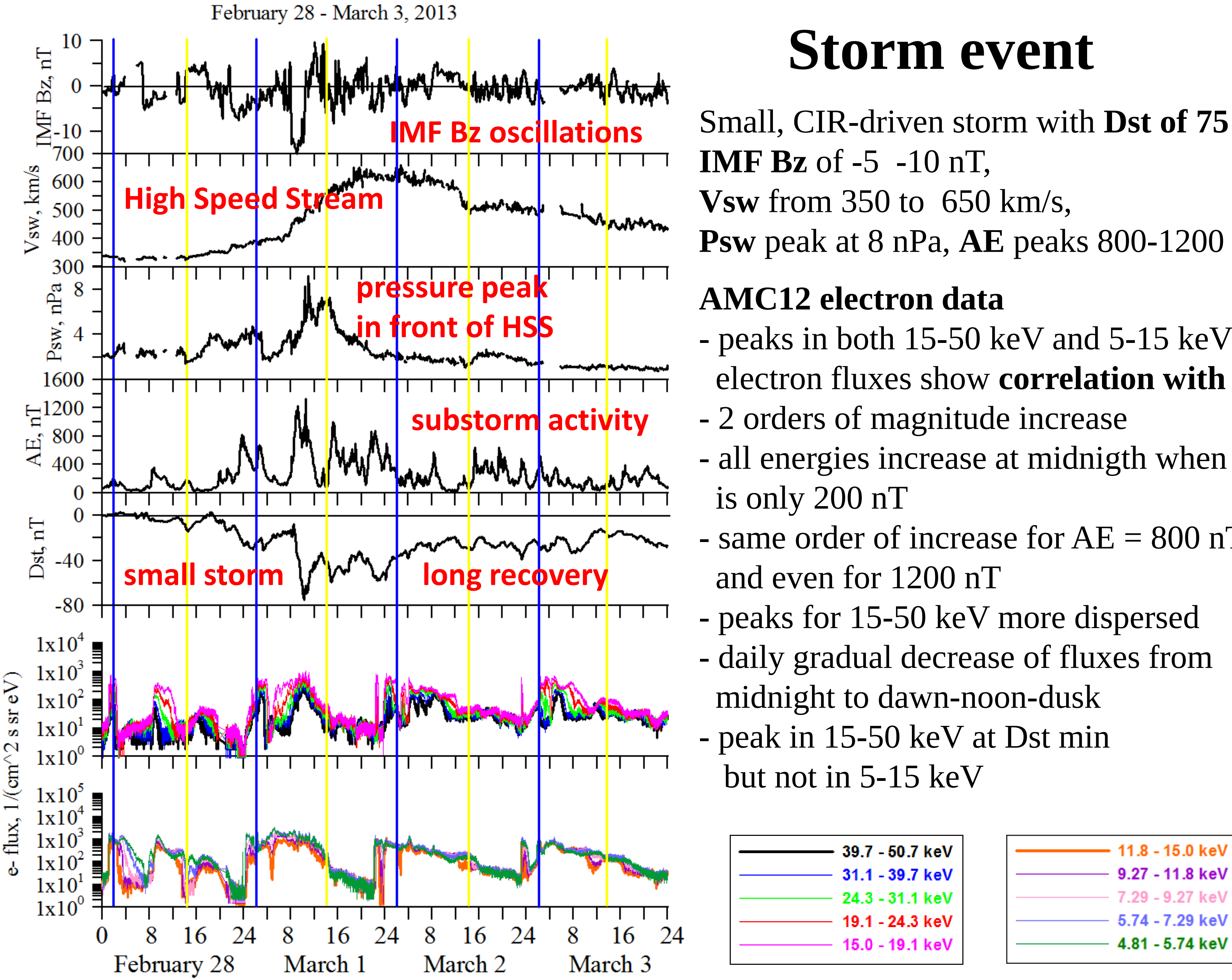
- Electrons of different channels behaves differently

