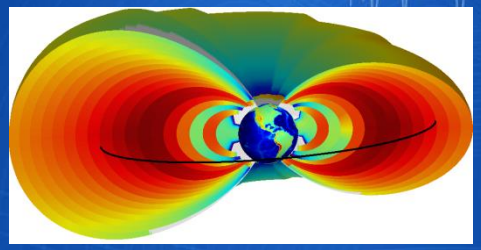

GREEN model

Global Radiation Earth Environment

(Version 0)

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R&T
SYSTEMES SPATIAUX

retour sur innovation

GREEN : Why a new model?

- **Existing global models:**

  - AE8/AP8 (reference models) composed of one model in solar MAX and an other model in solar MIN
  - AE9/AP9 composed of mean models and confidence levels

- **Existing local ONERA models:**

  - Electron: **SLOT** , **OZONE** (L>4), **IGE-2006** (geostationary orbit), **MEO**
  - Proton: **OPAL** (LEO)**, IGP** (geostationary orbit)

- **Why a new global model?:**

  - To address the well-known lacks in the existing global models
  - To dispose of an alternative specification model from US ones
  - To compare with AE9/AP9

GREEN : How to proceed?

- **Main principles:**

➔ GREEN (V0) is a new model composed of different existing global and local models

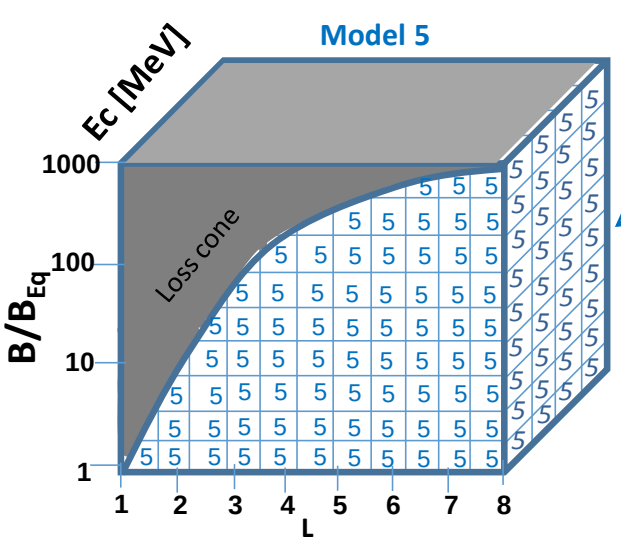
➔ A list of models to use has been defined in the case of electrons and another one for protons. These two lists can be expanded and discussed at any time.

➔ A 3 dimensions grid in Energy, B_{local}/B_{eq} and L has been defined and represents the global architecture of GREEN. This 3D grid is the same as the one used in the physical model Salammbô.

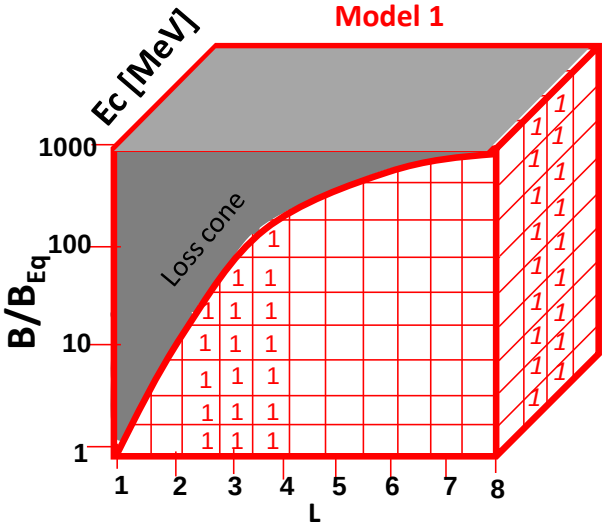
➔ Flux from each model integrated in GREEN have been calculated on this reference grid.

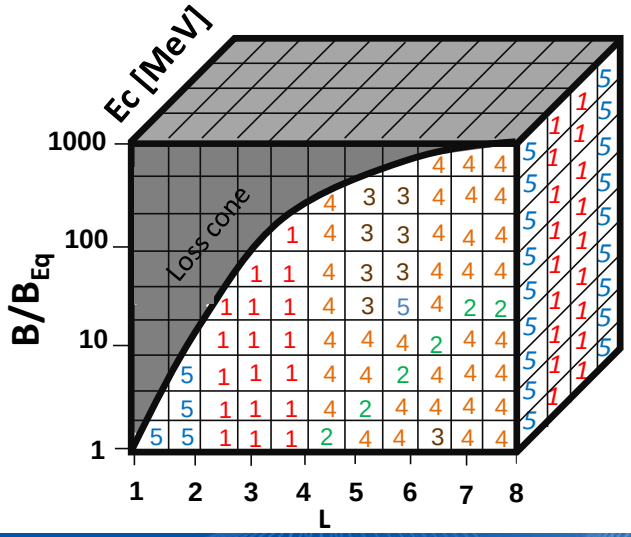
➔ Then a priority order of the different models to be used has been established according to space location and energy.

GREEN : Architecture (1/)



Default model
(AE8/AP8 and SPM)





GREEN

Model n° 1
Model n°2
Model n° 3
Model n° 4
Model n° 5

GREEN : Input/Output parameters

Input parameters =

- Number of points along s/c orbit to calculate
- Year, month, day, UT
- Coordinates of each point
- Coordinate system
- Particle specie (electron or proton)
- Number of energies
- Energy array

Core of the model →

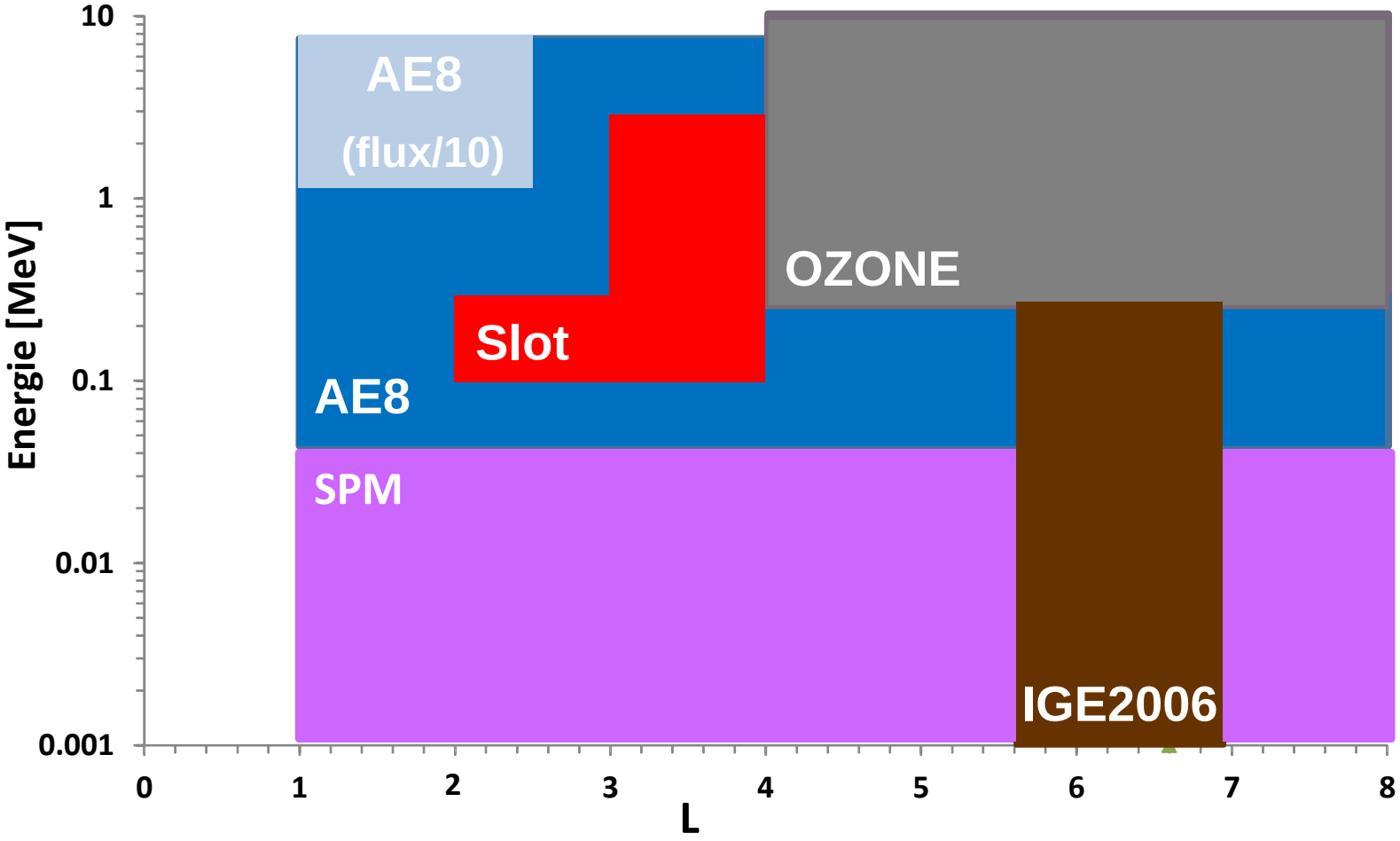
- Magnetic parameters L, L* et B/B_{eq} calculation
- Search of appropriate model vs orbit location
- Flux calculation by interpolation in the 3D grid

