

SERESSA 2022

5th to 9th of December at CERN, Geneva

Introduction to OMERE: a tool for space environment and radiation effects on electronics devices

Léo Coïc, TRAD



Agenda

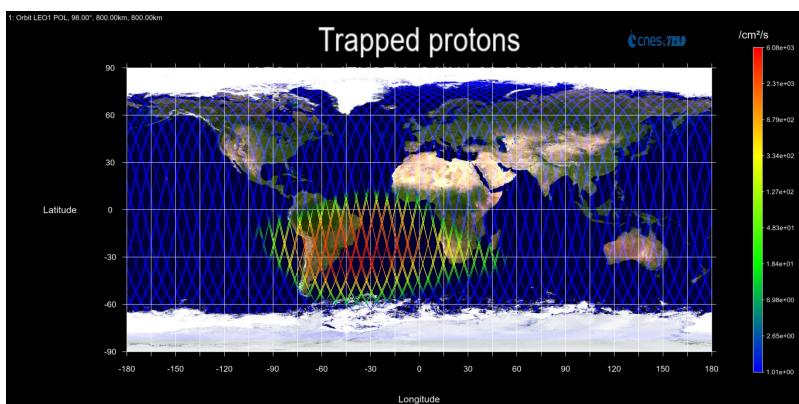
- ❑ Introduction
- ❑ Environment sources and variations
- ❑ Mission and environment definition in OMERE
- ❑ TID / TNID calculations
- ❑ Miscellaneous modules
- ❑ Calculation example

Introduction

TRAD & OMERE

□ TRAD benefits of more than 20 years of expertise in radiative environments and provides advanced services to help companies predict and minimize radiation effects on their products and systems.

- Test services
- Component selection
- Engineering support
- Software solutions

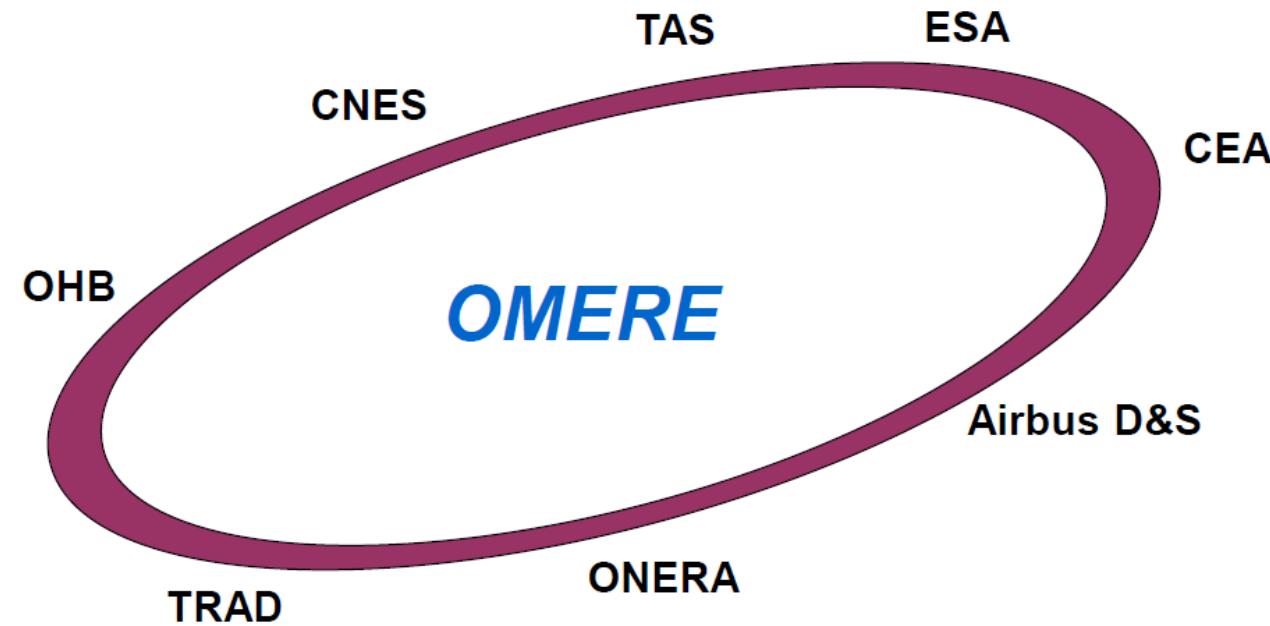


OMERE is the ultimate freeware for radiation environment calculation !

- ✓ Space Environment modelling
 - ✓ Trapped particles
 - ✓ Solar particles
 - ✓ Galactic Cosmic Rays
- ✓ Cumulative effects
 - ✓ Dose / Displacement damage depth curves
- ✓ Single Event Effects
 - ✓ SEE rate calculation
- ✓ Solar cells degradation
- ✓ Interplanetary missions

The OMERE software

- ❑ Developed by TRAD with CNES support
- ❑ Conceived to meet industrial requirements
- ❑ Partnership of european actors

