PEMEM: new probability model of keV plasma environment inside geostationary orbit.

S. Dubyagin, N. Ganushkina - Finnish Meteorological Institute (FMI)

A. Sicard, J.-C. Matéo-Vélez - The French Aerospace Lab (ONERA)

D. Heynderickx - DH Consultancy (DHC)

P. Jiggens, G. Deprez, F. Cipriani - ESTEC, ESA

Plasma Environment Modelling in the Earth's Magnetosphere (PEMEM)

ESA contract No. 4000128226/19/NL/AS

PEMEM model: probability model of plasma environment intended to be used for the surface charging risk assessment during the missions planning (focus is on EOR to GEO).

Surface charging is known to be controlled by electron flux at ~10keV energy and by cold ion population (e.g. *Thomsen et al.*, 2013, *Sarno-Smith et al.*, 2016, *Matéo-Vélez et al.*, 2015, 2018, 2019)

Energy range: electrons 1 keV - 100 keV integrated and differential flux
protons 100 eV - 50 keV differential flux

Model concept

Input:

- Orbital information
- Mission duration
- Percentile level
- Confidence level

Output (expected for given orbit):

- Percentile spectra for e- and p+
- Flux threshold which will not be exceeded for given confidence during the mission lifetime
- Worst case electron spectrum for given confidence

➢ Multi-Maxwellian parameters for the spectra can be used as input to SPIS.

➢ The same parameters for eclipse are output separately

Model modules:

- **I. Electron percentile flux:**

Statistical distributions of the differential (1-100 keV) and integrated (>1keV and up to 100keV) electron fluxes expected to be encountered by a planned mission (calculated along the mission orbit).

- **II. Proton percentile flux** (is not discussed today)**:**

Statistical distributions of the differential (100eV-50 keV) proton fluxes expected to be encountered by a planned mission (calculated along the mission orbit).

- **III. Electron flux enhancement events occurrence and worst case electron spectra:**

Monte-Carlo simulation driven by historical time-series of AE index.
It outputs worst-case electron spectrum and integrated flux for the specified confidence level.

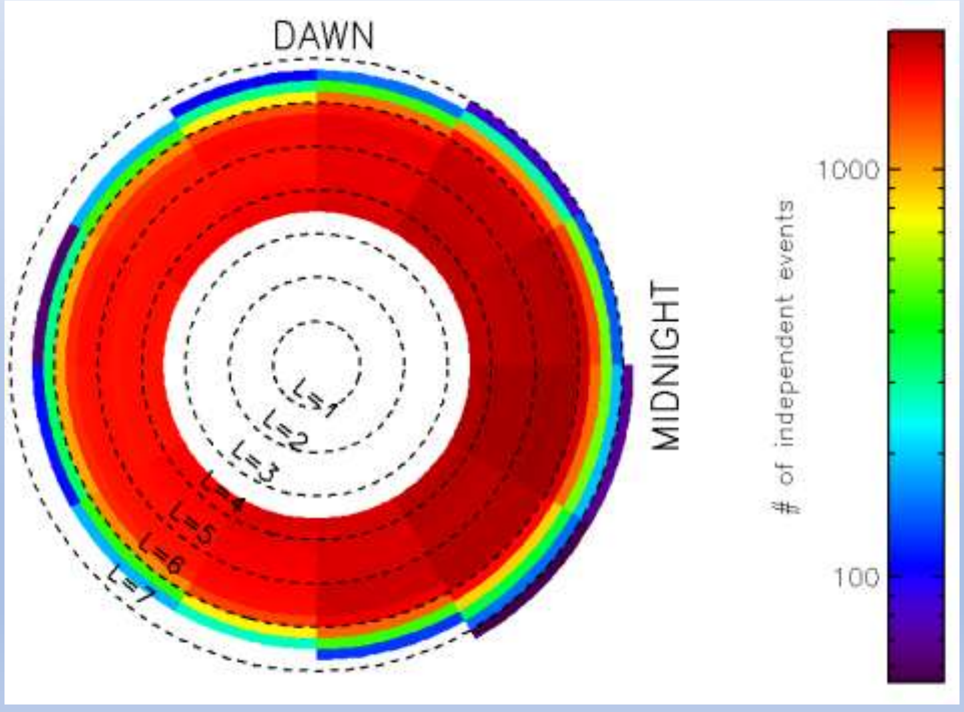
Model's parent dataset: Van Allen probes (RBSP) 2013-2018, omnidirectional flux (23 sec res.)
Electrons: HOPE+MagEIS 1keV-100keV
Protons: HOPE 100 eV - 50 keV