Output parameters =

- Mean flux spectrum for each location (depending on the year of the solar cycle)
- Maximum envelop of the mean flux spectrum (among several solar cycles) for each location (depending on the year of the solar cycle)
- Name of the appropriate model for each location.
- L*
- B/BEq

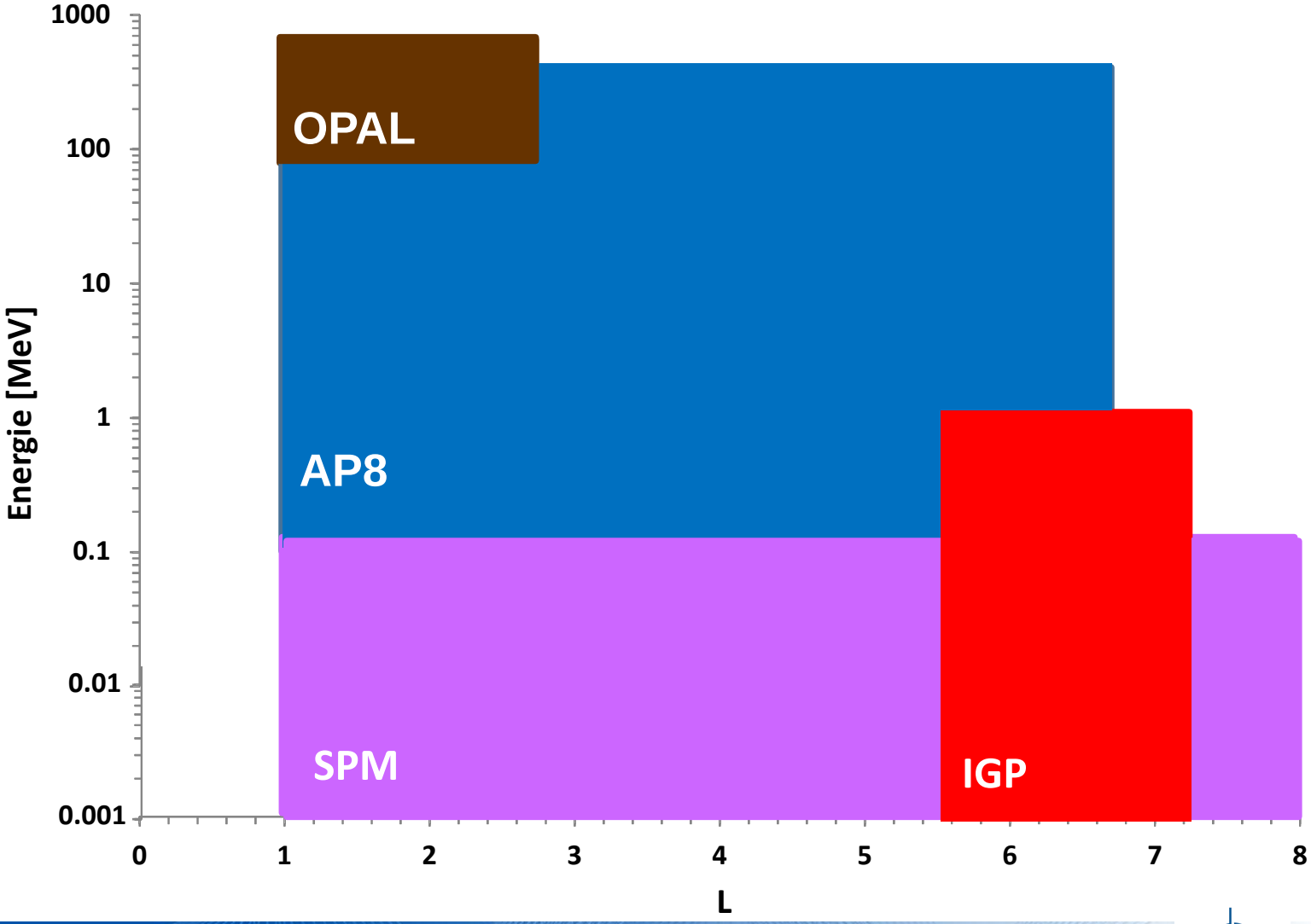
GREEN : Models contained in GREEN-e

➢ **Energy and L* (or L) coverage for models contained in GREEN-e:**



GREEN : Models contained in GREEN-p

➢ **Energy and L* (or L) coverage for models contained in GREEN-p:**