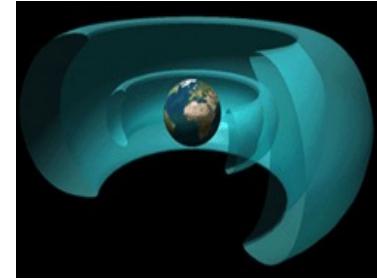


Environment sources and variations

Space radiation environment sources

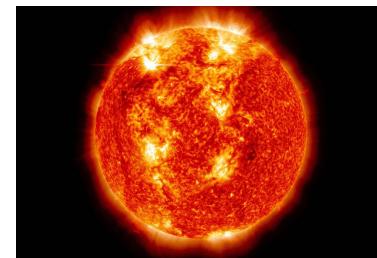
Van Allen radiation belt

Protons Electrons



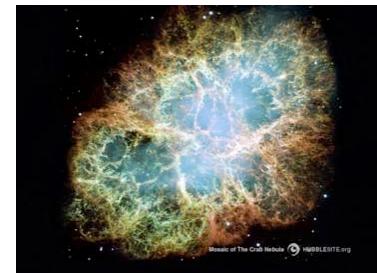
Solar particles

Protons Ions



Galactic cosmic rays

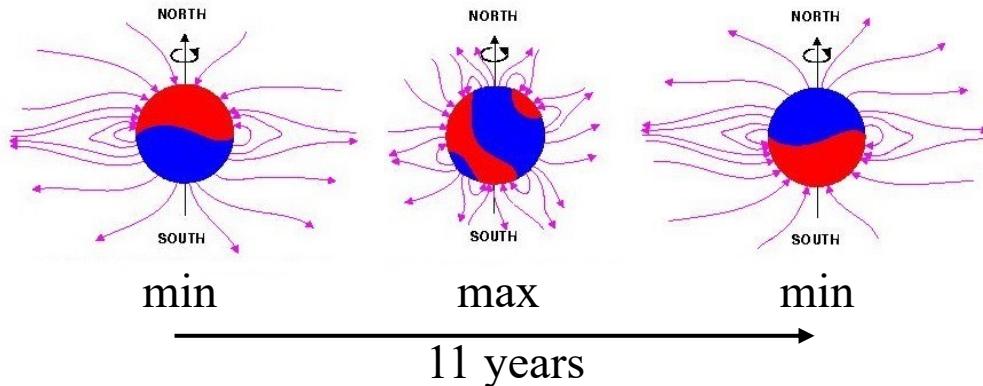
Protons Ions



Temporal variation

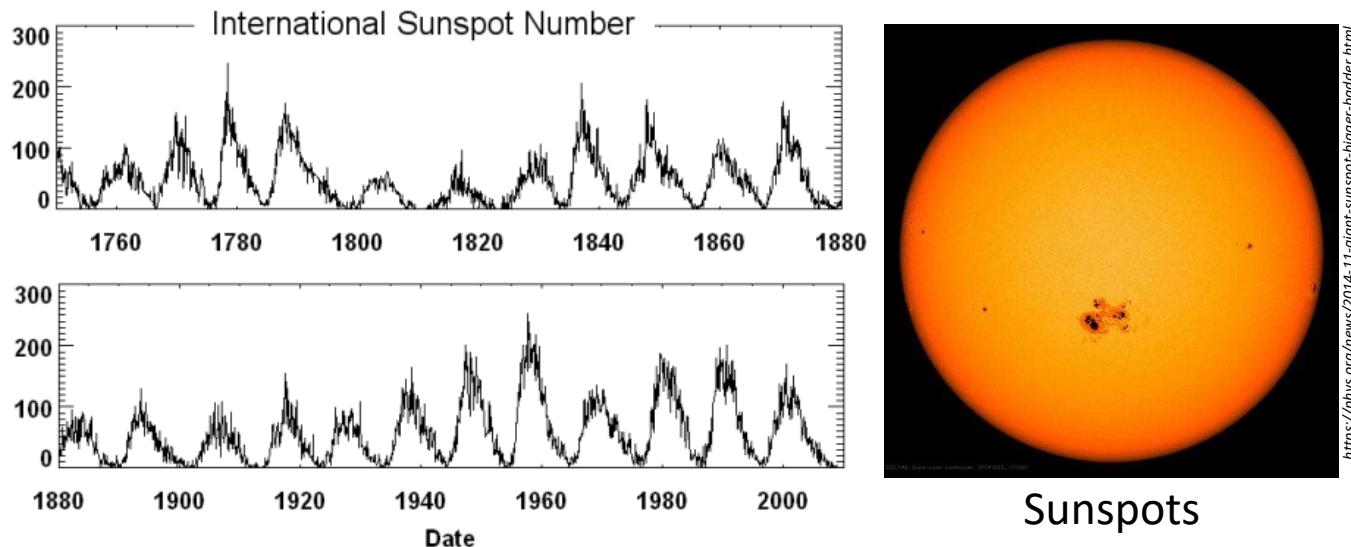
Solar magnetic field

- 11 years cycle (approximately)
- Dipole during solar minimum
- Complex during maximum



Solar activity has an impact on:

- Galactic cosmic rays
- Solar flares
- Trapped particles



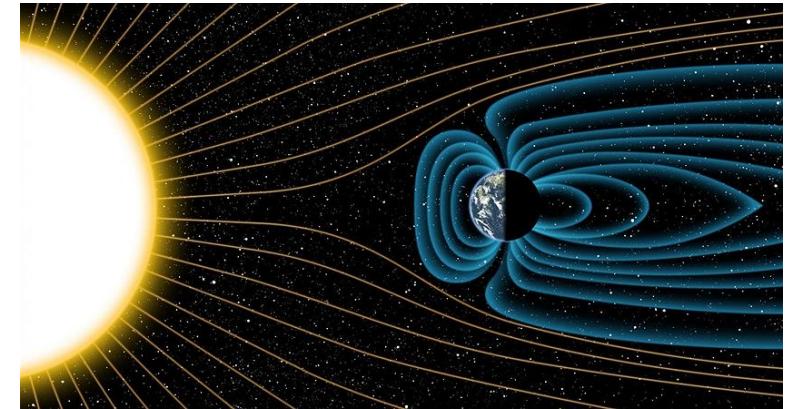
Today: Solar cycle #25

- *Min started in 2020*
- *Max would be reached in 2024*

Spatial distribution

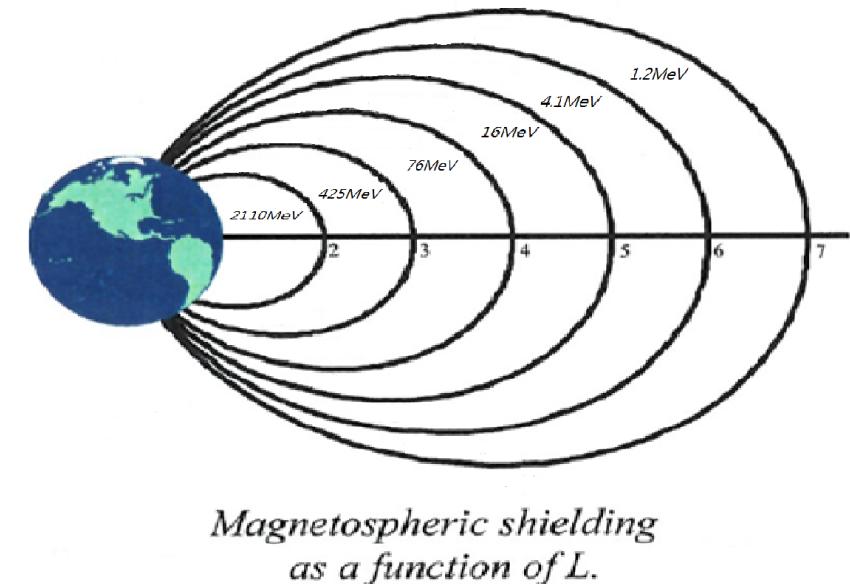
❑ Magnetosphere:

- Cavity where the magnetic field dominates
- **Natural protection** for the satellites (from **cosmic rays** and **solar flares**).
- **Trapping** of lower energetic particle
- Undergoes the pressure of the solar wind