Model coordinates: 2D, L-shell, MLT

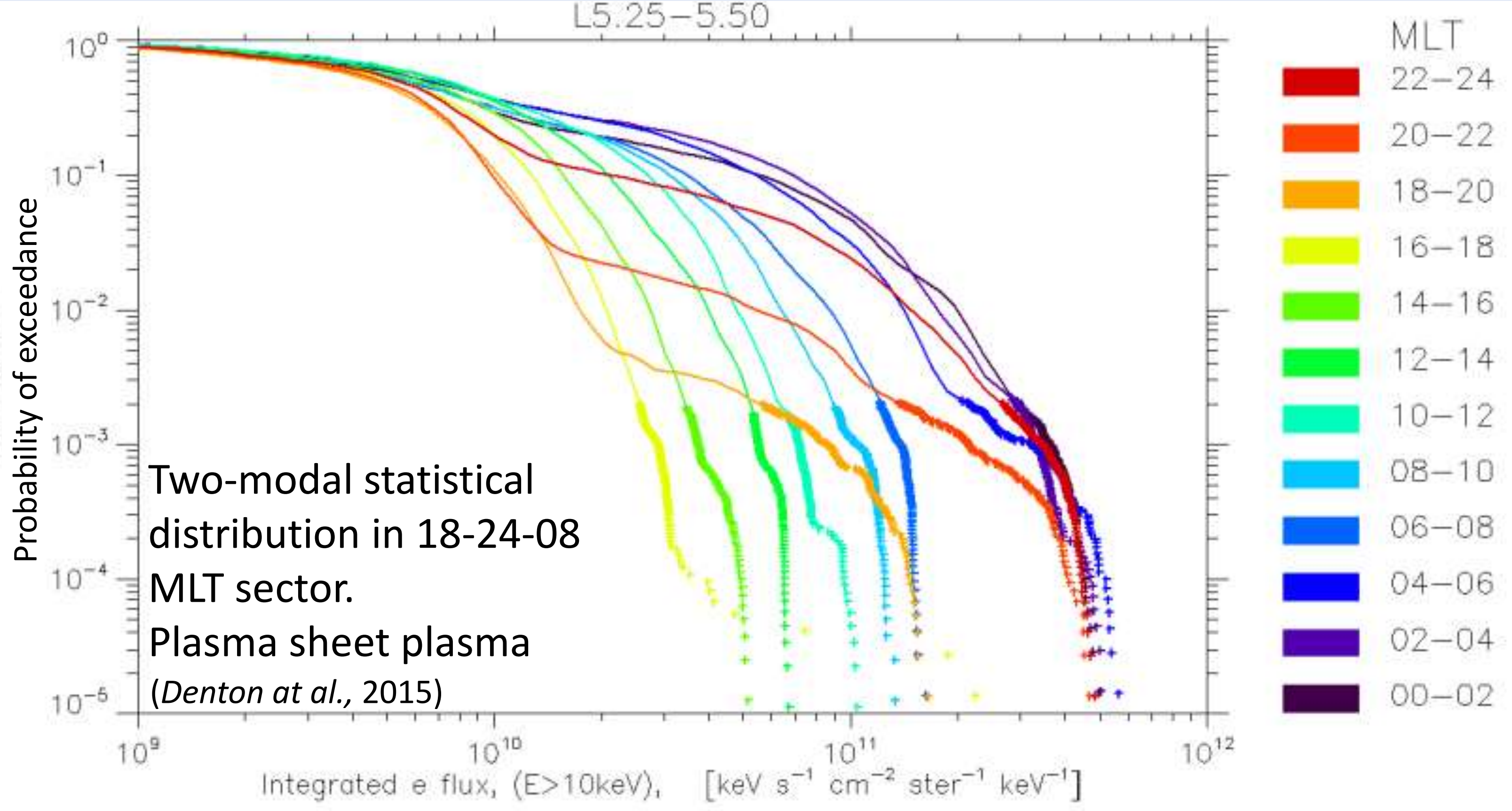
Spatial data binning: 2h MLT x 0.25 L

Modelled region (RBSP coverage):
3.5 < L < ~6.5 (can be extended outwards up to L~8), near-equatorial