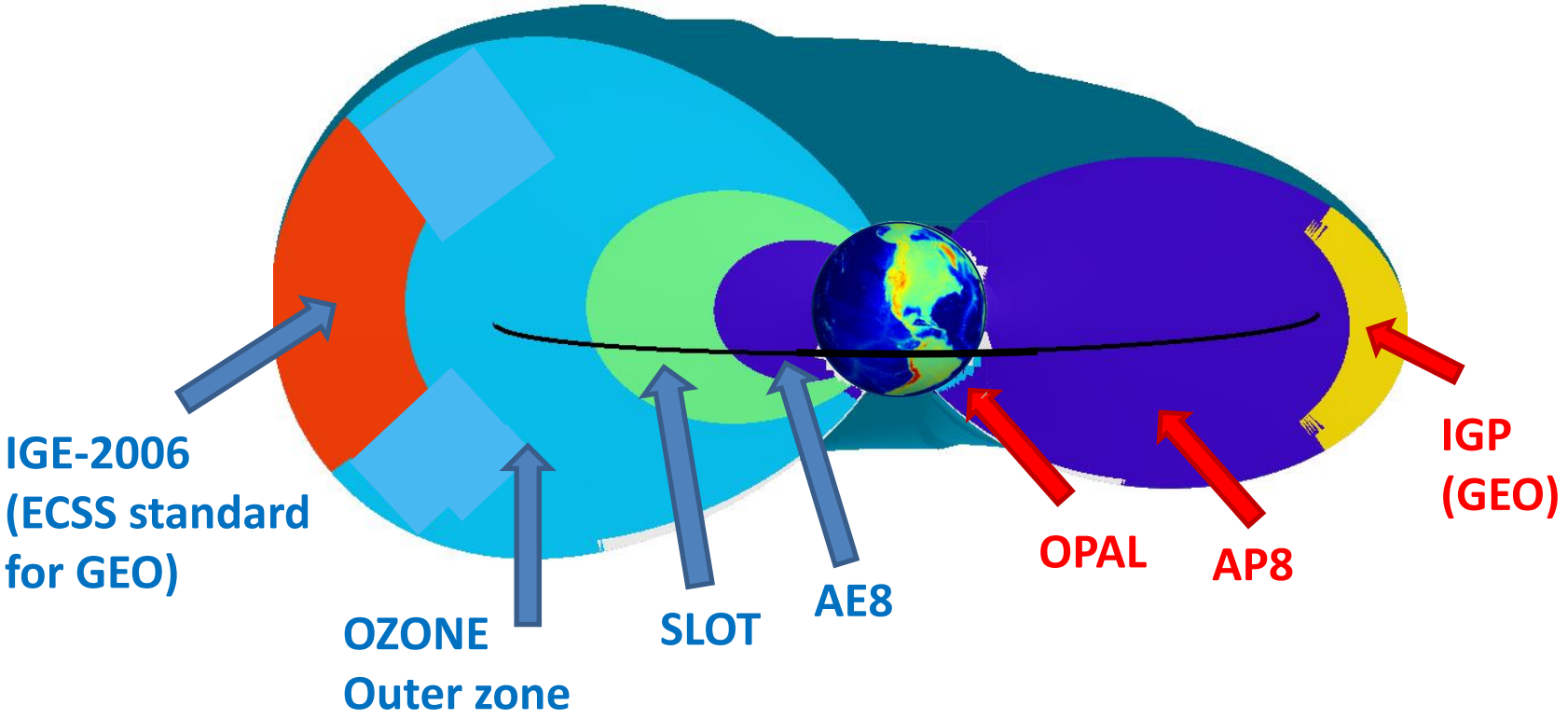


GREEN : Overview of models contained in GREEN

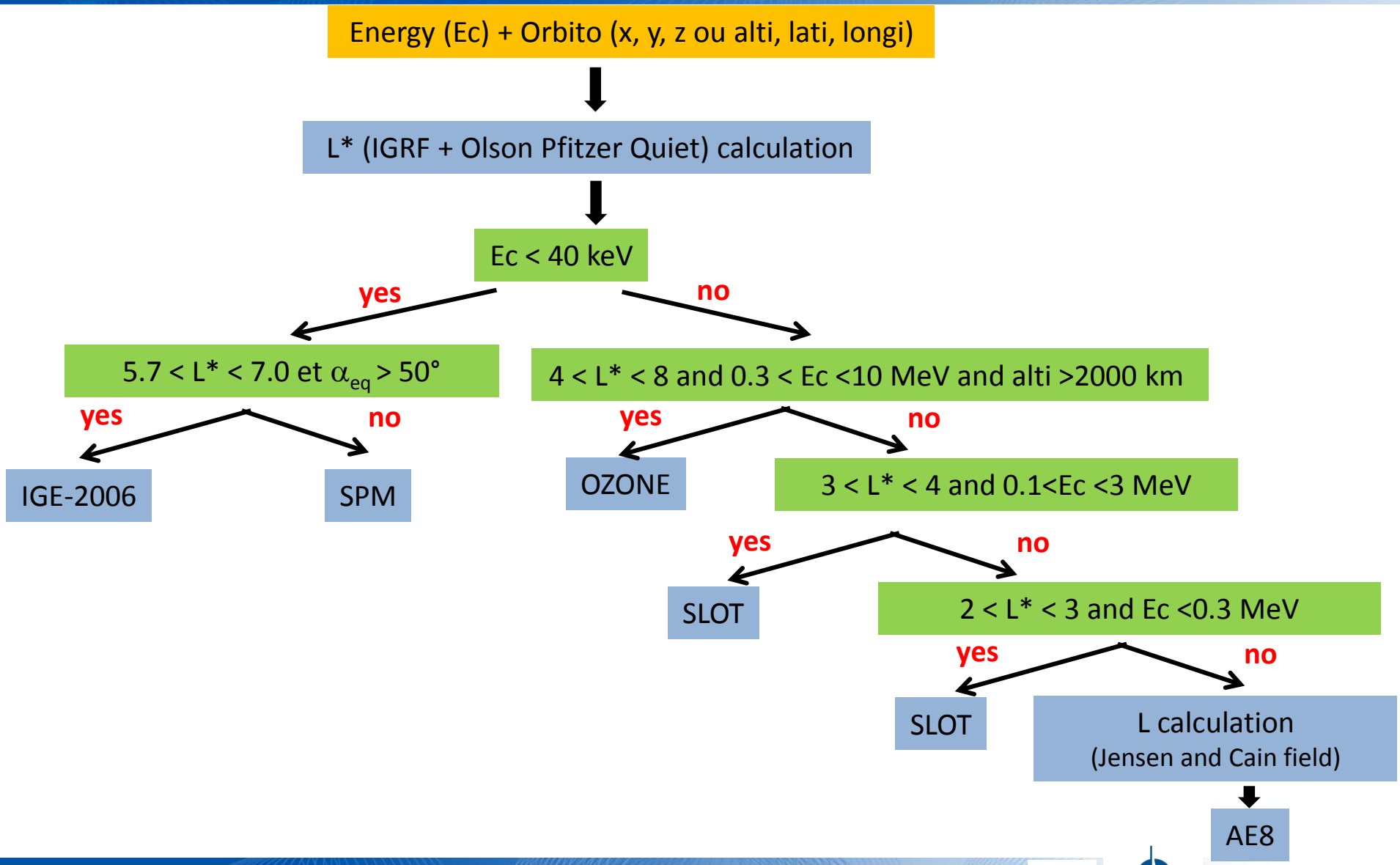
GREEN

GREEN-e
Electrons

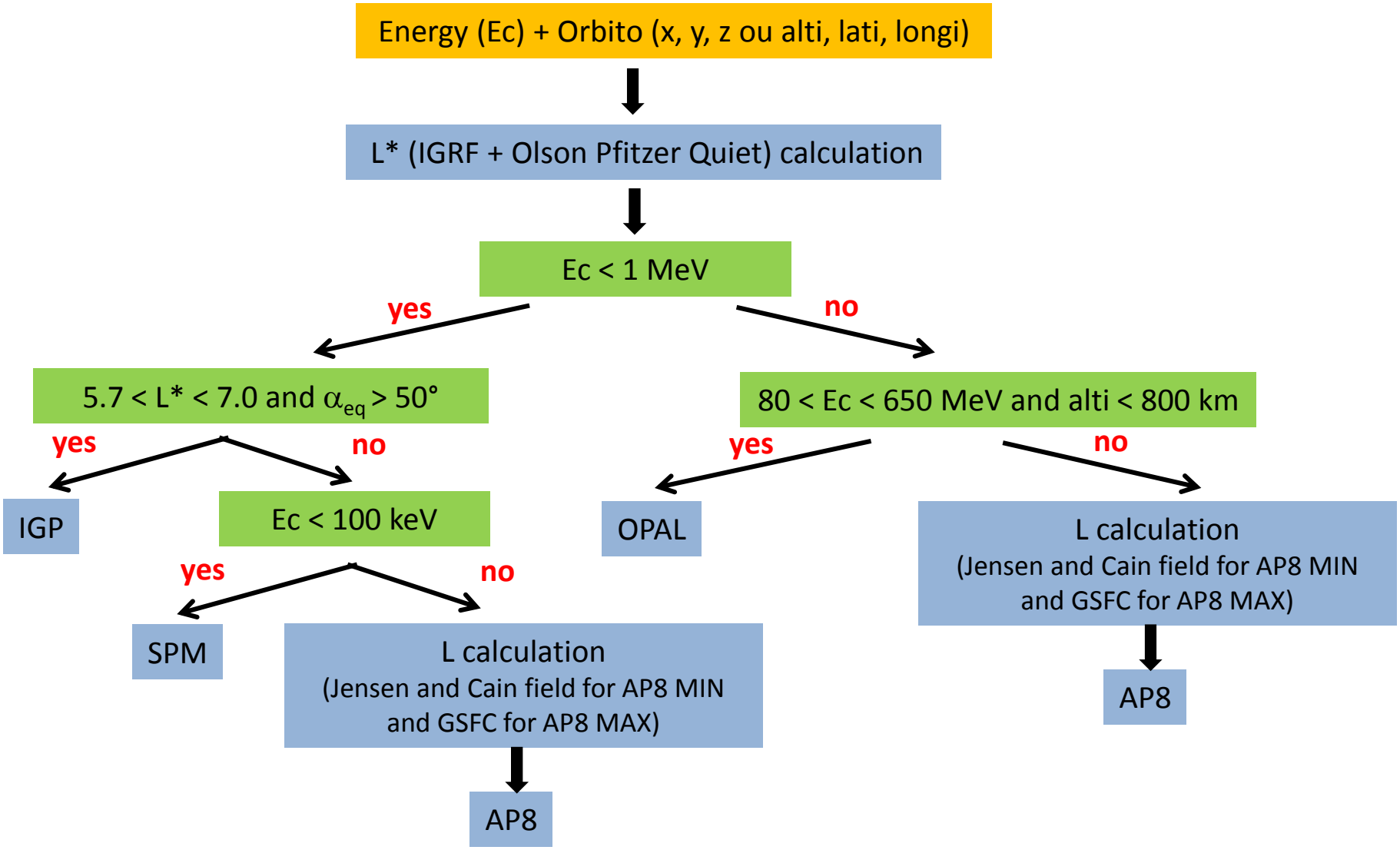
GREEN-p
Protons



GREEN : Architecture of the GREEN-e code



GREEN : Architecture of the GREEN-p code



GREEN : SLOT model (1/3)

➢ Data used:

Only few models in this region exist. AE8 is well-known to under-estimate electron flux in this zone.

➔ New model was needed and has been developped in 2013.

