# Wave-particle interactions for low energy electrons in the inner Earth's magnetosphere

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# 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!

# The Model: IMPTAM

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**

**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 (<200 keV) 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.

# Inner Magnetosphere Particle Transport and Acceleration Model (IMPTAM)

♦ 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.

♦ all details are given in

**Ganushkina, N. Y**., M. W. Liemohn, O. A. Amariutei, and D. Pitchford (2014), Low-energy electrons (5–50 keV) in the inner magnetosphere, JGR, 119, doi:10.1002/2013JA019304.
**Ganushkina, N. Y**., et al. (2013), Transport of the plasma sheet electrons to the geostationary distances, JGR, 118, doi:10.1029/2012JA017923.

# 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)**: $\tau_{sd} = \left(\frac{\gamma m_0}{p}\right)\left[\frac{2\Psi B_h}{1-\eta}\right]$

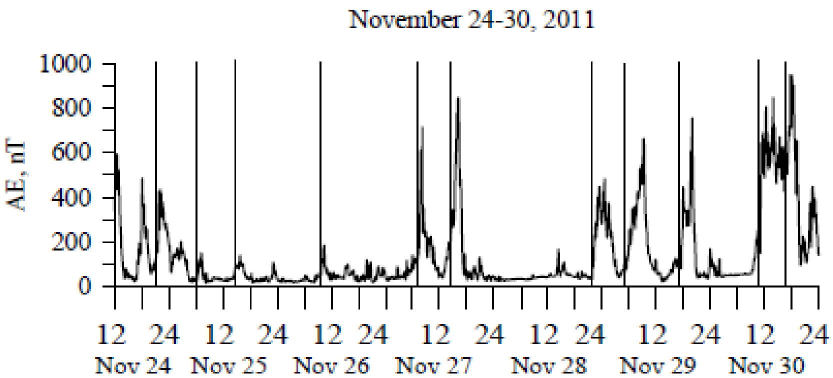
**Weak diffusion (L=2-6)**: $\tau_{wd} = 4.8 \cdot 10^4 B_w^{-2} L^{-1} E^2, \quad B_w^2 = 2 \cdot 10^{2.5+0.18Kp}$

**Electromagnetic pulses at substorm onsets:**

$$E_\phi = -E_0 \left(1 + c_1 \cos(\phi - \phi_0)\right)^p \exp\left(-\xi^2\right),$$