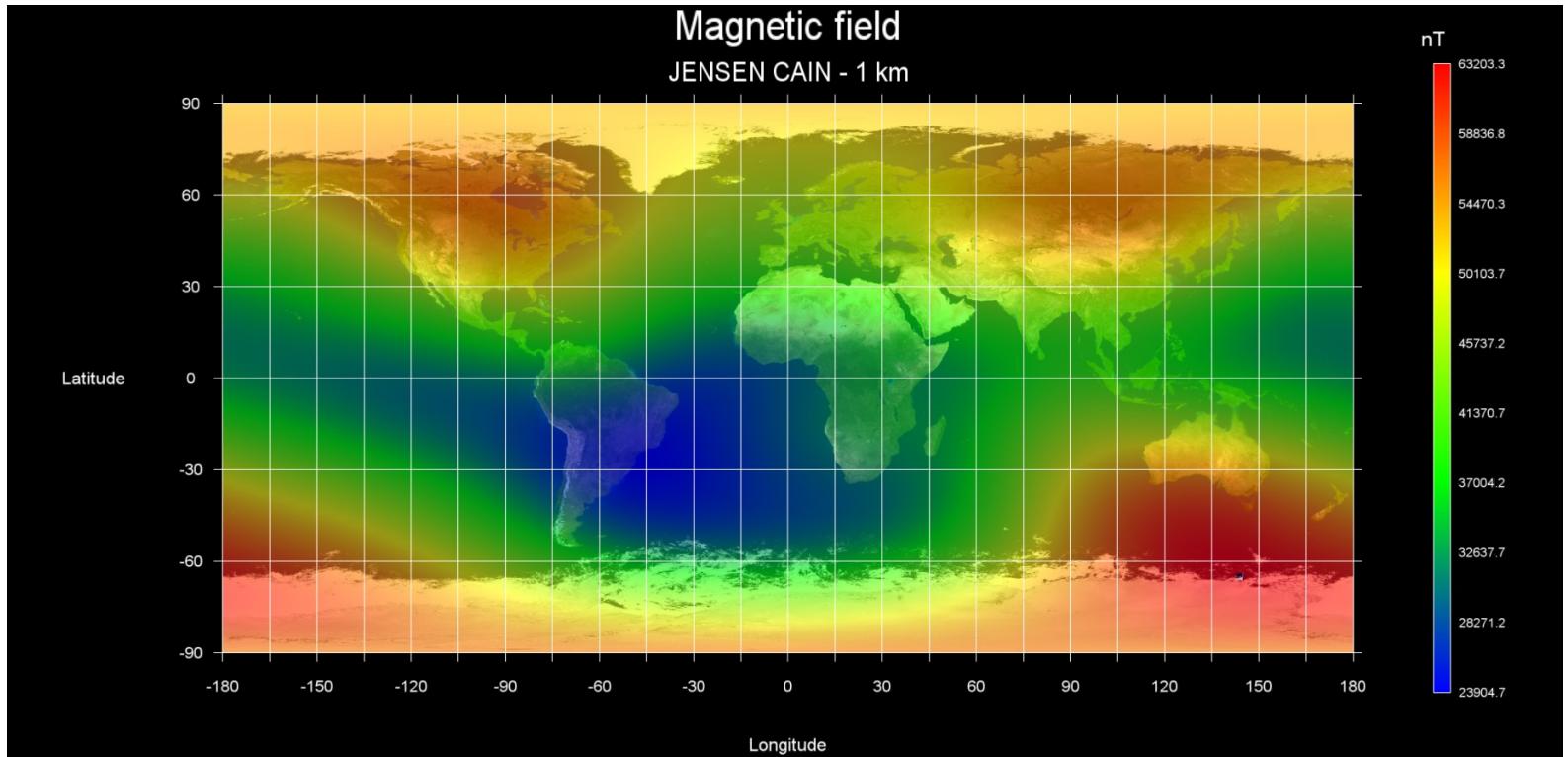
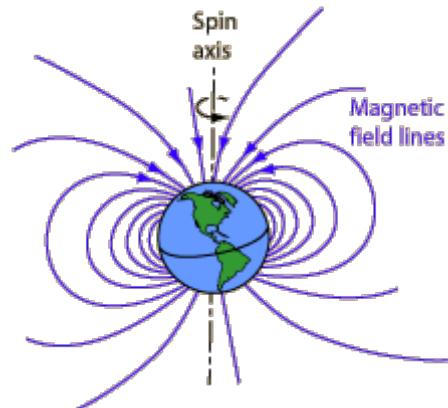
❑ Charged particles are deflected by the magnetic field

- Particles have to be very energetic to reach low altitude orbits.
- Electrons can not penetrate the shield
- No protection near the magnetic poles
- **Efficient against solar particles and cosmic rays**



The magnetosphere

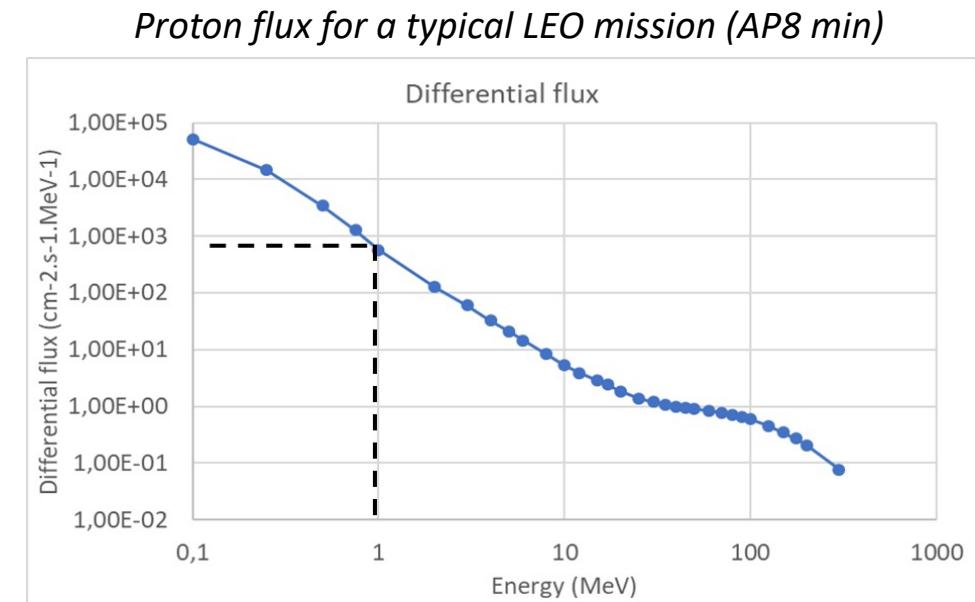
- Earth magnetic field (B_{earth})
 - Dipole
 - Tilted wrt spin axis (11°)
 - Off-centered (500km)
- South Atlantic Anomaly (SAA)



Particle spectra

□ What is a particle spectrum ?

- Gives the amount of a given particle above or at a given energy
- The quantity of particle is expressed as a flux or a fluence:
 - **Flux:** Number of particles crossing a surface per time unit [/cm²/s]
 - **Fluence:** Total number of particles crossing a surface during a given time [/cm²]
- Two different kinds of spectra:
 - **Differential**
 - Particles around a given energy (/cm²/s/MeV)
 - **Integral**
 - Particles above a given energy (/cm²/s)
 - Output of engineering space environment model

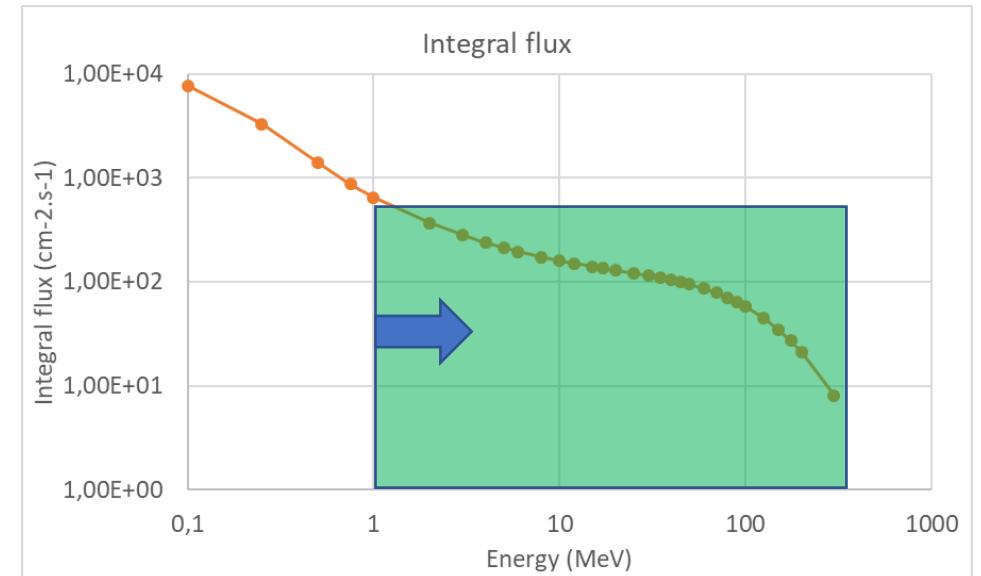


Particle spectra

□ What is a particle spectrum ?