- 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

Storm event



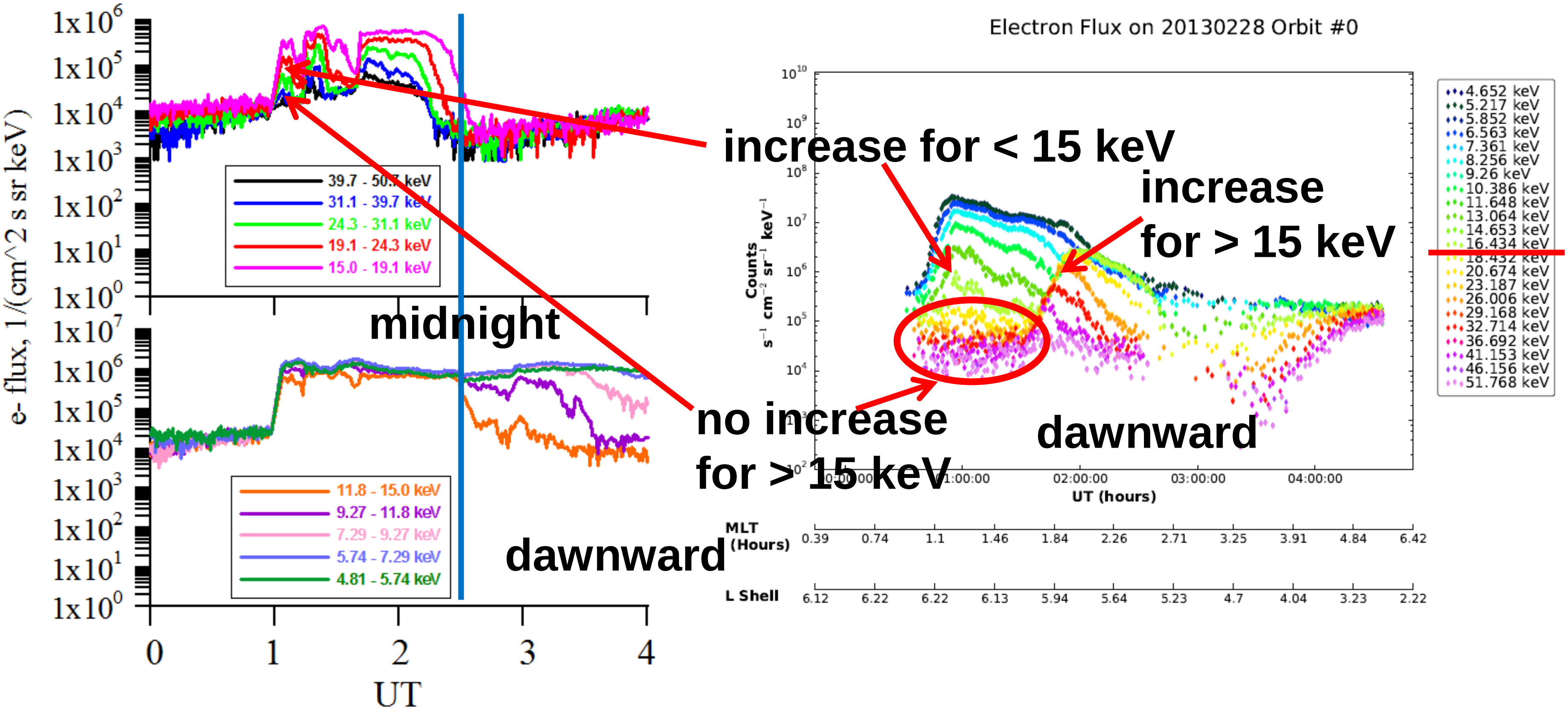
Small, CIR-driven storm with **Dst of 75 nT**
IMF Bz of -5 -10 nT,
Vsw from 350 to 650 km/s,
Psw peak at 8 nPa, **AE** peaks 800-1200 nT

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 midnigth when AE is only 200 nT
- same order of increase for AE = 800 nT and even for 1200 nT
- peaks for 15-50 keV more dispersed
- daily gradual decrease of fluxes from midnight to dawn-noon-dusk
- peak in 15-50 keV at Dst min but not in 5-15 keV

February 28, 2013, closer look

AMC 12, CEASE II | **Van Allen Probe A, ECT HOPE**



- **AMC 12 and Van Allen Probe A are close**, moving dawnward, AMC 12 at geostationary, Van Allen Probe moves inward (L from 6.2 to 3.2)
- **Flux values**: 1 order of magnitude difference AMC 12 fluxes being lower
- Similar: initially, no increase for > 15 keV, increase for < 15 keV, later increase for > 15 keV

Inner Magnetosphere Particle Transport and Acceleration Model (IMPTAM)

(*Ganushkina et al., 2005, 2012, 2013, 2014*)

♦ traces **ions and electrons** with arbitrary pitch angles from the plasma sheet to the inner L-shell regions with energies up to **hundreds of keVs** 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.