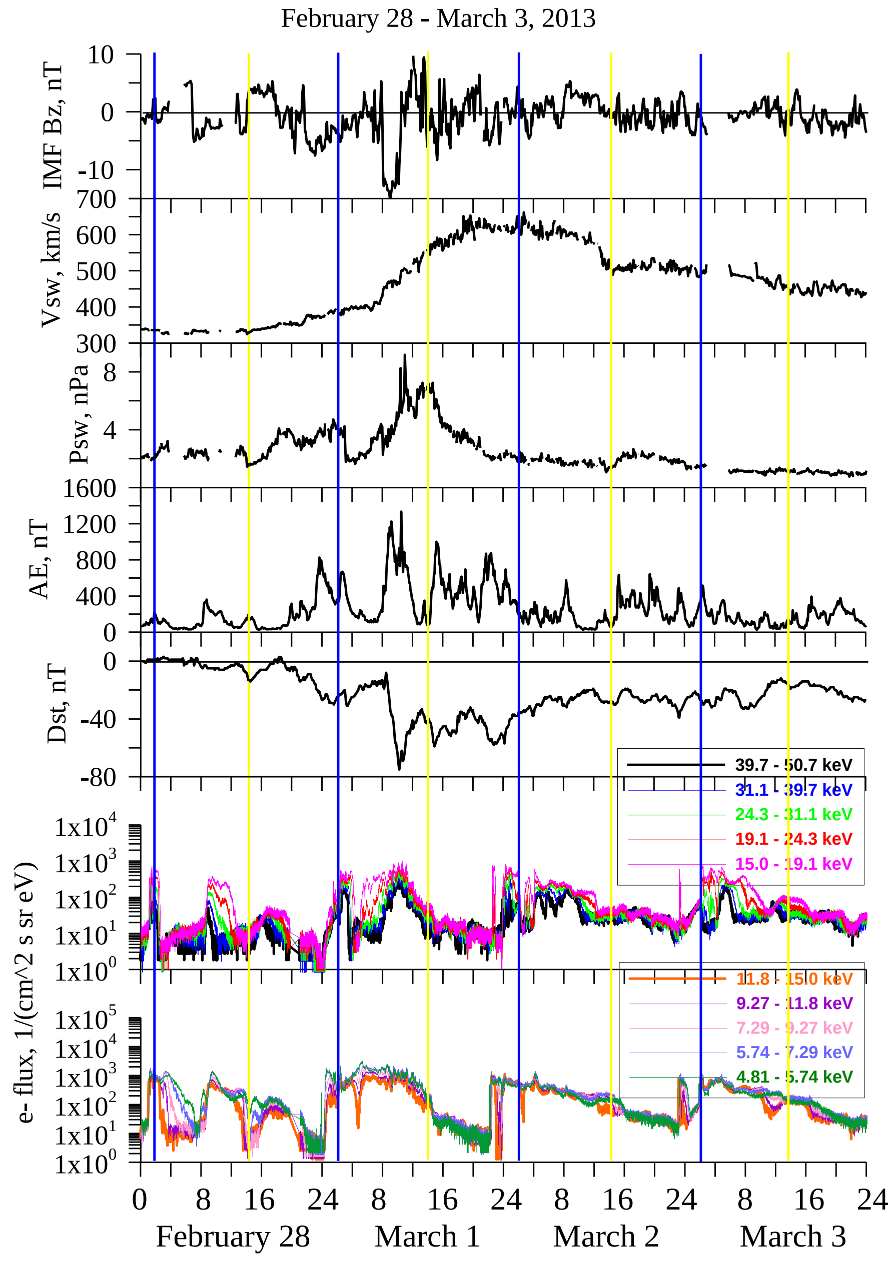
(*Li et al.*, 1998; *Sarris et al.*, 2002)