Sicard-Piet et al., IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 61, NO. 4, AUGUST 2014

37 years of data at LEO !!

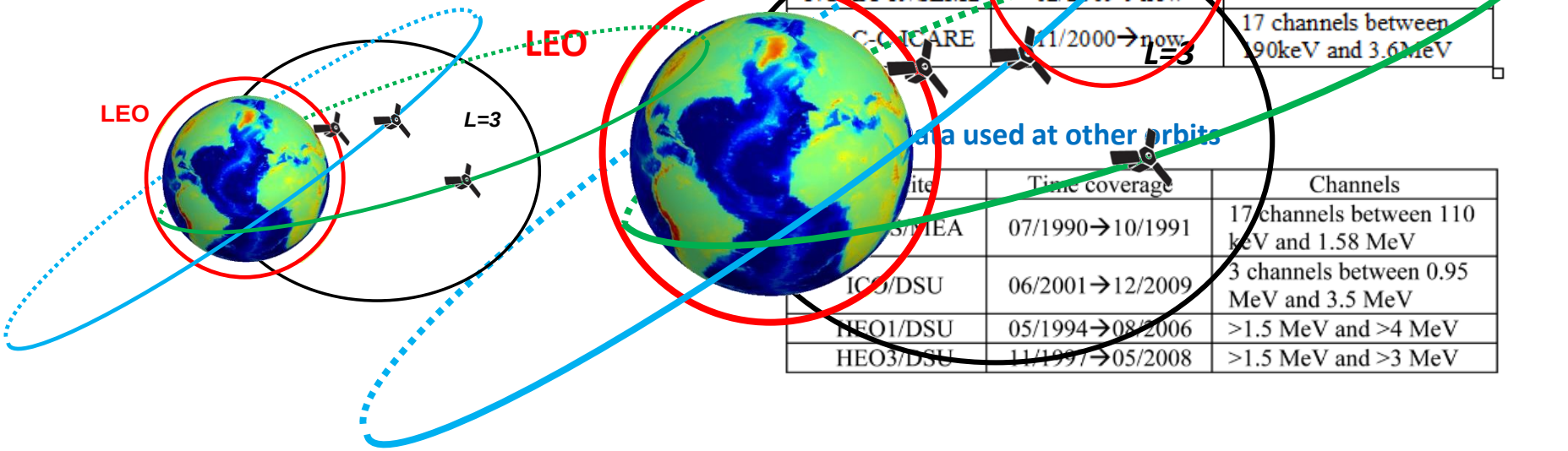
This SLOT model is based on the correlation between flux at LEO orbit and flux along the magnetic field line

Data used at LEO orbit

Spacecraft	Time coverage	Channels
NOAA-6/SEM	07/1979→11/1986	
NOAA-8/SEM	05/1983→11/1987	>100keV
NOAA-10/SEM	10/1986→08/1991	>300keV
NOAA-12/SEM	06/1991→07/2002	>1.1MeV
NOAA-14/SEM	01/1995→12/2004	
NOAA-15/SEM2	07/1998→now	
NOAA-16/SEM2	10/2000→now	>100keV
NOAA-17/SEM2	07/2002→now	>300keV
NOAA-18/SEM2	06/2005→now	~3.35MeV
NOAA-19/SEM2	02/2009→now	
C-C/ICARE	11/2000→now	17 channels between 190keV and 3.6MeV

Data used at other orbits

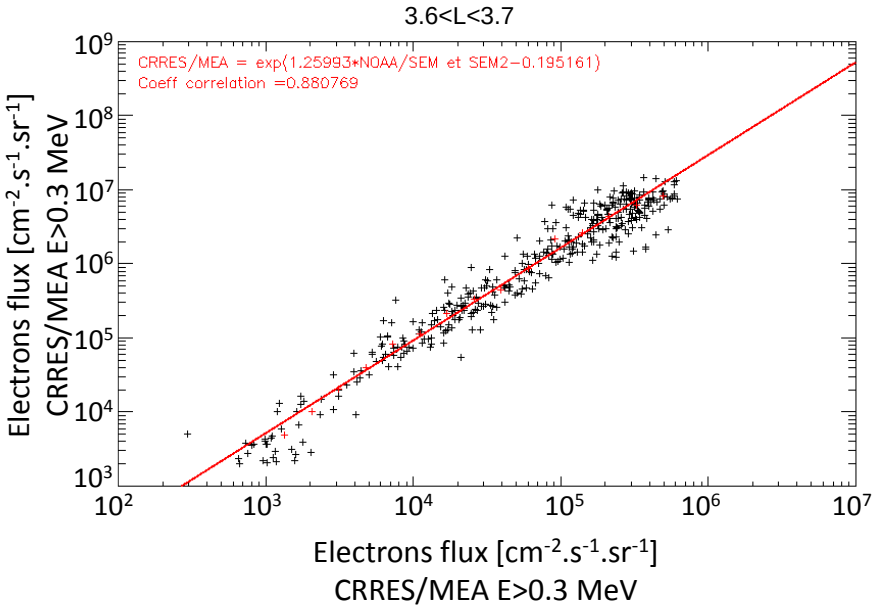
Satellite	Time coverage	Channels
GOES/MEA	07/1990→10/1991	17 channels between 110 keV and 1.58 MeV
ICO/DSU	06/2001→12/2009	3 channels between 0.95 MeV and 3.5 MeV
HEO1/DSU	05/1994→08/2006	>1.5 MeV and >4 MeV
HEO3/DSU	11/1997→05/2008	>1.5 MeV and >3 MeV



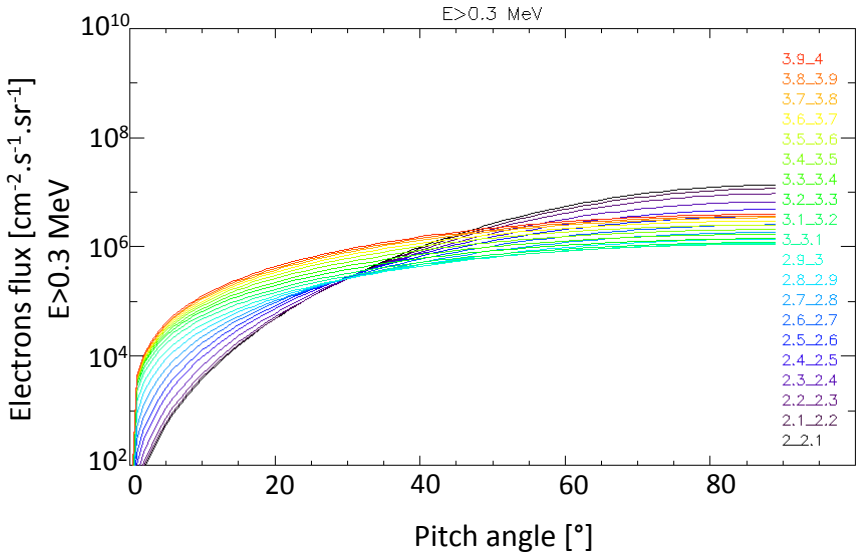
GREEN : SLOT model (2/3)

➢ Principles of the SLOT model:

- SLOT model is based on more than three solar cycles of NOAA electron data in LEO orbit between 100 keV and 3 MeV.
- Correlations with other data provide electron flux along the magnetic field lines from L*=2 to L*=4.