IMPTAM modelling

Main question: which variations in the observed electron fluxes are caused by
(1) Variations of SW and IMF parameters (used in time-dependent boundary conditions, magnetic and electric fields;
(2) Electron losses;
(3) Variations of electromagnetic fields associated with substorms.

Magnetic field model: T96 (Dst, Psw, IMF By and Bz)
Electric field model: Boyle (Vsw, IMF B, By, Bz)
Boundary conditions: Tsyganenko and Mukai (Vsw, IMF Bz,Nsw)

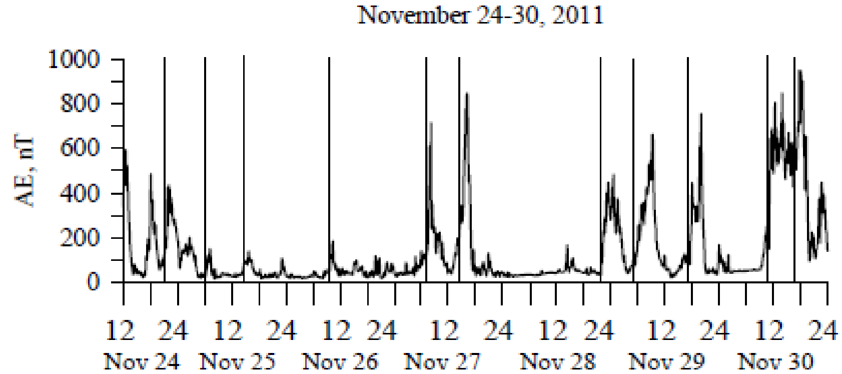
Losses: Kp, magnetic field
Strong diffusion (L=10-6): $\tau_{sd} = \left(\frac{\gamma m_0}{p}\right)\left[\frac{2\Psi B_h}{1-\eta}\right]$ (*Chen et al.*, 2005)

Weak diffusion (L=2-6): $\tau_{wd} = 4.8 \cdot 10^4 B_w^{-2} L^{-1} E^2, \quad B_w^2 = 2 \cdot 10^{2.5+0.18Kp}$
(*Shprits et al.*, 2007)

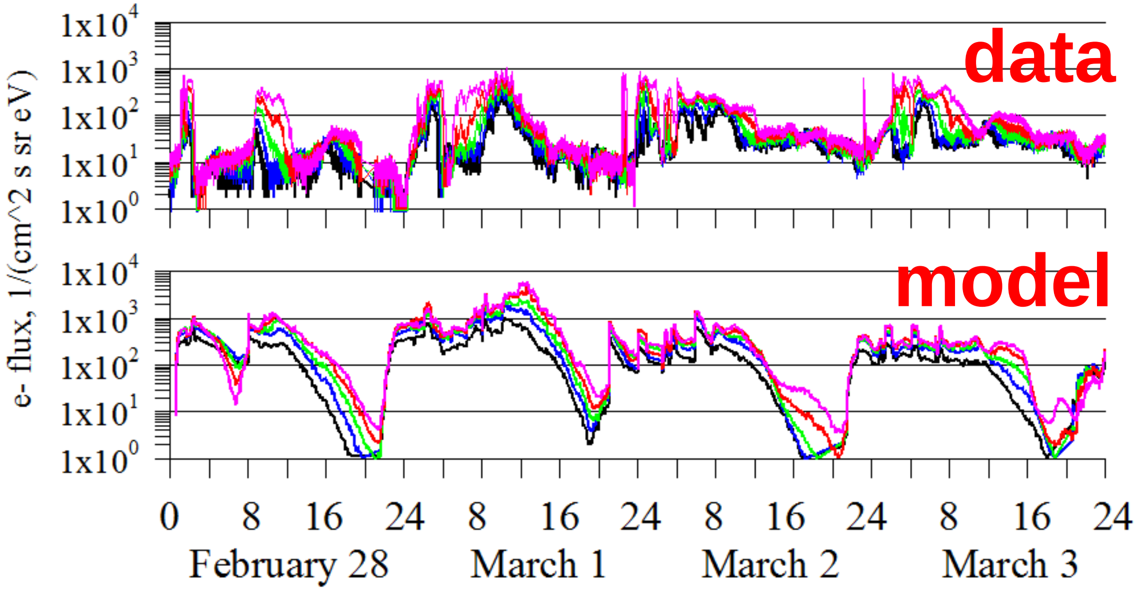
Electromagnetic pulses at substorm onsets:

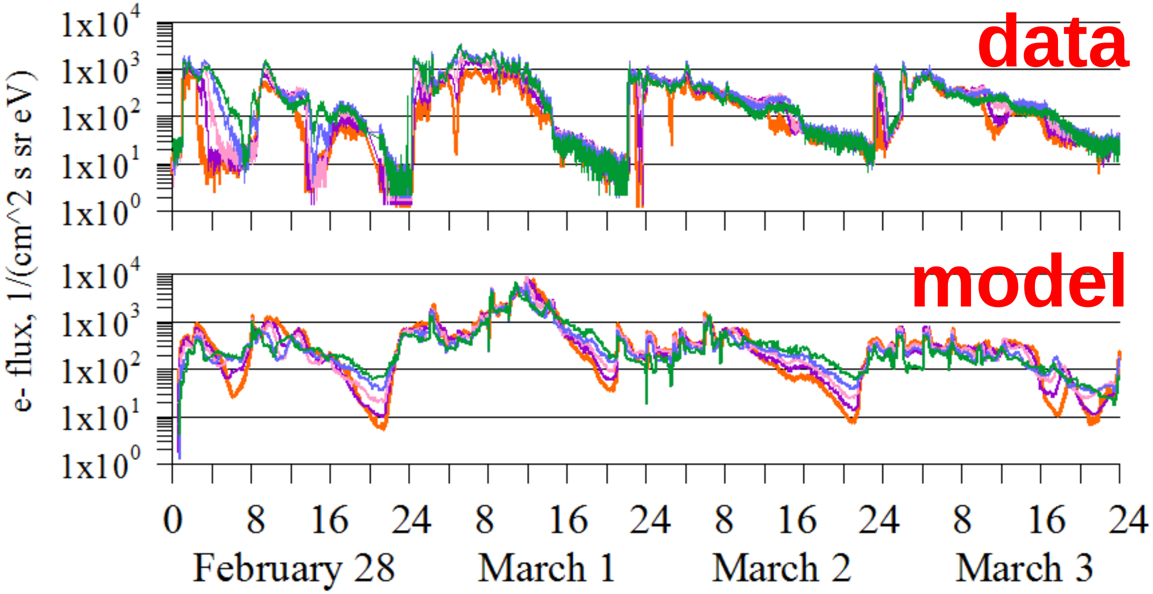
$$\mathrm{E}_\phi = -\mathrm{E}_0 \left(1 + \mathrm{c}_1 \cos(\phi - \phi_0)\right)^{\mathrm{p}} \exp\left(-\xi^2\right),$$

(*Li et al.*, 1998; *Sarris et al.*, 2002)
Timing and amplitude from AE index



February 28 – March 3, 2013 modeling results for 15-50 keV (AMC 12 geostationary)





- Modeled fluxes at observed levels of magnitude

- Main peaks followed but not large enough

- Losses responsible for flux daily decrease

-5-15 keV are better modeled!

- Pulse representation needs to be corrected: peaks are not as big as observed

Summary

1. The variations of fluxes for **5-50 keV electrons** observed by CEASE II ESA instrument onboard AMC 12 satellite were analyzed.
   - During non-storm times, flux peaks are related to AE peaks (even small substorms)
   - Flux increase by 2 orders of magnitude, same for AE=400 nT and 1200 nT
   - Substorm-associated electromagnetic fields play a significant role in the electrons' transport and acceleration from the plasma sheet to the inner magnetosphere

2. Modeling for small CIR- storm:
   The variations in the observed electron fluxes are caused by
   (1) **Variations of SW and IMF parameters** (used in time-dependent boundary conditions, magnetic and electric fields:
   only main peaks and general pattern, when SW and IMF variations are significant.

   (2) **Electron losses** (represented as electron lifetimes, dependent on magnetic field and Kp index): main trends in flux daily decrease when going duskward via noon.

   (3) Variations of electromagnetic fields associated with **substorms**:
   needed to explain flux variations correlated with AE index peaks, uniform representation of electromagnetic pulse scaled by AE value can not be used, flux peaks are not dependent on AE magnitude.