Timing and amplitude from AE index



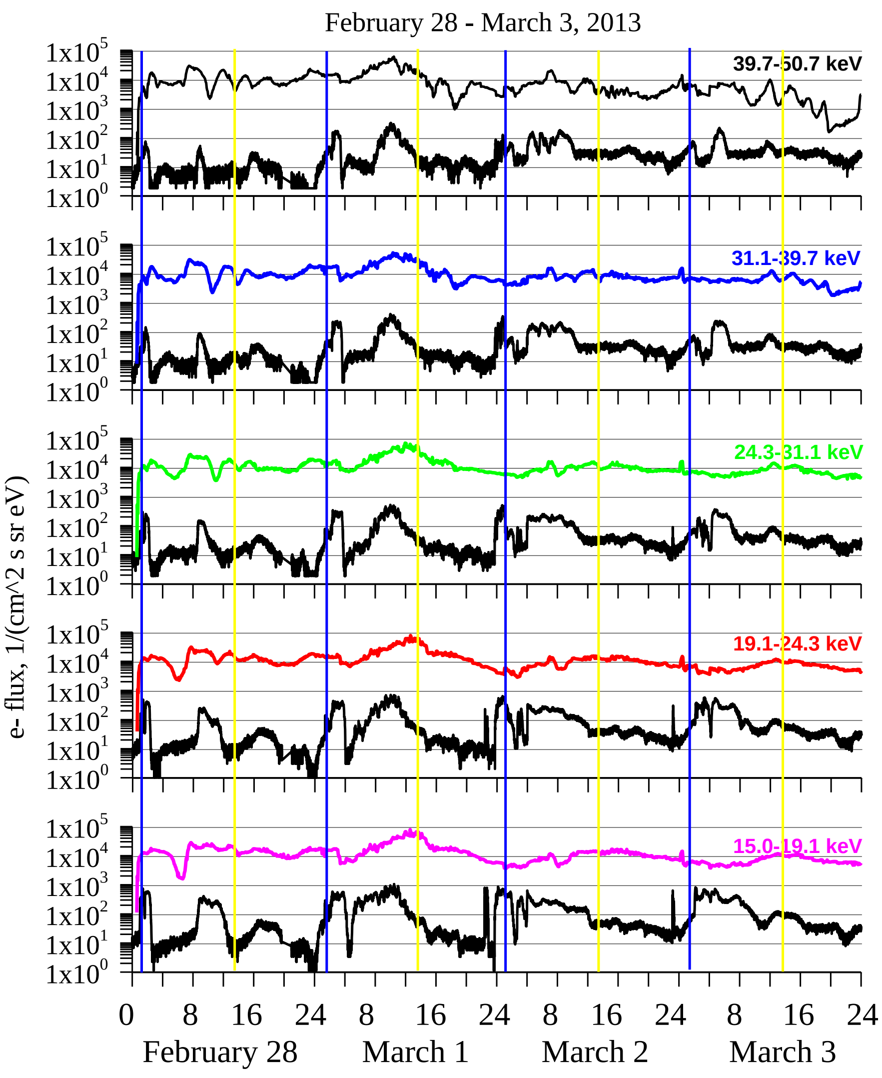
# AMC 12 CEASE II ESA data

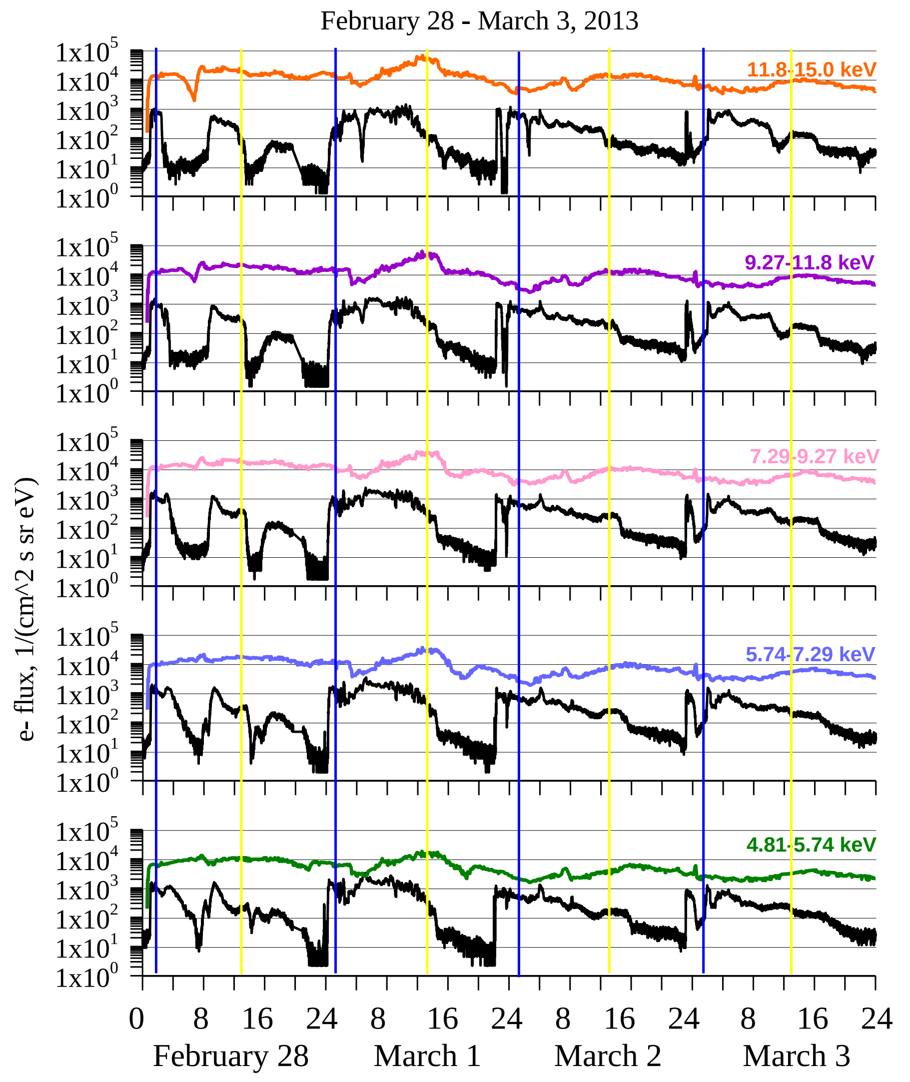
AMC 12 geostationary satellite, CEASE-II instrument contains an Electrostatic Analyzer (ESA) for measuring low energy electron fluxes in 10 channels, 5 - 50 keV.