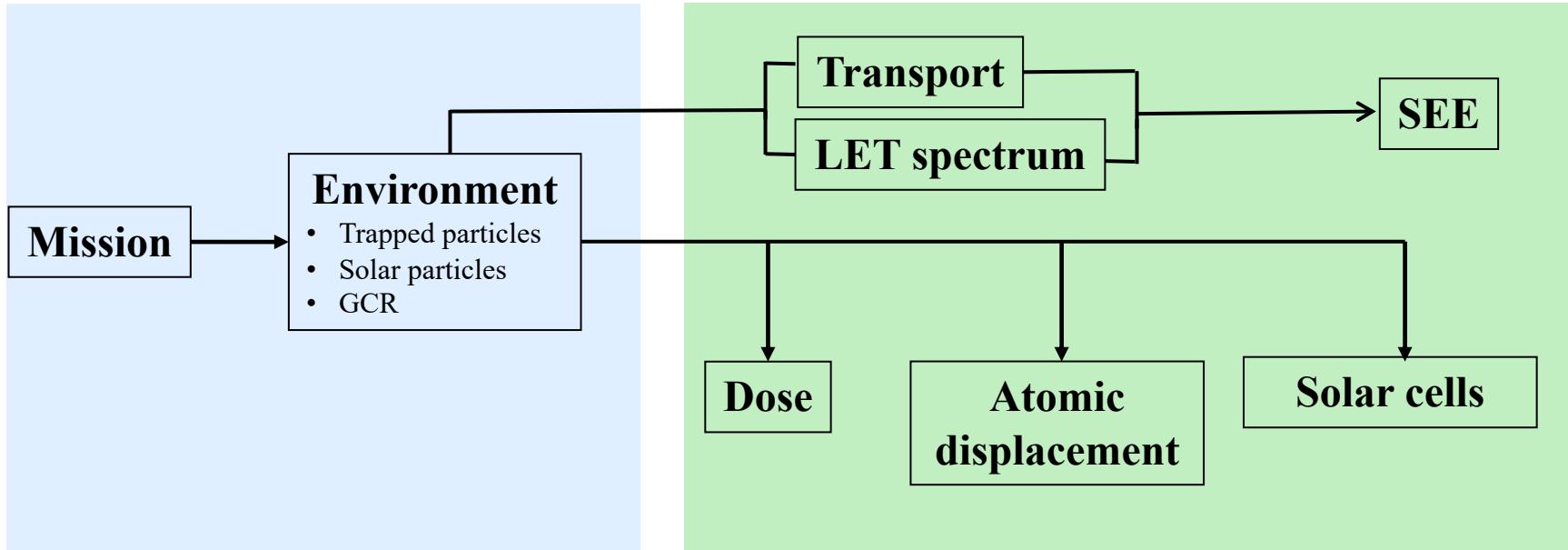
- Gives the amount of a given particle above or at a given energy
- The quantity of particle is expressed as a flux or a fluence:
 - **Flux:** Number of particles crossing a surface per time unit [/cm²/s]
 - **Fluence:** Total number of particles crossing a surface during a given time [/cm²]
- Two different kinds of spectra:
 - **Differential**
 - Particles around a given energy (/cm²/s/MeV)
 - **Integral**
 - Particles above a given energy (/cm²/s)
 - Output of engineering space environment model

Proton flux for a typical LEO mission (AP8 min)



Mission and environment definition in OMERE

OMERE architecture



1- Determines the spectra around the spacecraft

- Isotropic environment
- No shielding considered

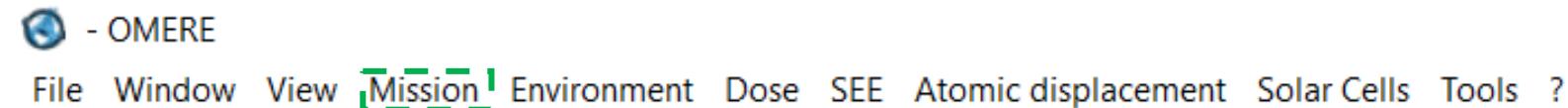
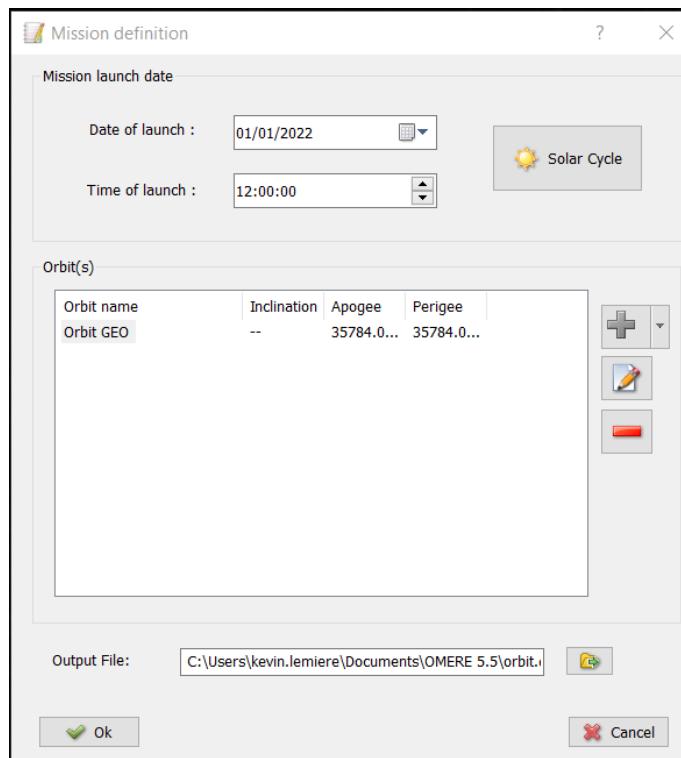
2- Estimates the effects on components

- SEE rate, ionizing dose, non-ionizing dose
- Shielding: simple geometry only

Mission definition

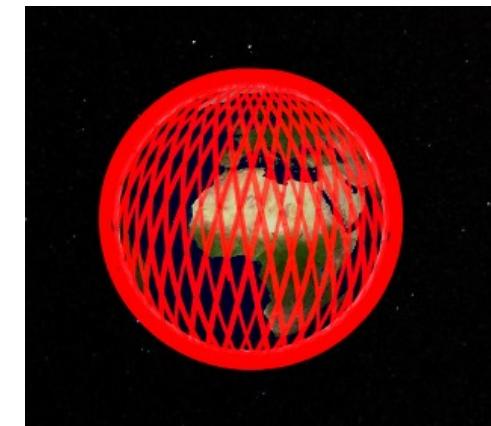
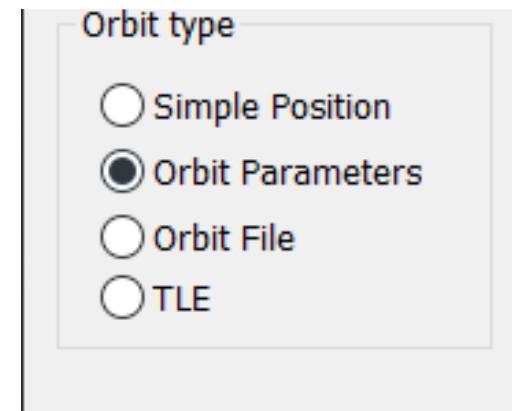
❑ Define the mission:

- Orbit
- Launch date



❑ Orbit type:

- Simple Position
- Orbit Parameters
- Orbit File
- Two Lines Elements (TLE)

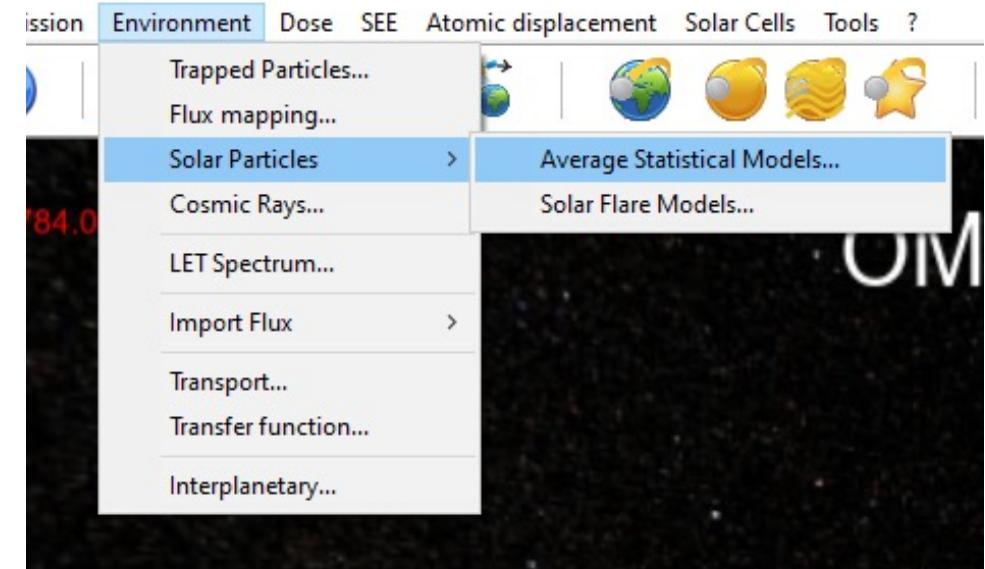


LEO polar orbit
Altitude : 800km
Inclination: 98°
Duration: 5 years

Environment definition

- ❑ Each environment source → dedicated module

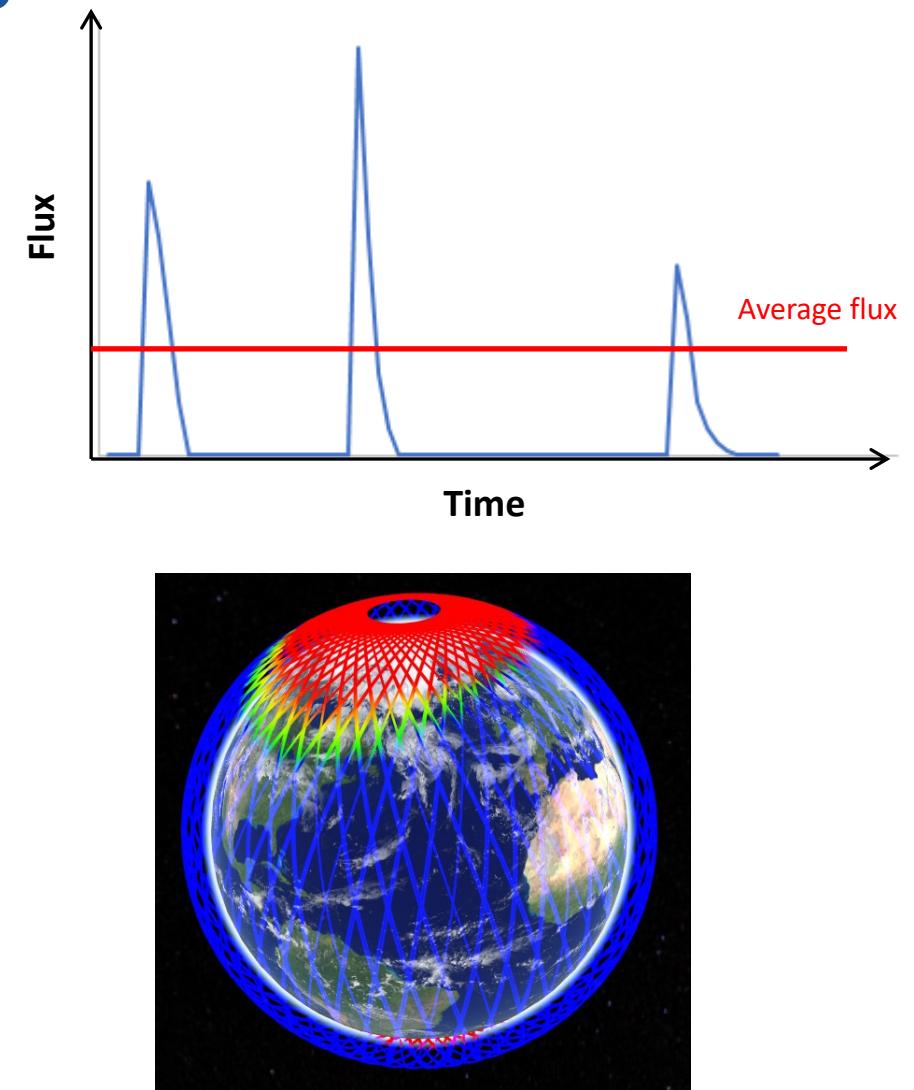
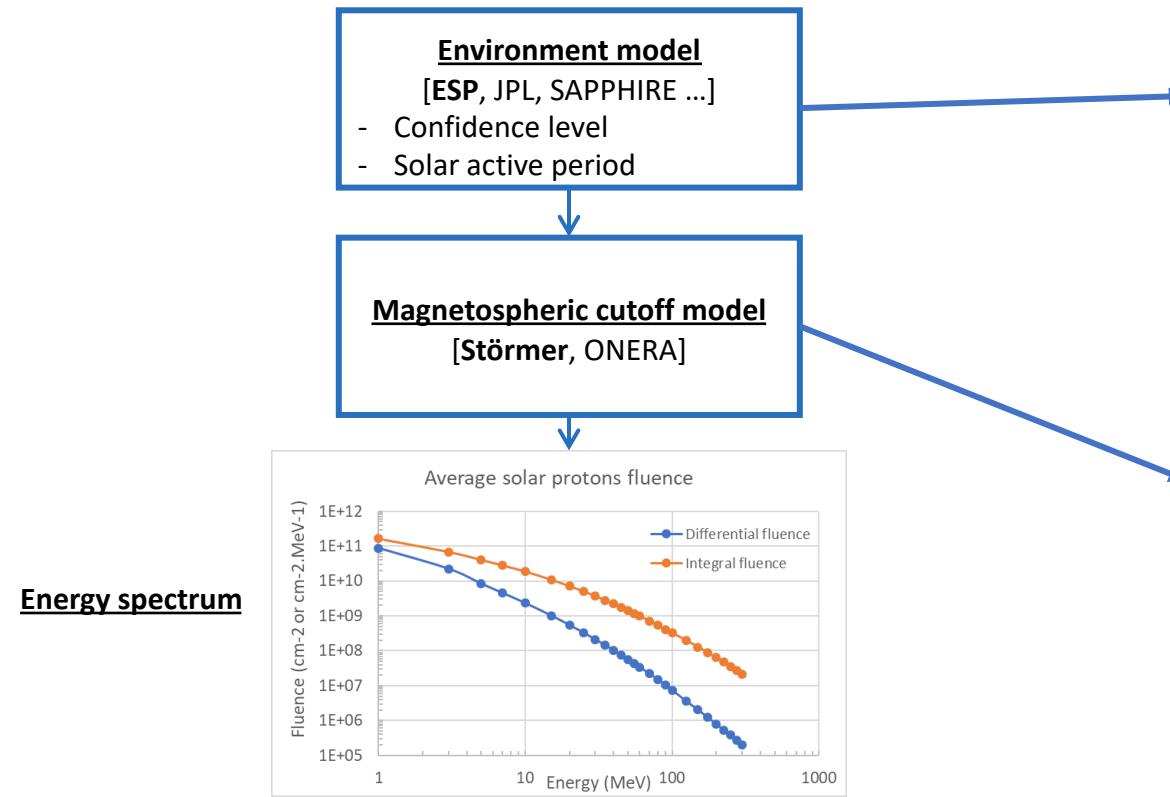
- Solar particles
 - Average
 - Flare
- Galactic Cosmic Rays
- Trapped particles