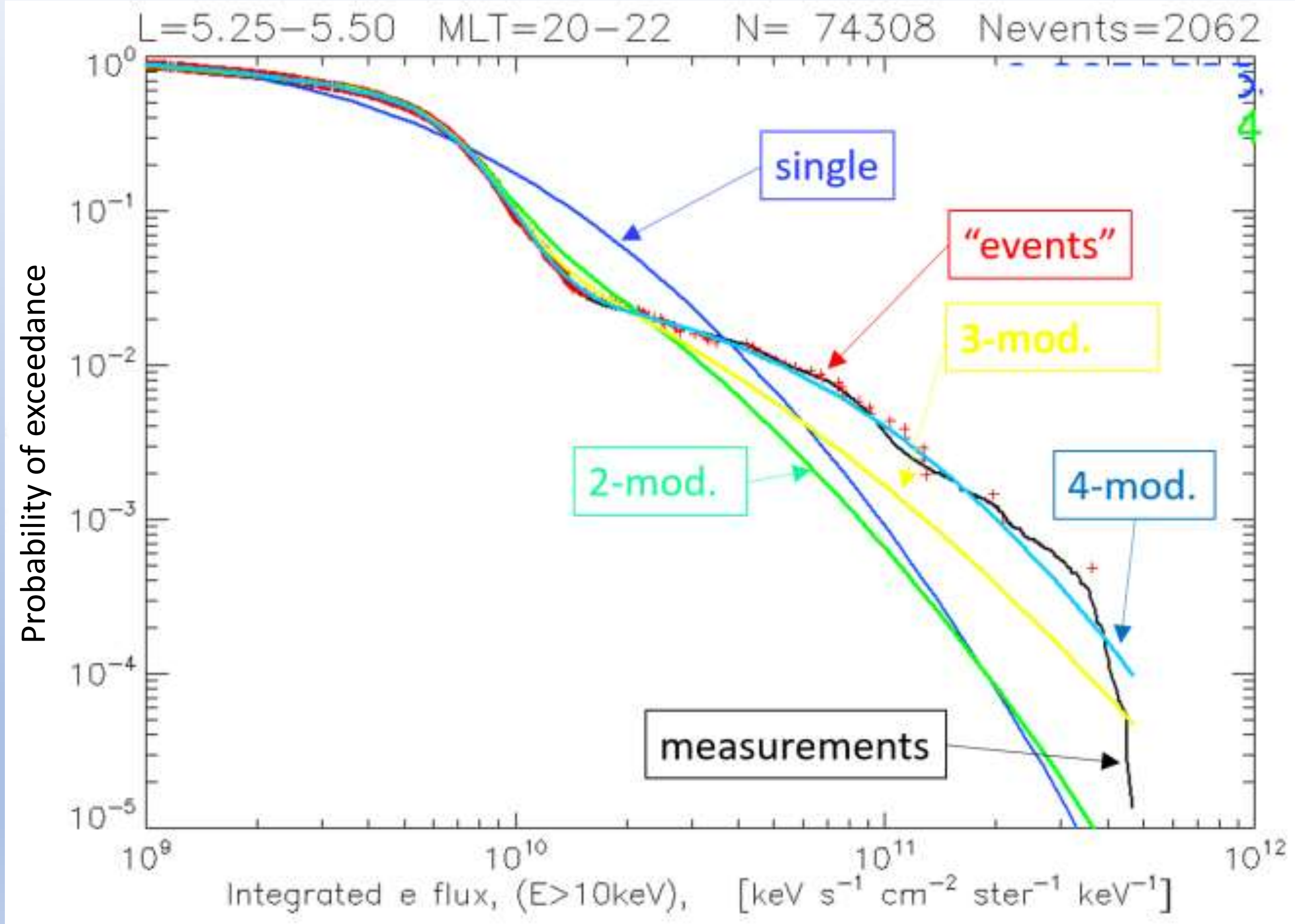
Data reduction:
For each bin, one orbit is represented by one measurement (randomly sampled).



Electron flux statistical distributions and MLT dependence



Fitting statistical distributions



4-modal log-normal distribution works well

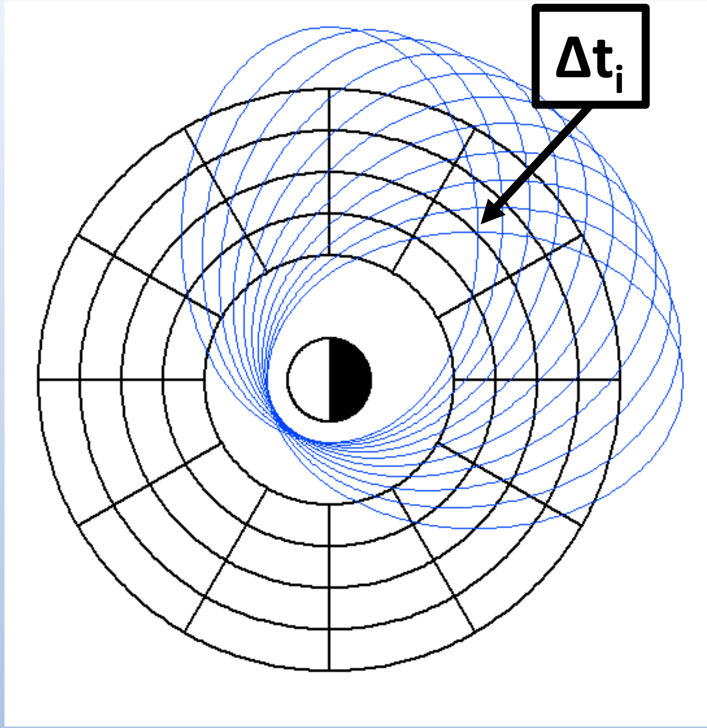
Percentile modules (I, II)

- The user provides the coordinates of the orbit for the expected mission duration.
- The total time (Δt_i) which spacecraft will spend is each bin can be evaluated (as well as the time (ΔT) the spacecraft will spend outside the region of the surface charging risk).
- The statistical distribution of the differential flux encountered during the mission can be obtained as:

$$P(E_k, eflux) = \sum_i w_i \cdot P_i(E_k, eflux),$$

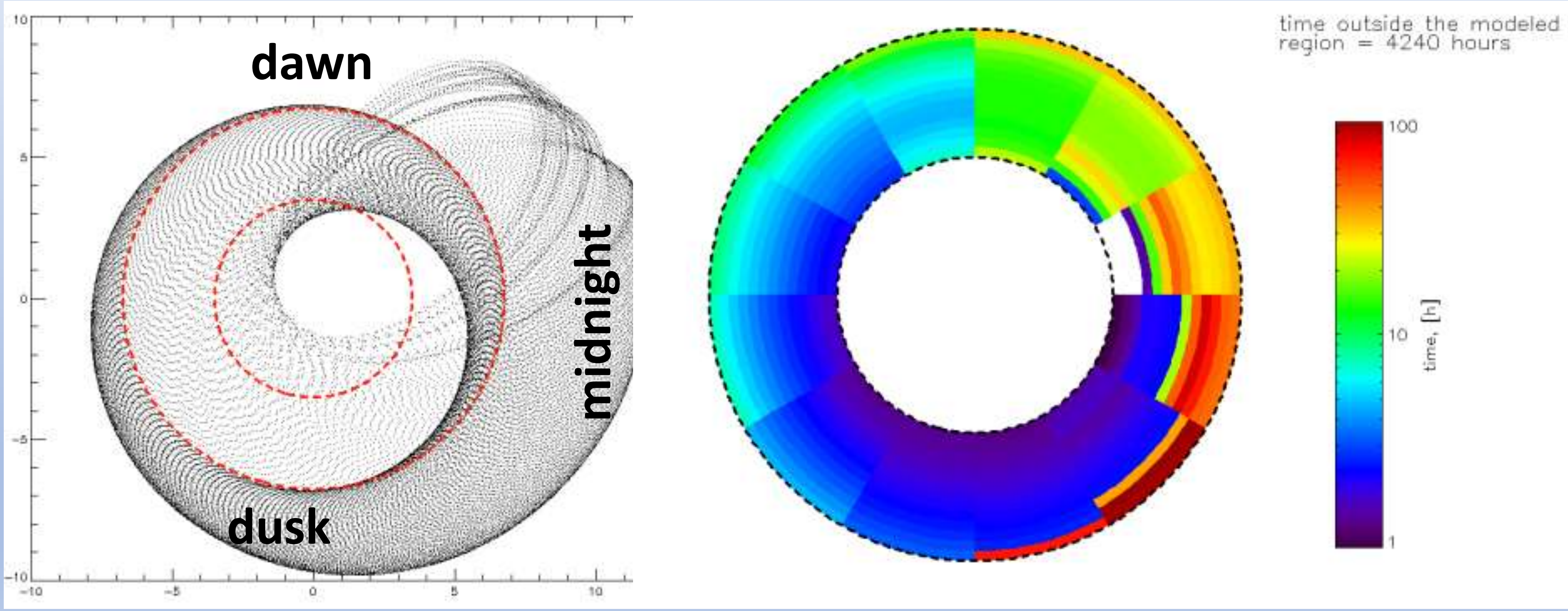
Where weight coefficients are

$$w_i = \frac{\Delta t_i}{\Delta T + \sum_i \Delta t_i}$$

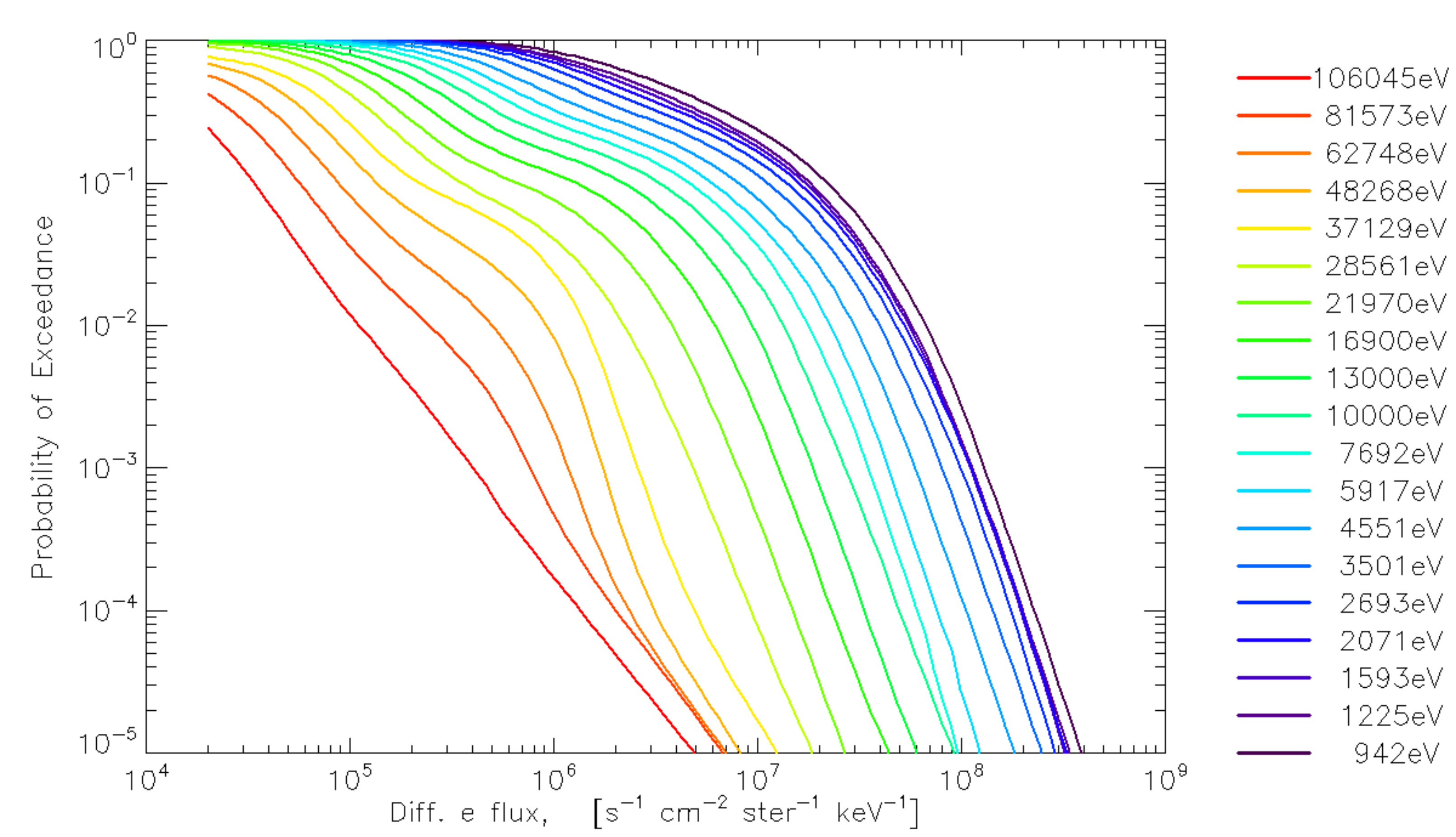


Test case:

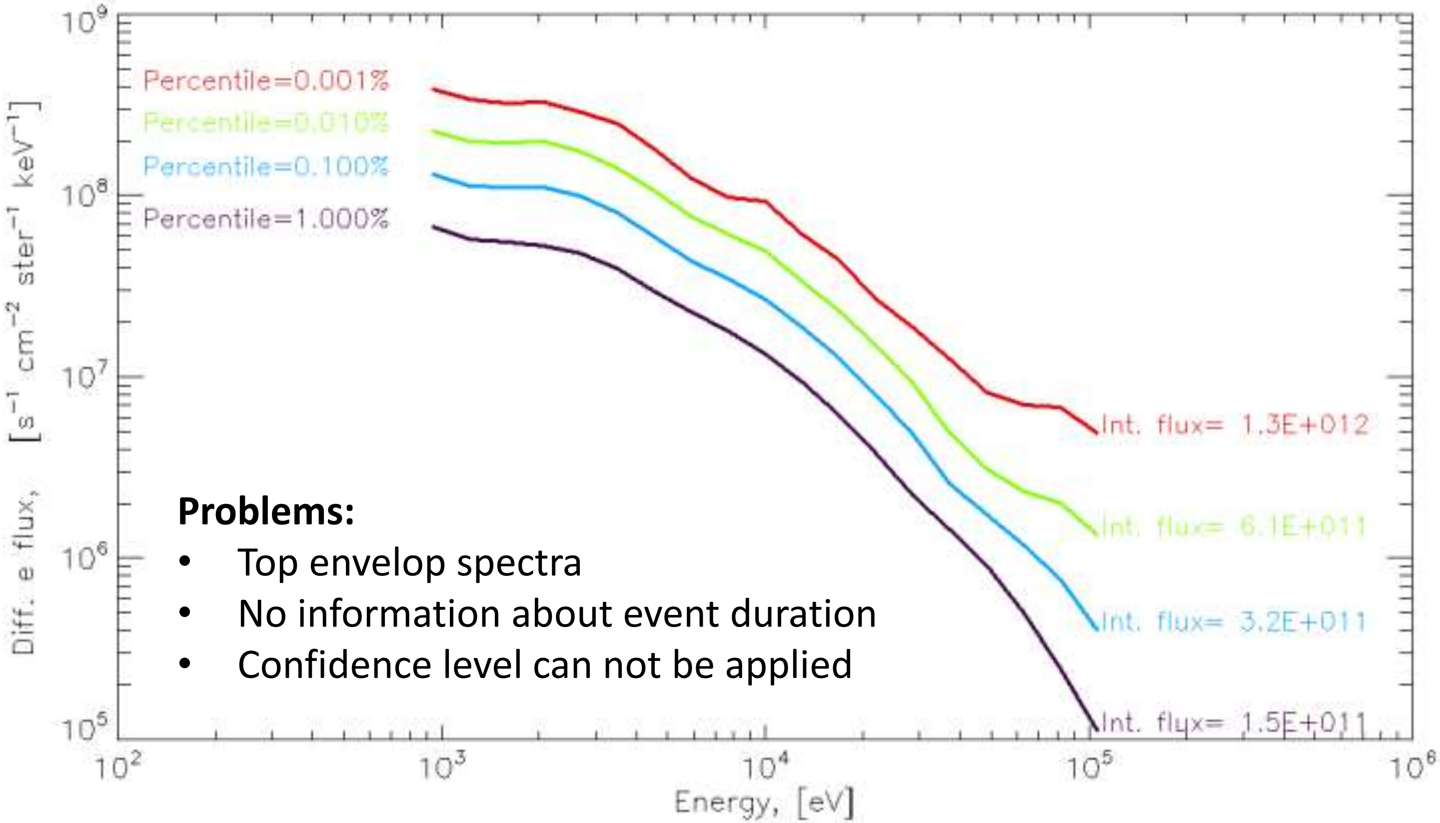
Spacecraft with EOR, 500s resolution



Electron differential flux statistical distributions for different energies



Electron flux spectra for four percentiles



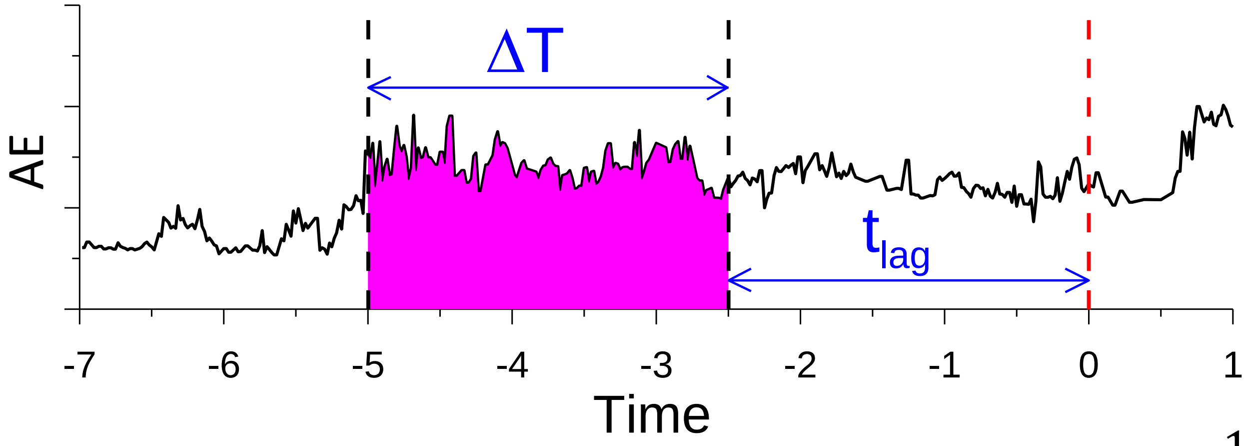
Problems:

- Top envelop spectra
- No information about event duration
- Confidence level can not be applied

Module III. Electron flux enhancement events occurrence and worst-case electron spectra