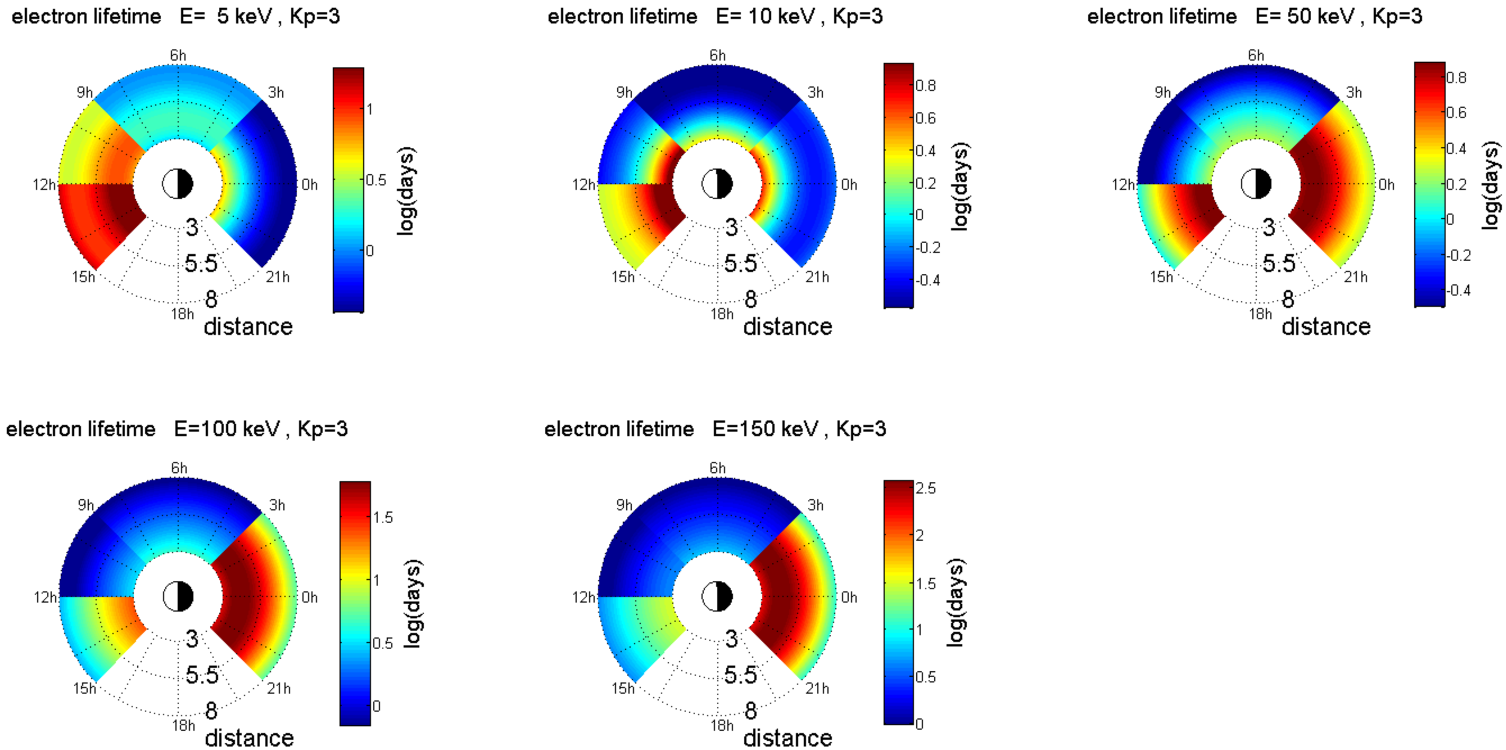
# Electron fluxes observed by AMC 12 CEASE II ESA instrument for 5-50 keV energies and modeled. No losses are considered.