- ❑ Define model (standard or not)
- ❑ Enter calculation parameters (specific to each module)
- ❑ Calculate energy spectra

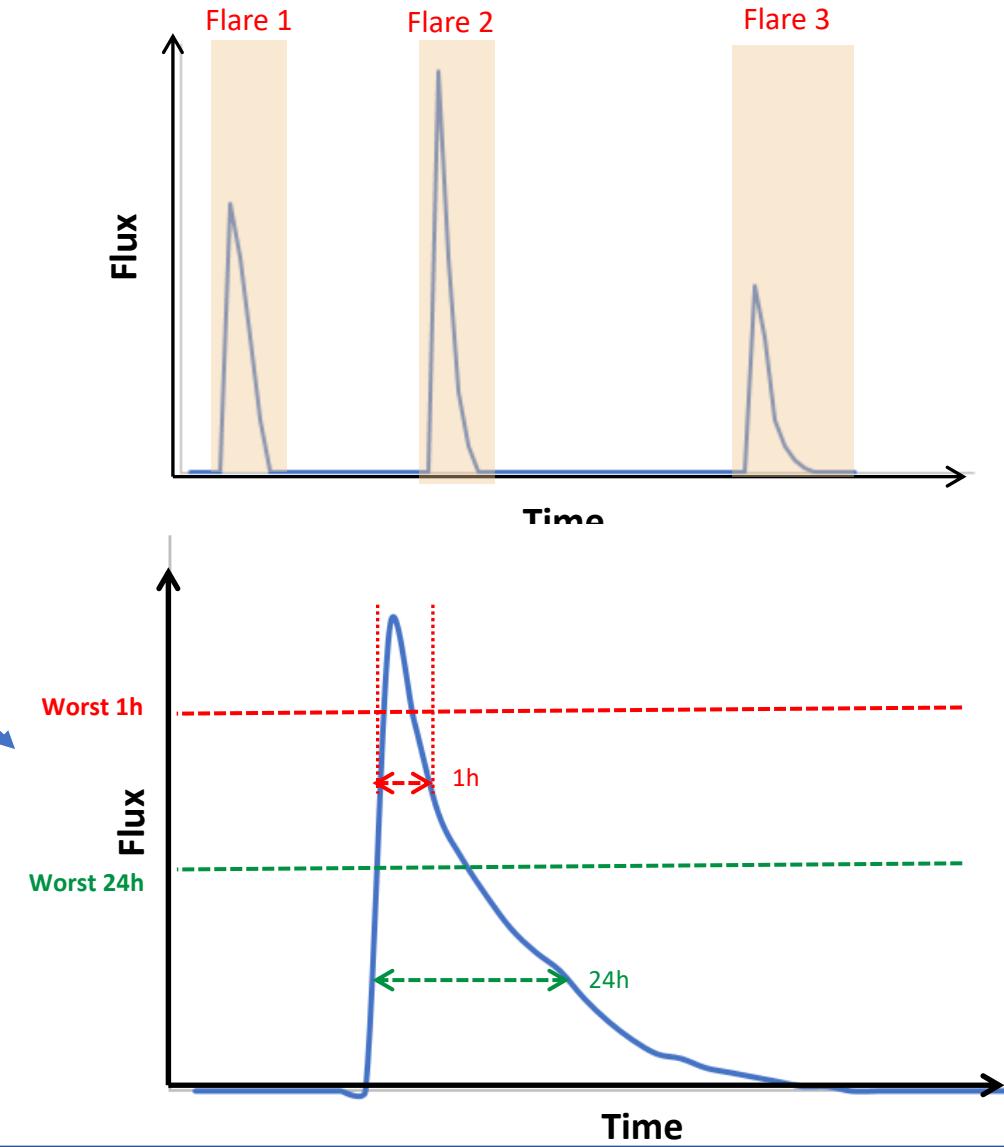
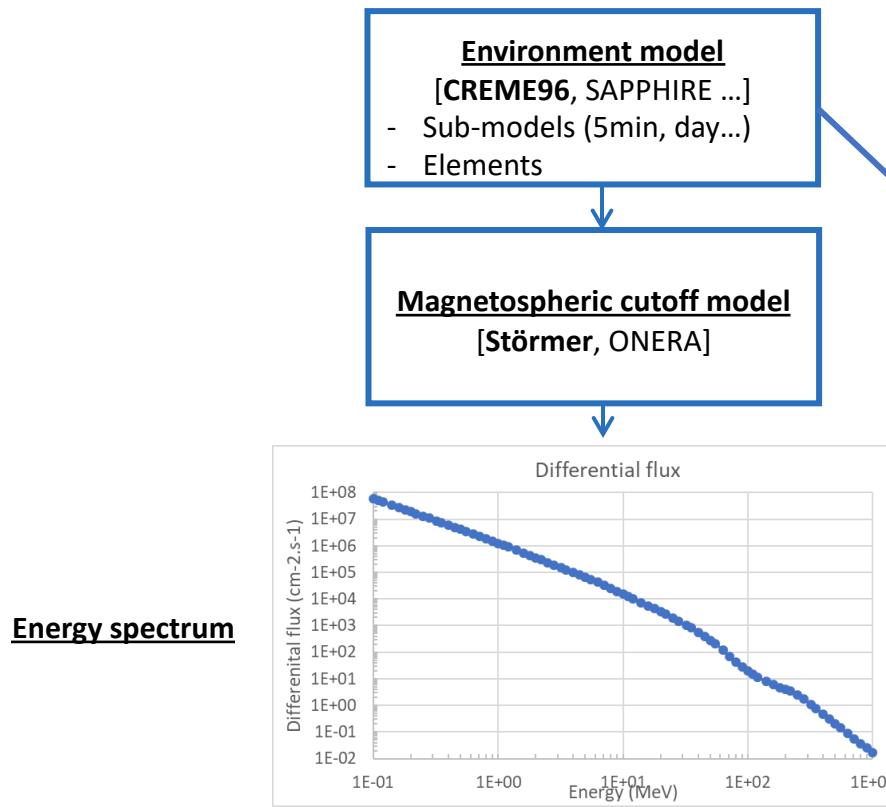
Solar particles average models