Example of correlation between CRRES/MEA and NOAA/SEM at 300 keV

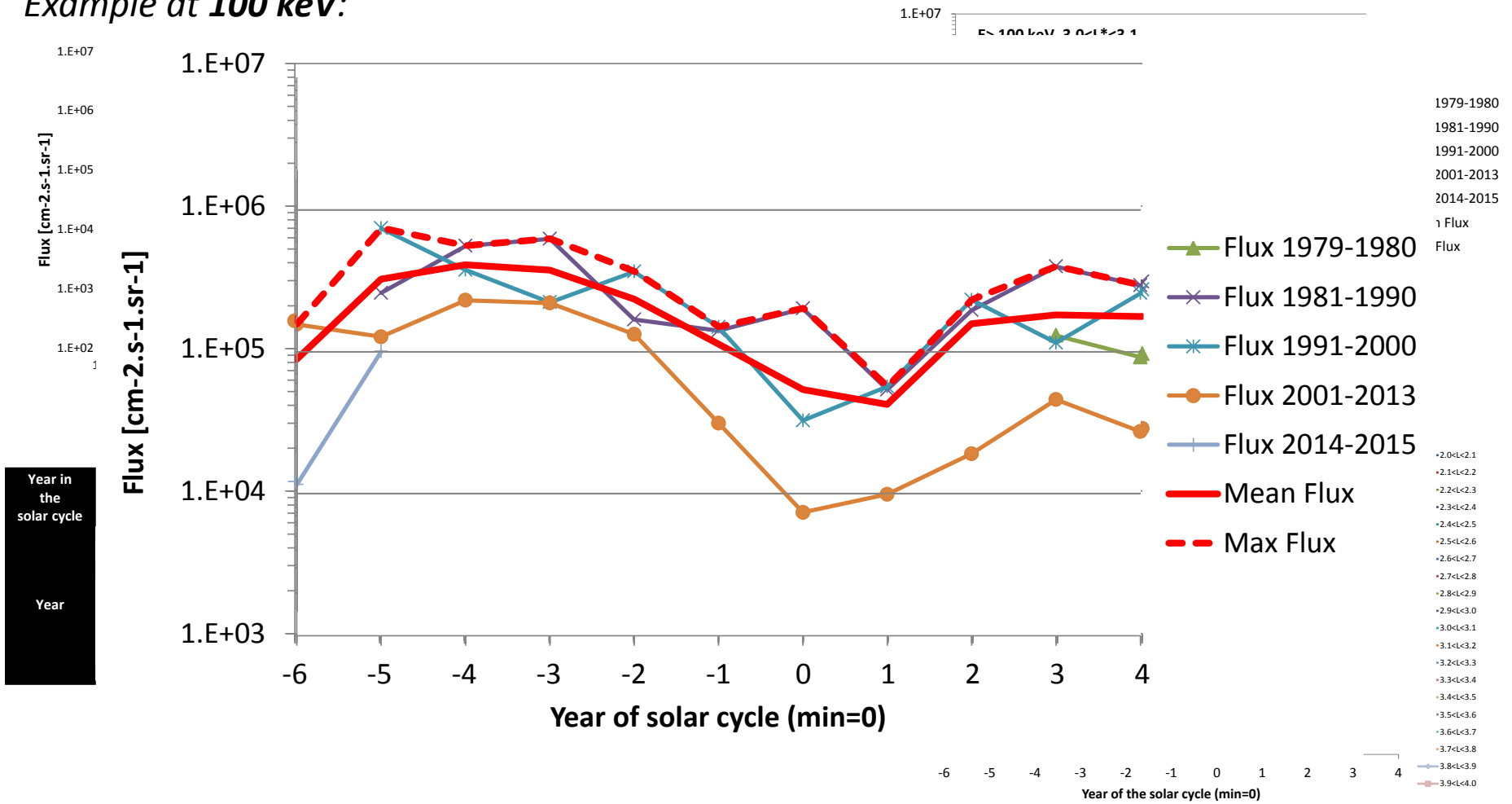


Example of electron flux along the magnetic field lines at 300 keV

GREEN : SLOT model (3/3)

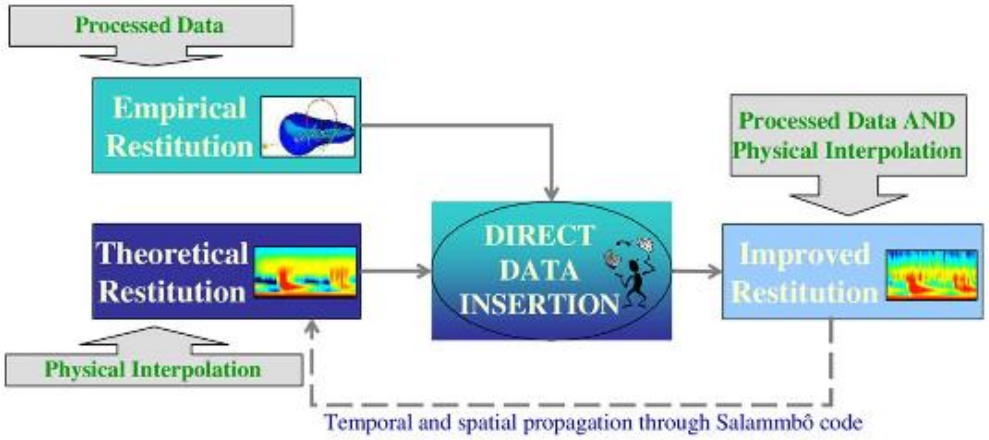
➢ **In 2016 SLOT model has been improve with a solar cycle dependency based on NOAA data:**

*Example at **100 keV**:*



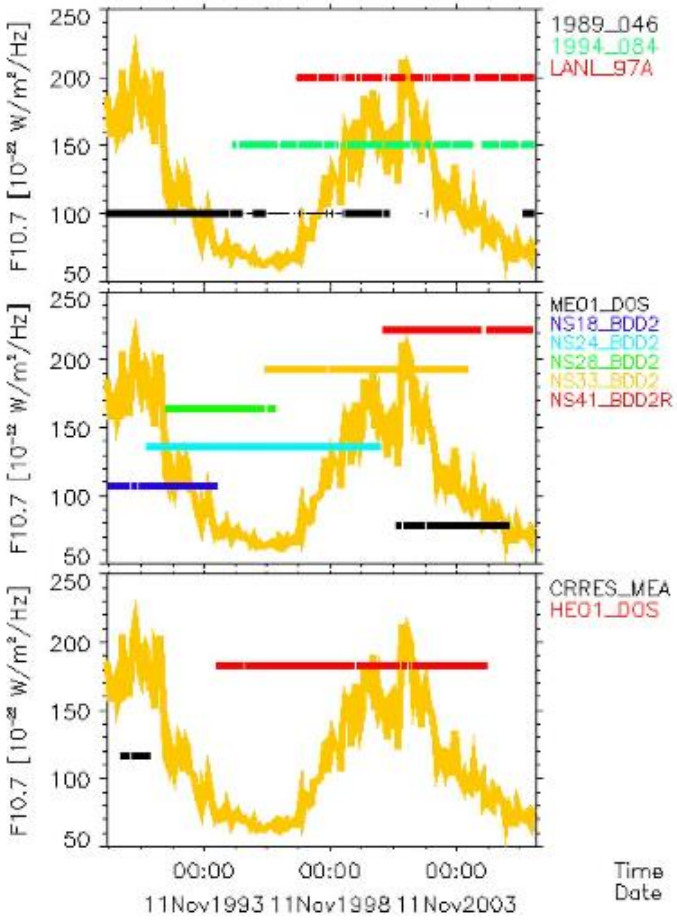
GREEN : OZONE model (1/2)

➢ **OZONE : an outer belt electron model based on data assimilation :**



OZONE =
Salammbô physical model + data assimilation

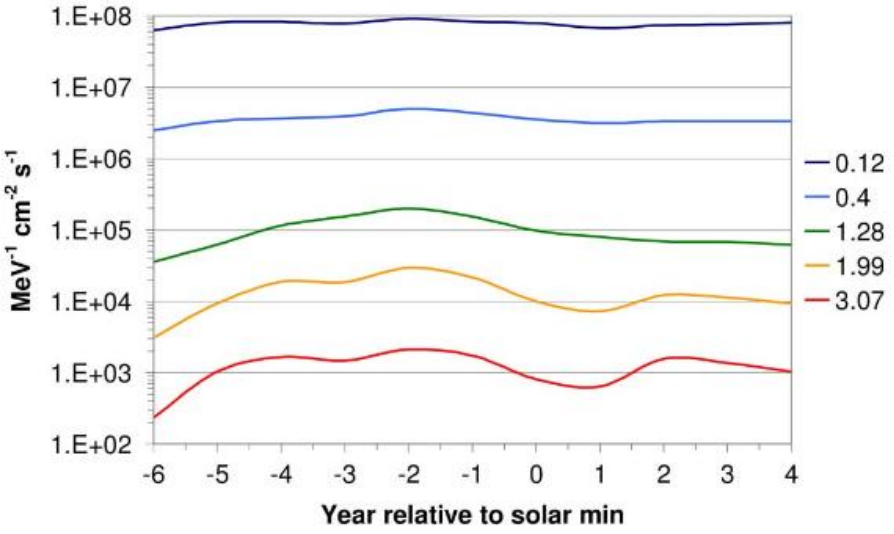
Model valid for L*>4 and between 300 keV and 10 MeV, depending on the year of the solar cycle



Bourdarie et al., IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 56, NO. 4, AUGUST 2009