With *Tsyganenko and Mukai* (2003) boundary conditions



# Losses for low energy electrons due to wave-particle interactions

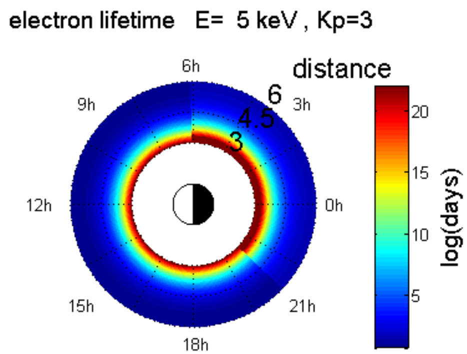


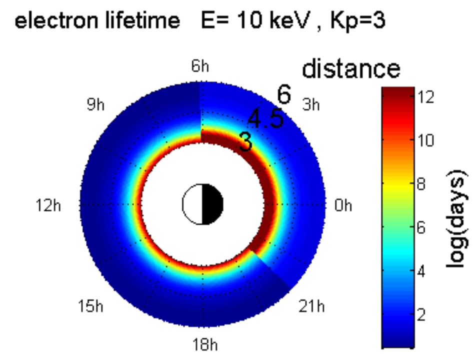

**Parameterization of the electron lifetimes due to interactions with chorus waves** [*Orlova and Shprits*, 2014]:

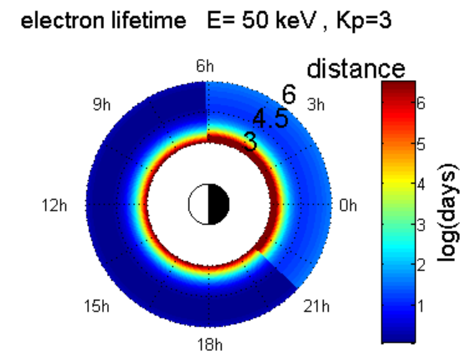
polynomial expressions with 33 coefficients dependent on energy, radial distance, MLT sector and Kp.

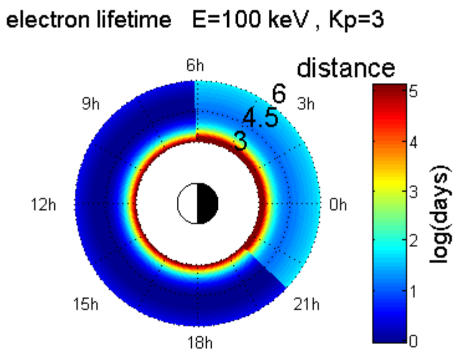
The model can be used for R=3-8 $R_E$, Kp= 0-6, and electron energies from 1 keV to 2 MeV. MLT sectors include the night ($-3 \leq MLT \leq 3$), dawn ($3 \leq MLT \leq 9$), prenoon ($9 \leq MLT \leq 12$), and postnoon ($12 \leq MLT \leq 15$) segments.

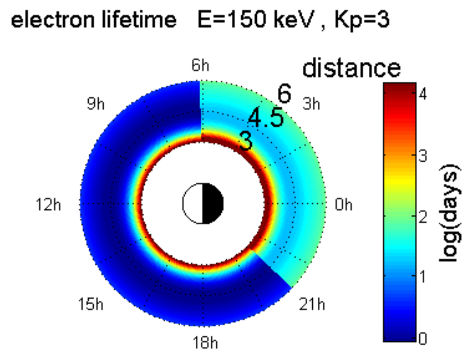
# Losses for low energy electrons due to wave-particle interactions