- ❑ Mostly used for TID
 - ECSS Standard: ESP



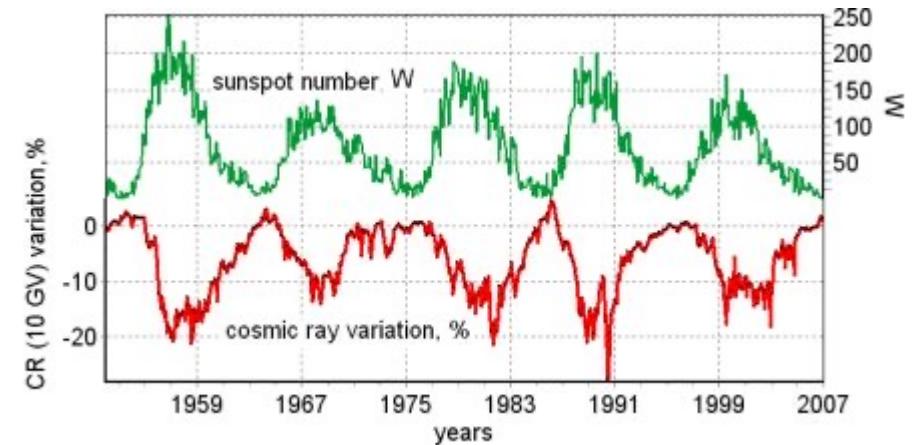
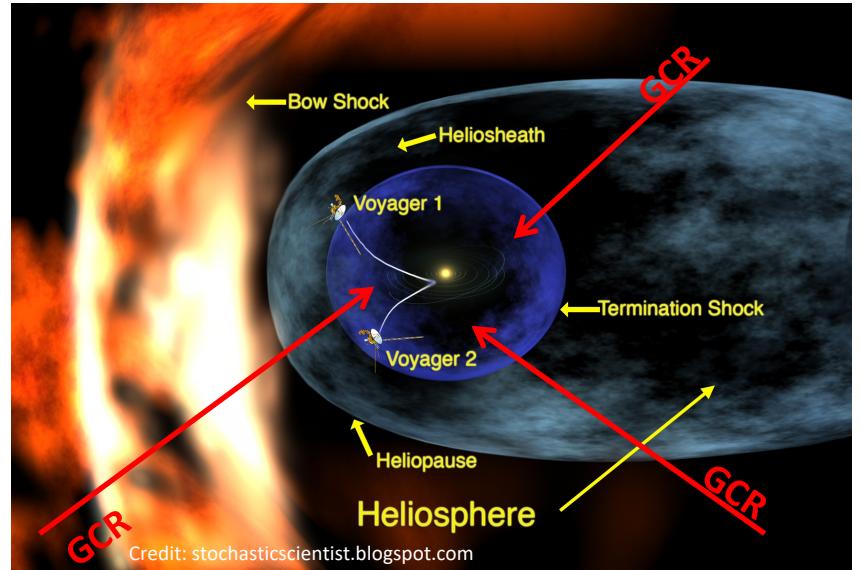
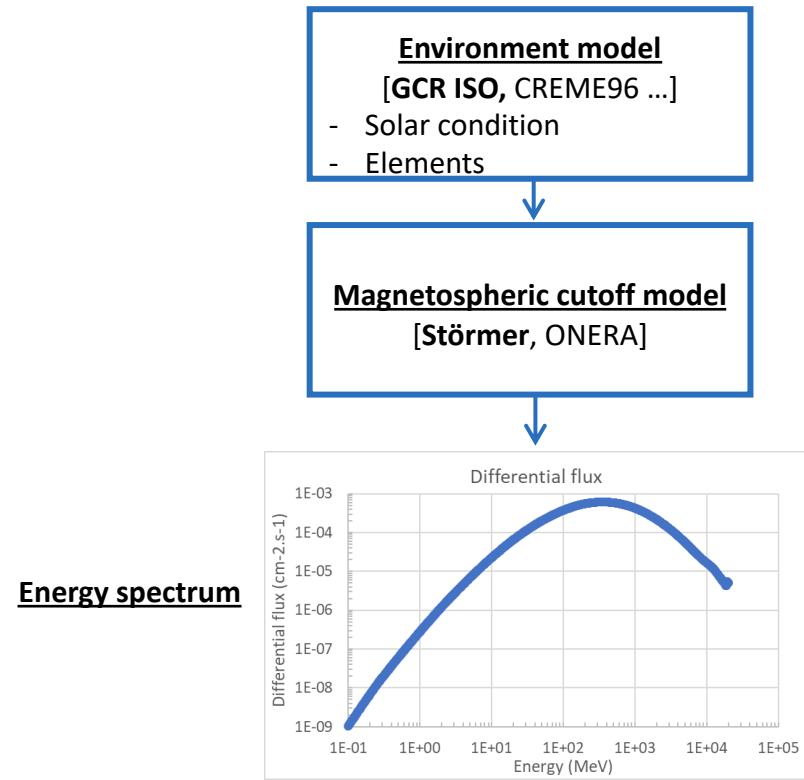
Solar particle Flare models

- Mostly used for SEE rate calculation
 - ECSS Standard: CREME 96 (for protons & ions)