Generation of the synthetic time-series of the electron flux values along the orbit using AE index as a driver.

Integrated and lagged AE index as a driver:



$$P_{AE}\left(t, t_{lag}, \Delta T\right) = \frac{1}{\Delta T} \int_{t-t_{lag}-\Delta T}^{t-t_{lag}} AE(h)\,dh$$

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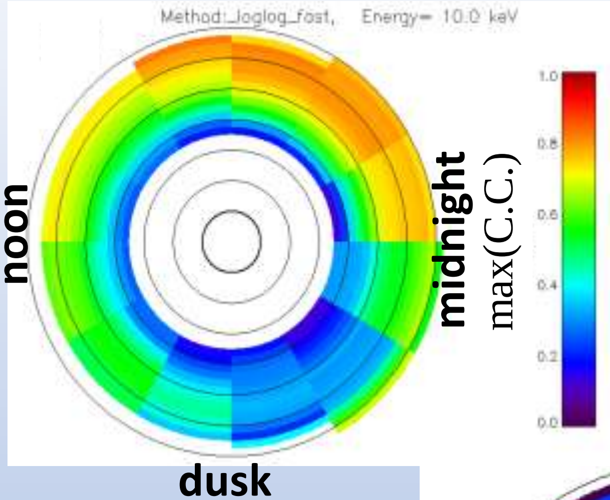
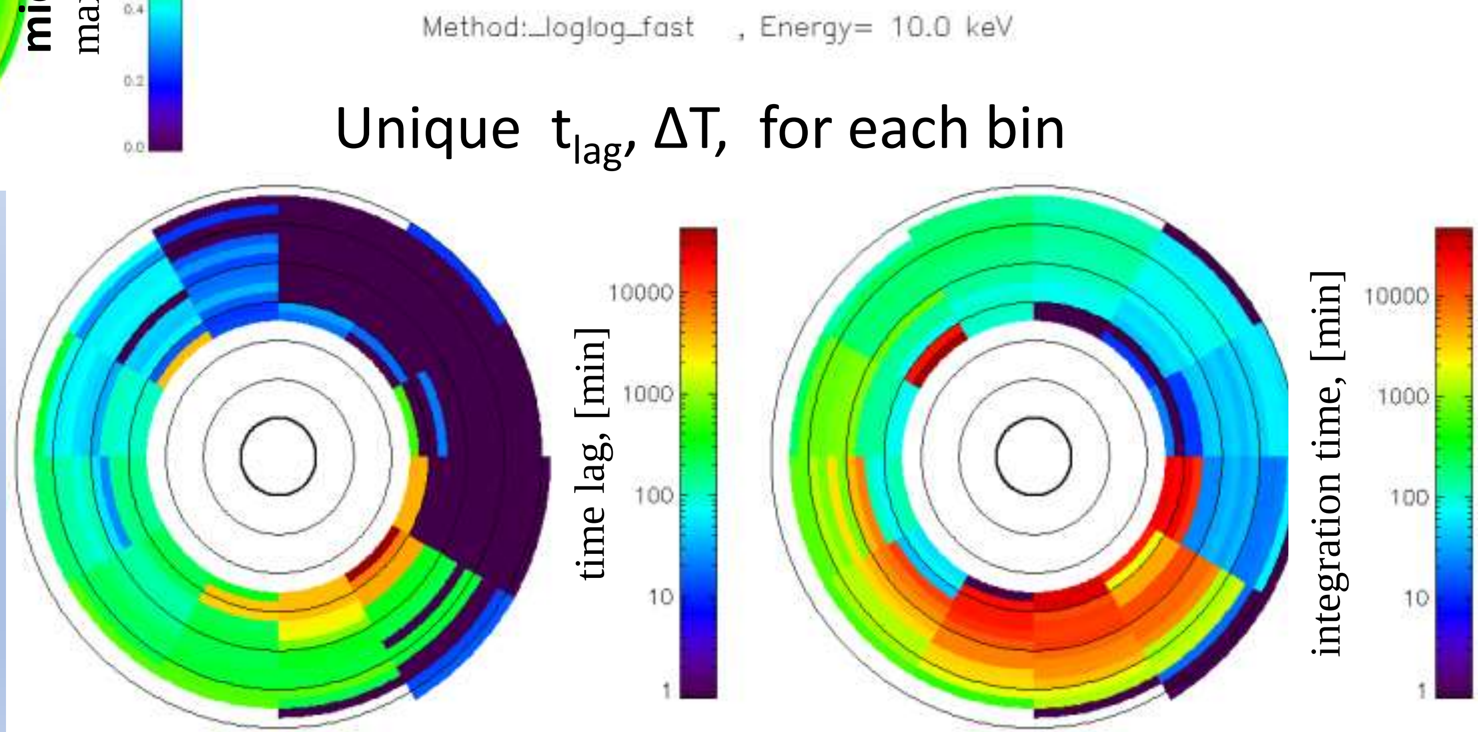
E = 10 keV