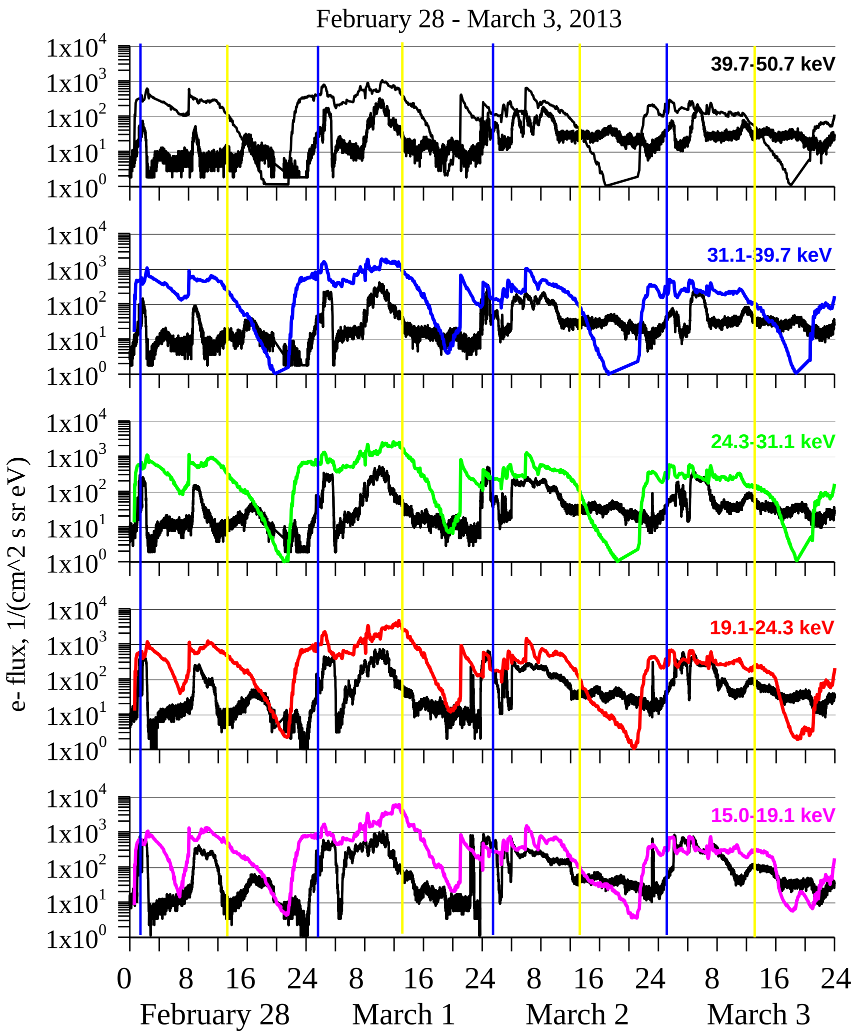



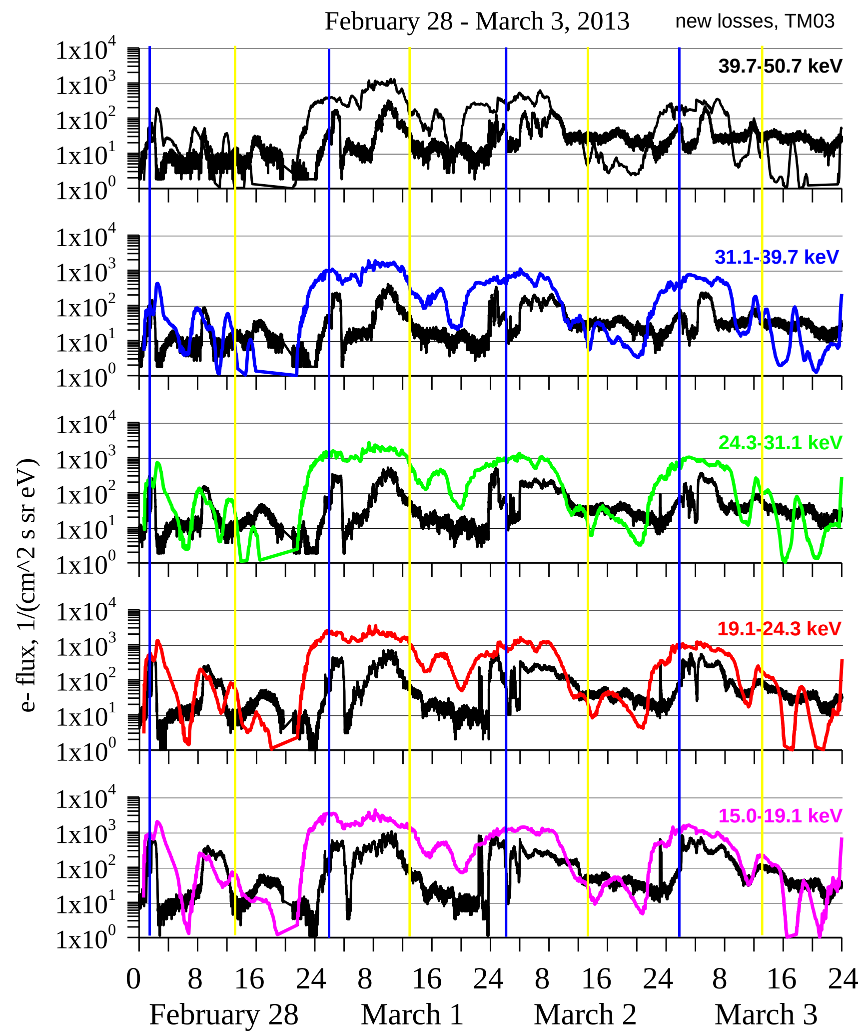

**Parameterization of the electron lifetimes due to interactions with hiss waves**
[*Orlova et al.*, 2014]:
two sectors, nightside at 21-06 MLT and dayside at 06-21 MLT,
with corresponding coefficients. The obtained parameterization is valid for distances from 3 to 6 