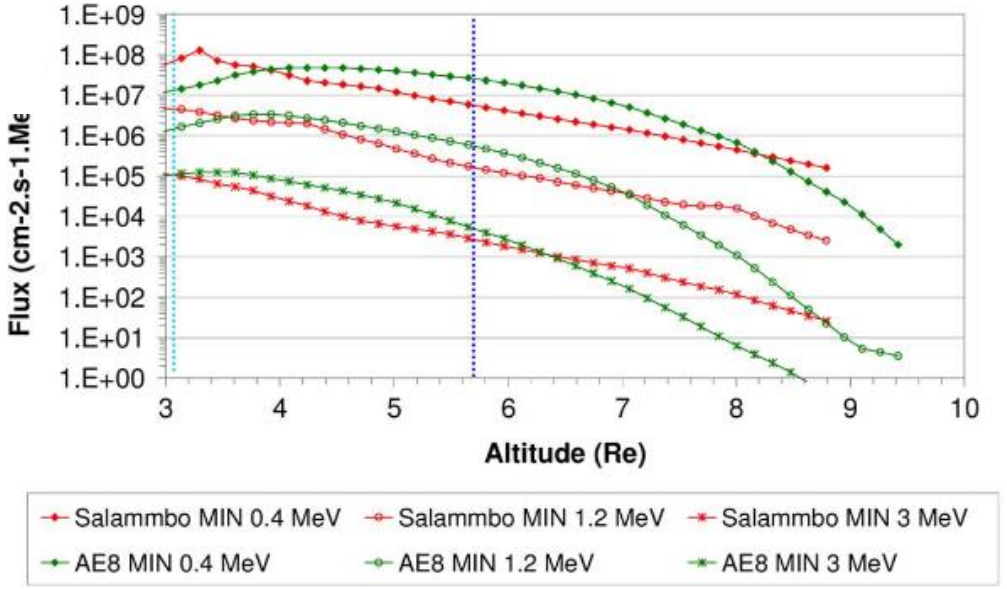
GREEN : OZONE model (2/2)

➢ **Examples of results:**



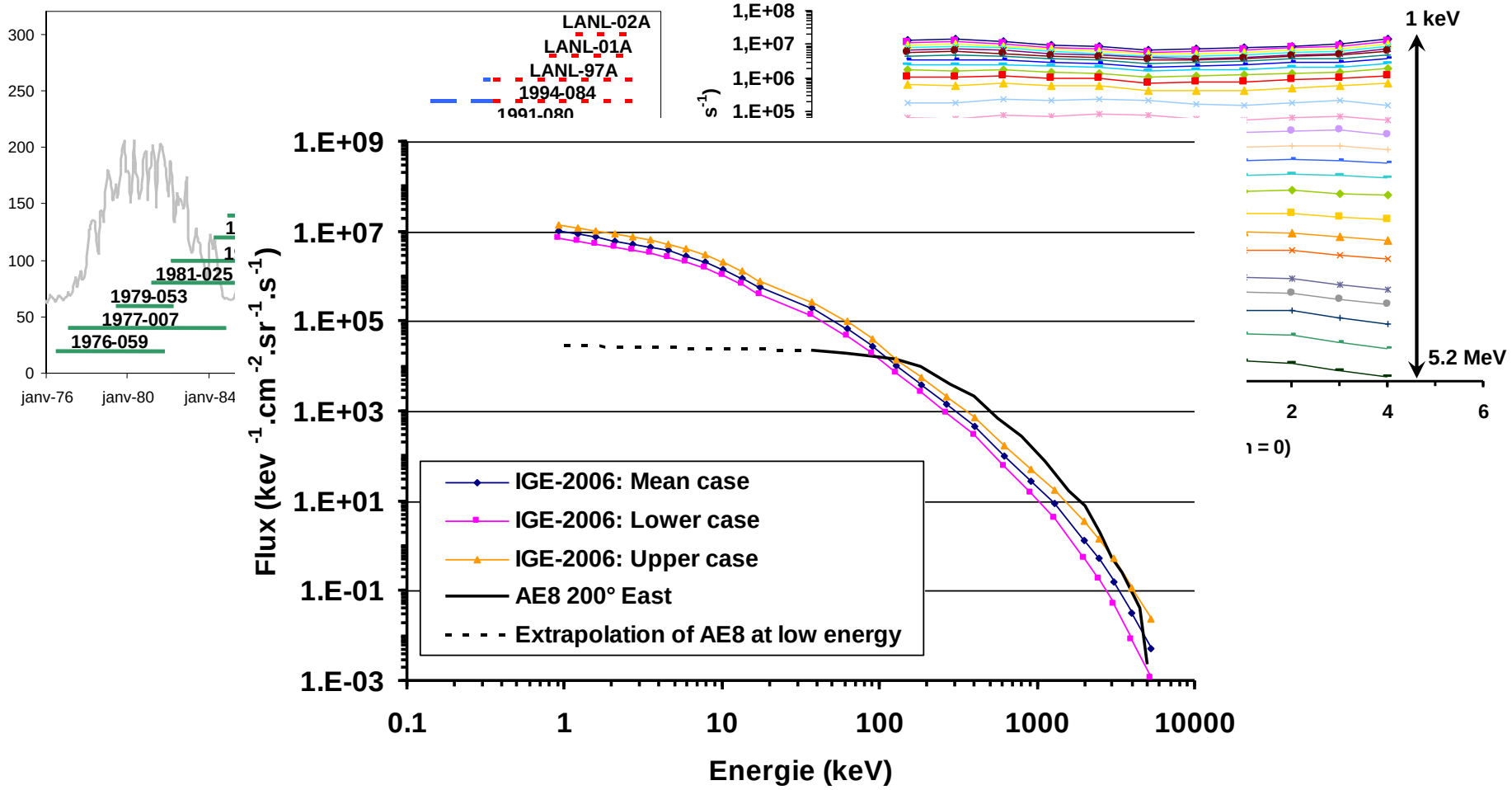
Omnidirectional differential fluxes at magnetic equator in the outer electron belt versus year relative to solar minimum at L=6*

Comparison of omnidirectional differential fluxes for 3 energies function of altitude between OZONE and AE8 min.



GREEN : IGE-2006 model

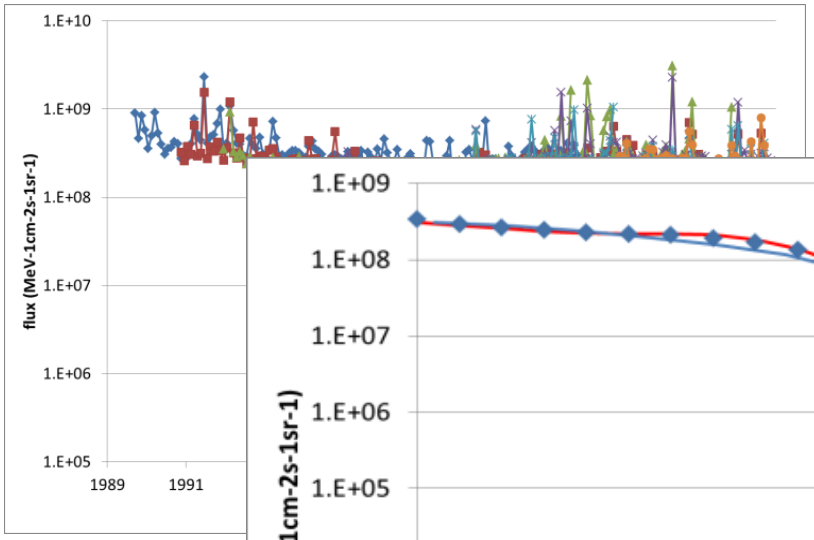
- **Model for electrons at geostationary orbit based on LANL data from 1976 to 2005:**



Sicard-Piet et al., A new international geostationary electron model: IGE-2006, from 1 keV to 5.2 MeV, Space Weather, 6, S07003, 2008.