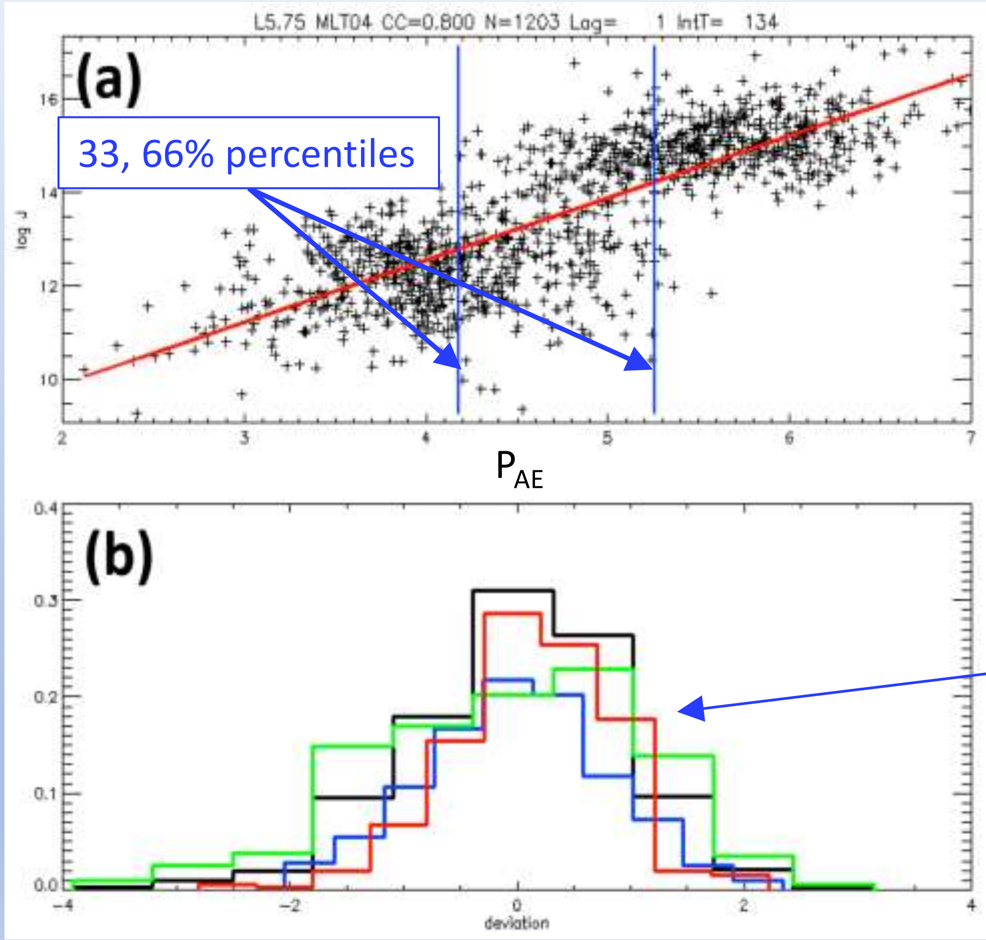
Correlations, $\log J$ and $\log P_{AE}$