Re, *Kp*-indices up to 6, and energies from 1 keV to 10 MeV.

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

***Chen et al.*** **[2005]** electron lifetimes for strong and ***Shprits et al.*** **[2007]** for weak diffusion

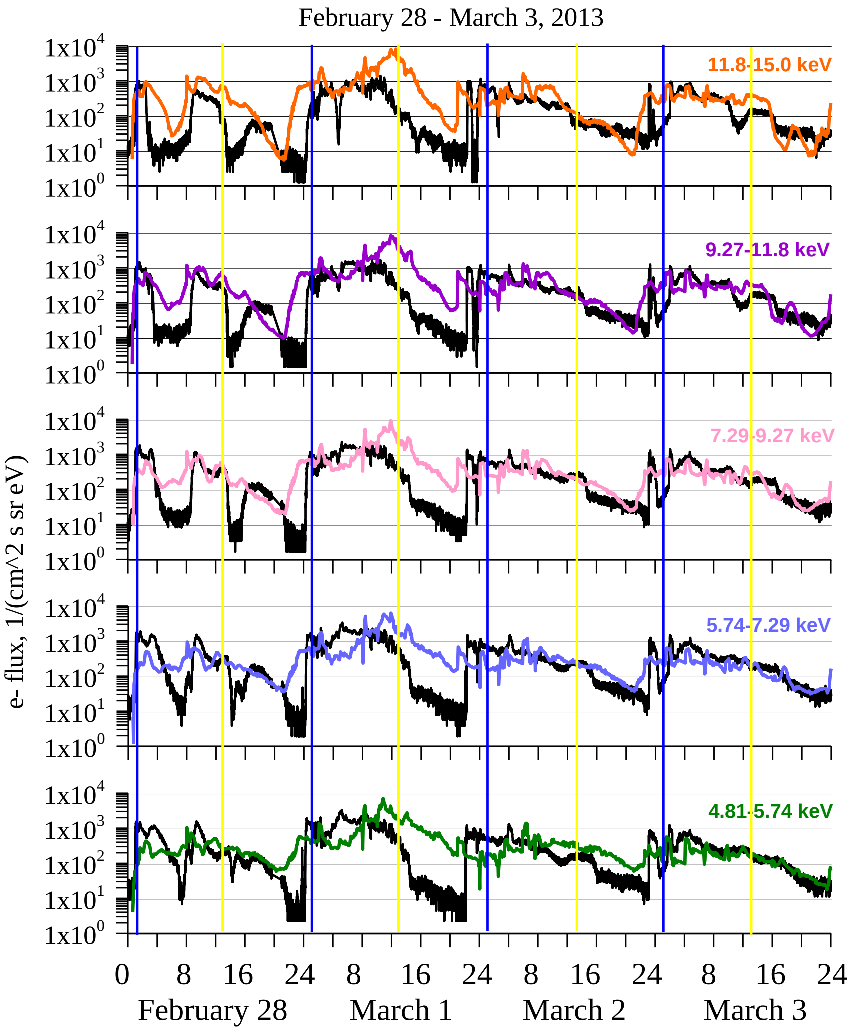
***Orlova and Shprits*** **[2014] and *Orlova et al.*** **[2014]** electron lifetimes