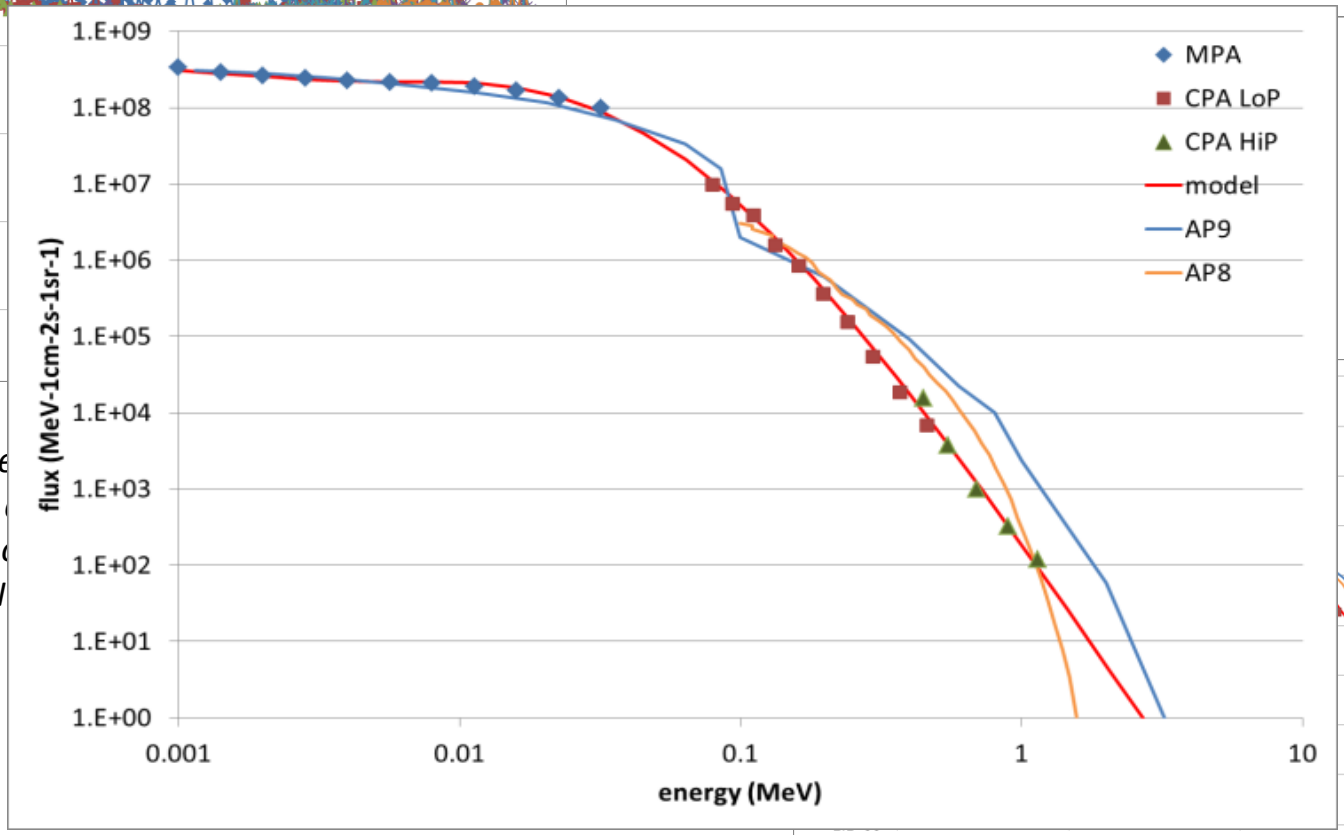
GREEN : IGP model

- **Model for protons at geostationary orbit based on LANL data from 1976 to 2005:**



*Monthly average **1 keV** proton flux measured at GEO by the **MPA** detector on board the different LANL spacecraft*

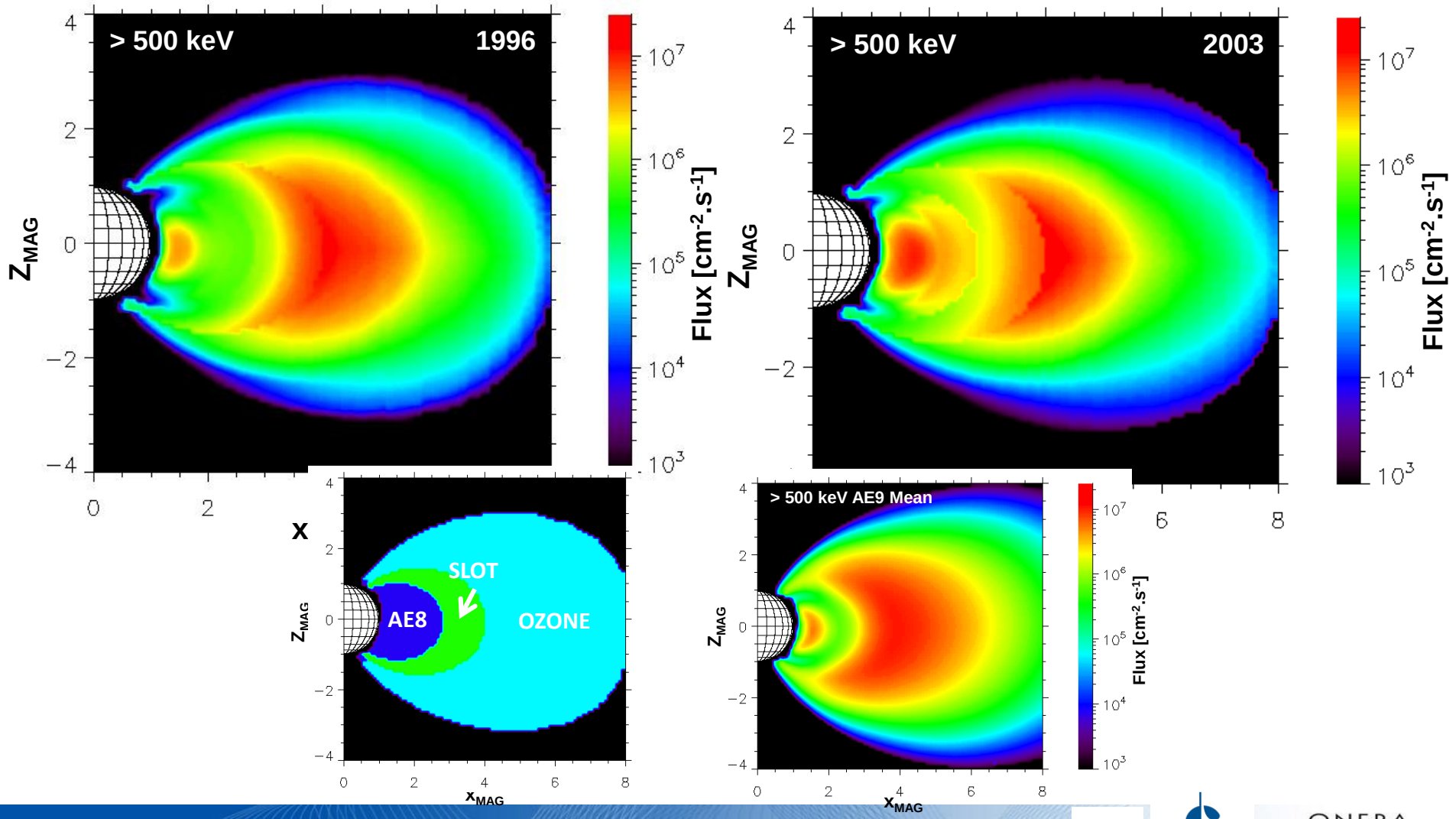
*Monthly average flux measured ... **CPA** detector ... different LAN...*