Unique t_{lag}, ΔT, for each bin



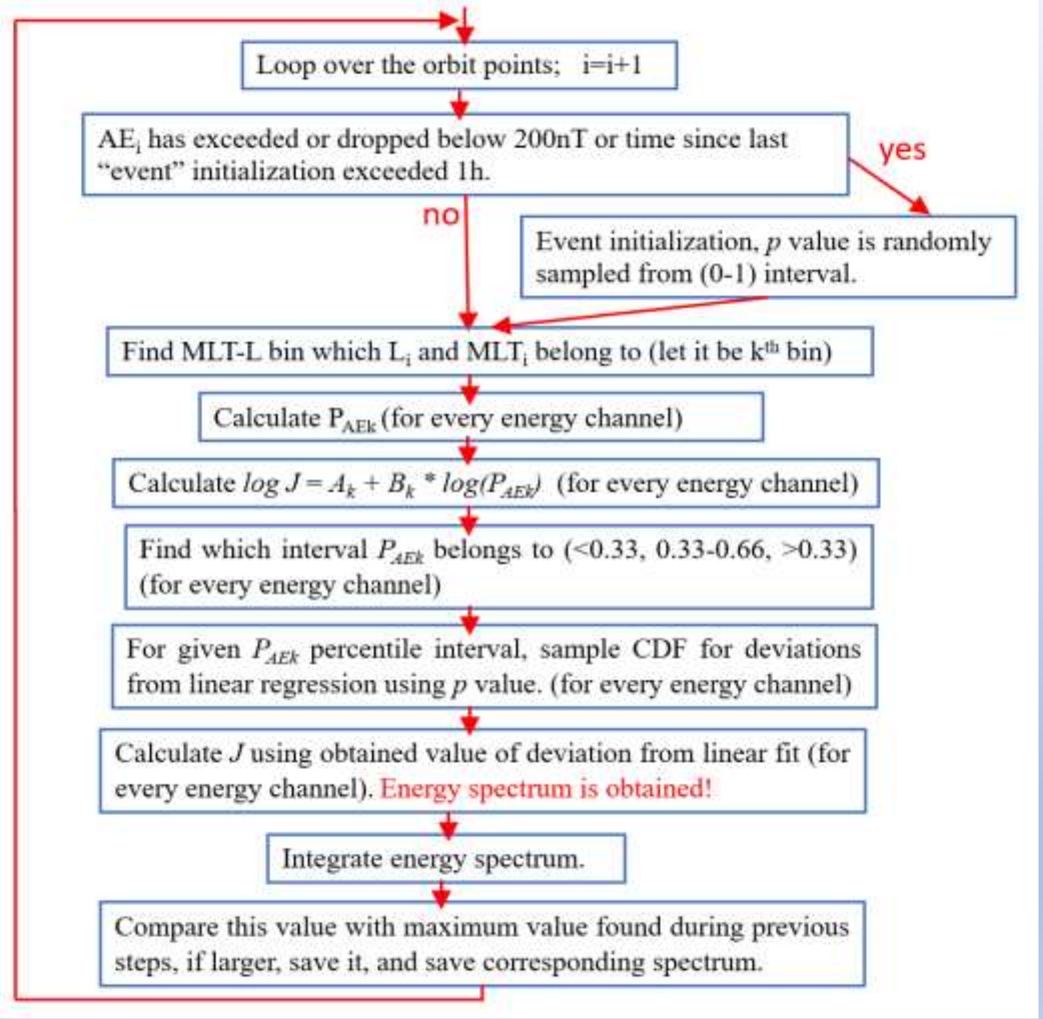
Example of scatter plot for one bin



Electron flux time series generation:

$$\log J_i = \log P_{AEi} + \delta_i$$

These distributions can be randomly sampled. However, distributions for different energies can not be sampled independently (to avoid saw-shaped spectra).
It is better not to sample independently adjacent measurements in time (to have continuous events).



- Multiple runs are performed for the same orbit (possibly time-shifted AE index time-series). Maximum flux and spectrum are saved for each run.
- The results for all runs are sorted.
- Desired confidence level is used to select the final result from the sorted array.

The parameters of the multi-Maxwellian approximations are also output and can be used to feed SPIS simulation.

New probability model of keV plasma environment inside GEO is coming soon!

PEMEM model summary:

Input:
- Orbital information
- Mission duration
- Percentile level
- Confidence level

Output (expected for given orbit):
- Percentile spectra for e- (1keV-100keV)
- Percentile spectra for p+ (100 eV – 50 keV)
- Integrated e- flux threshold which will not be exceeded for given confidence during the mission lifetime
- Worst case electron spectrum for given confidence
  (worst-case is defined as highest integrated e- flux, for user-specified lower integration limit)

- ➢ Multi-Maxwellian parameters for the spectra are output and can be used as input to SPIS.
- ➢ All parameters are separately calculated for eclipse periods

Suggestions from potential model users are highly welcomed!!

stepan.dubyagin@fmi.fi