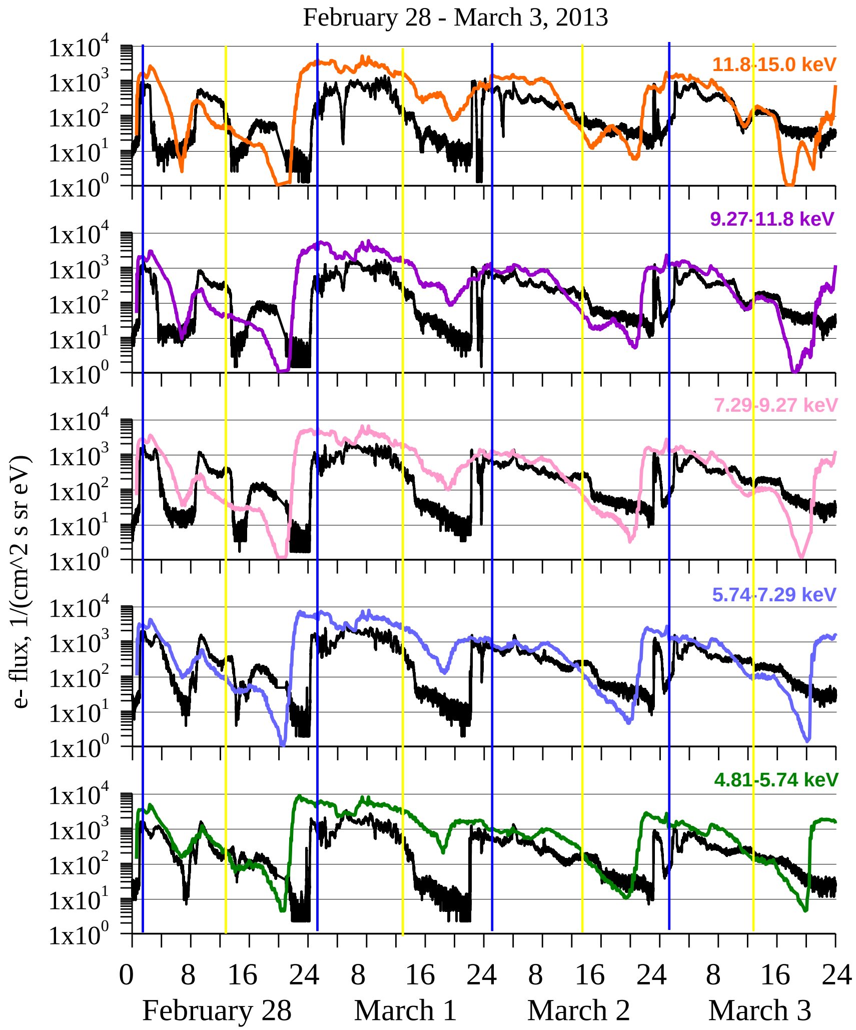



# Electron fluxes observed by AMC 12 CEASE II ESA instrument for 5-15 keV energies and modeled

*Chen et al.* [2005] electron lifetimes for strong and *Shprits et al.* [2007] for weak diffusion




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



# Summary

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].

When these losses incorporated into IMPTAM, the modeled fluxes follow reasonable well the observed ones. The comparison was done for AMC 12 CEASE II electron data for 5-50 keV.

At the same time, there are time intervals, especially during storm main phase, when there are deviations of modeled fluxes from the observed. We plan to continue working under correct loss processes for low energy electrons by incorporating pitch angle diffusion coefficients from radiation belts models.