cycles of LANL data

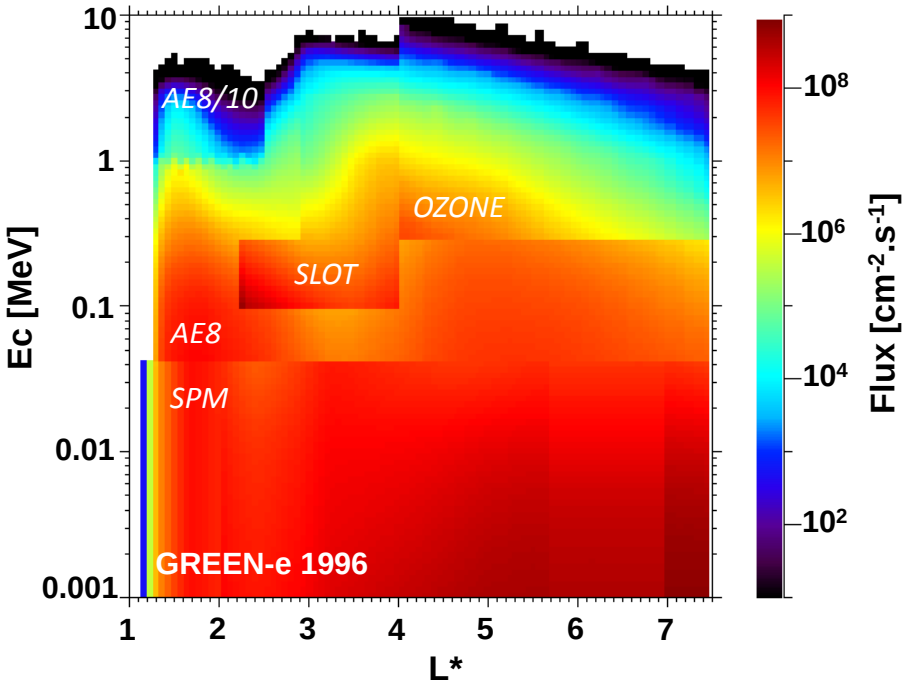
GREEN : Example of results for GREEN-e

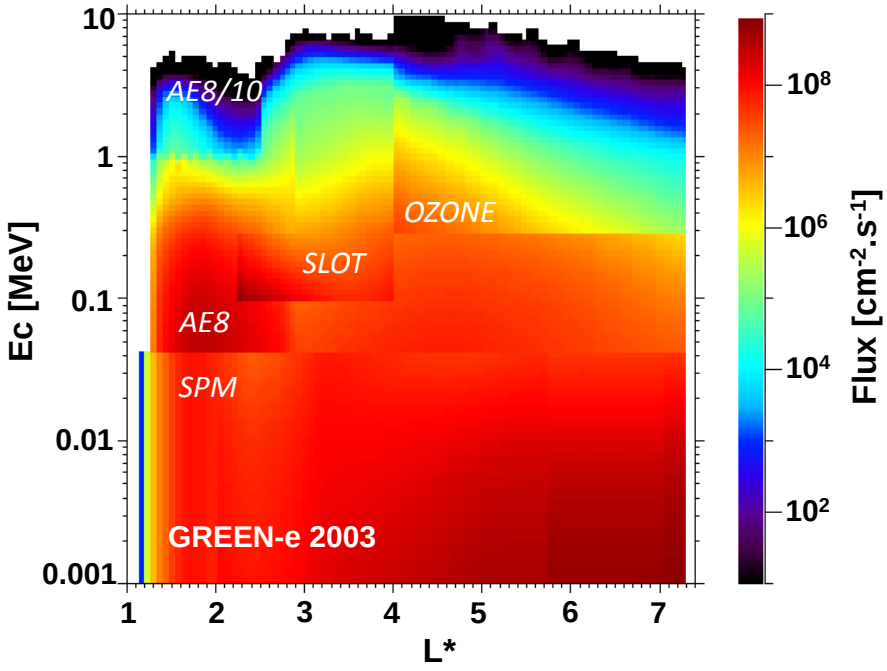
- **Meridian maps of >500 keV electron flux in 1996 (solar min) and 2003 (solar max):**



GREEN : Example of results for GREEN-e

➢ **Mapping of electron flux in 1996 (solar min) and 2003 (solar max) versus L* and Energy:**

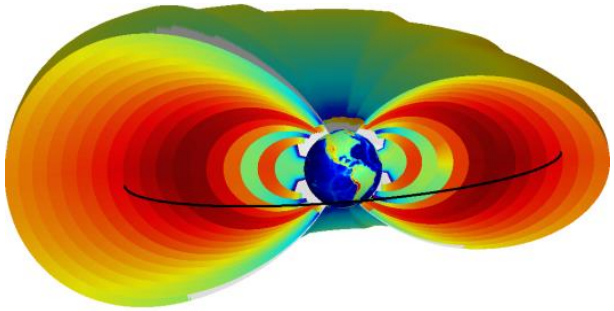




➔ **Some discontinuities exist at the interface of models**

GREEN : Conclusions and Perspectives

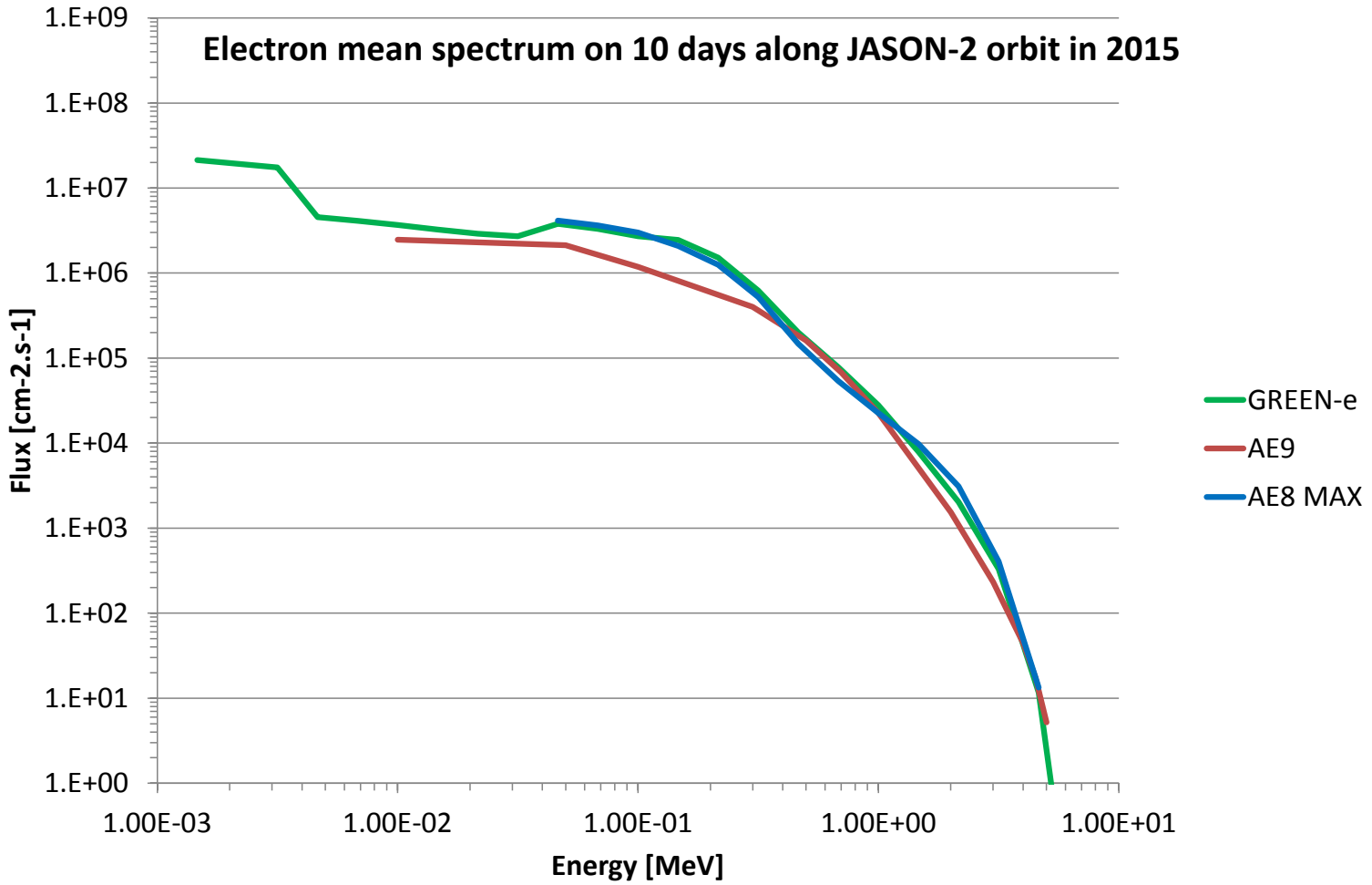
- ✓ GREEN-e model is composed of AE8, SPM, SLOT, OZONE and IGE-2006 and is valid from **1 keV to 10 MeV**
- ✓ GREEN-p model is composed of AP8, SPM and OPAL and is valid from **1 keV to 650 MeV**



- ✓ Discontinuities exist between models and will be smoothed in the next versions of GREEN:
  - A new version of SLOT model is in progress (taking into account RBSP data and new analysis of NOAA data)
  - The interface between SLOT model and OZONE will be also investigated
  - Geostationary models (IGE-2006 and IGP) will be better introduced in GREEN in order to not consider a constant flux between L*=5.7 and L*=7
- ✓ New local models are needed where only AE8 and AP8 are available. Data with good quality and statistics are essential to develop reliable local models.

GREEN : Example of used of GREEN-e

➢ **Comparison of electron flux provided by GREEN-e and AE8/AE9:**



GREEN : Example of used of GREEN-p

- **Comparison of electron flux provided by GREEN-p and AP8/AP9:**