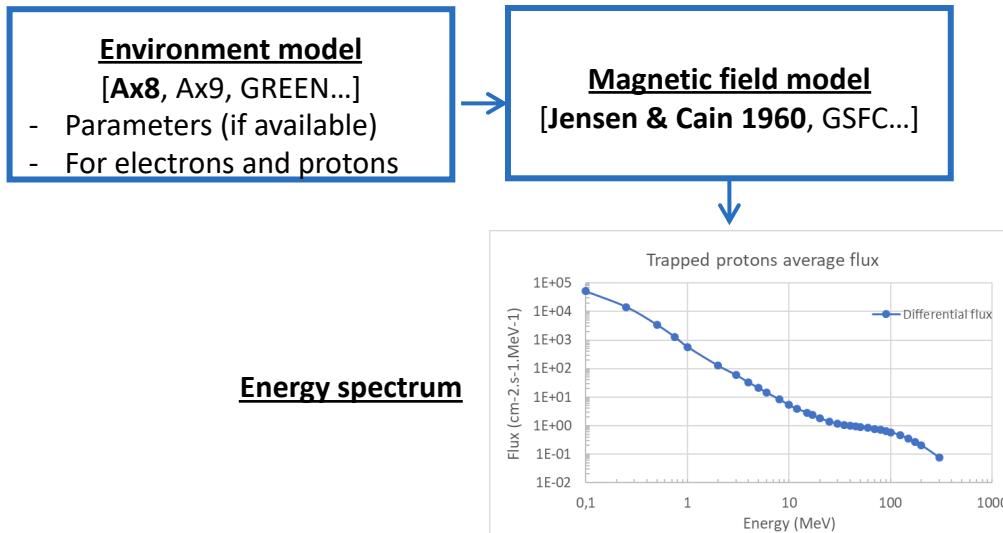
Galactic Cosmic Rays

- ☐ Anti-correlated with solar cycle
 - ECSS Standard: ISO 15390

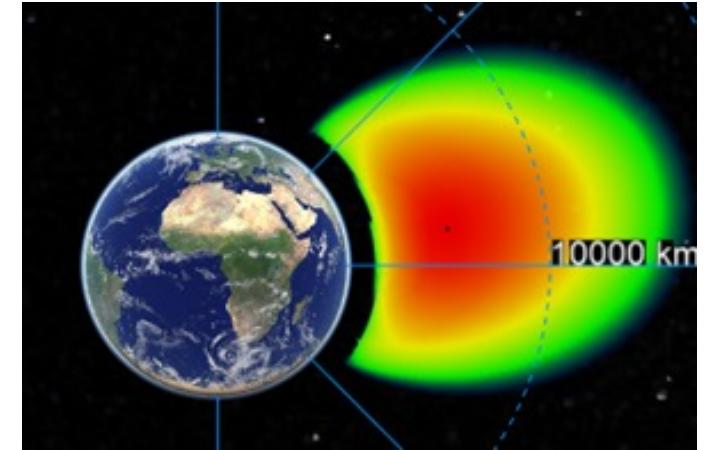


Trapped particles

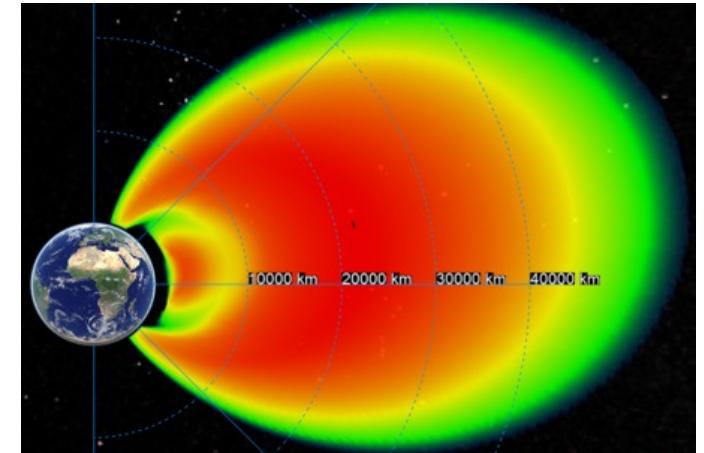
- 1 lower proton belt
- 2 Electron belts
 - ECSS Standard : AP8 for protons
 - ECSS Standard: AE8 (or orbit specific models) for Electrons



Protons
Source : GCR + Solar wind
Solar cycle dependency: anti-correlated



Electrons
Source : Solar wind
Solar cycle dependency: mostly correlated



Available models

Models:

- In-situ measurements
- Range of validity of L and energy
- Standards

Options:

- Solar min/max
- Confidence level [%]
- Magnetic field
- Magnetospheric cutoff

Cosmic rays

- GCR ISO 15390
- CREME 86
- CREME 96

Trapped particles

- Electrons
- AE8
- IGE 2006
- MEO
- OZONE
- SLOT
- AE9
- GREEN
- Protons
- AP8
- AP9
- OPAL
- GREEN

Solar particles

- Protons (average)
 - ESP
 - JPL91
 - JPL91 Extended
 - SOLPRO
 - SPOF
 - SAPPHIRE
- Ions (average)
 - PSYCHIC
 - Helium
 - SAPPHIRE
- Solar flare models
 - CREME 86
 - CREME 96
 - IOFLAR
 - SAPPHIRE

Magnetospheric cutoff

- Störmer
- ONERA

Magnetic field

- Jensen Cain
- Dipolar
- IGRF
- GSFC

Calculations

Ionizing Dose

□ The dose depth curve is calculated with SHIELDOSE-2 considering:

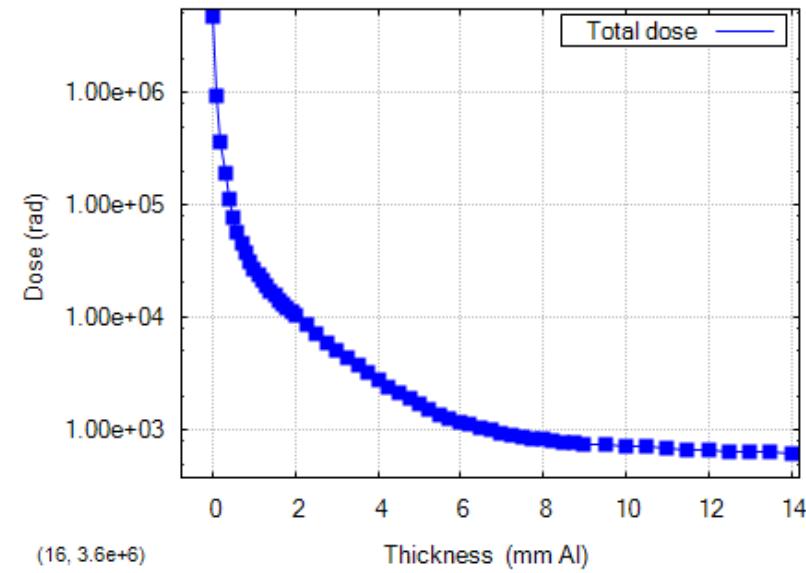
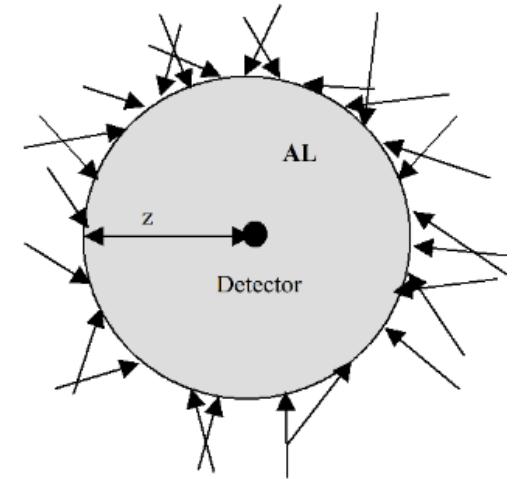
- Energy spectra
- Calculation parameters: geometry, target material

□ Inputs: energy spectra

- *From mission*: the spectra are calculated considering the mission and models selected in the environment module.
- *From files*: user directly inputs the spectra

□ Parameters:

- Geometry: simple geometry considered for the dose calculation
- Target material: the dose estimated in a given material



Atomic Displacement

- OMERE

File Window View Mission Environment Dose SEE **Atomic displacement**

☐ The dose depth curve is calculated considering:

- Energy spectra
- Calculation parameters: NIEL data

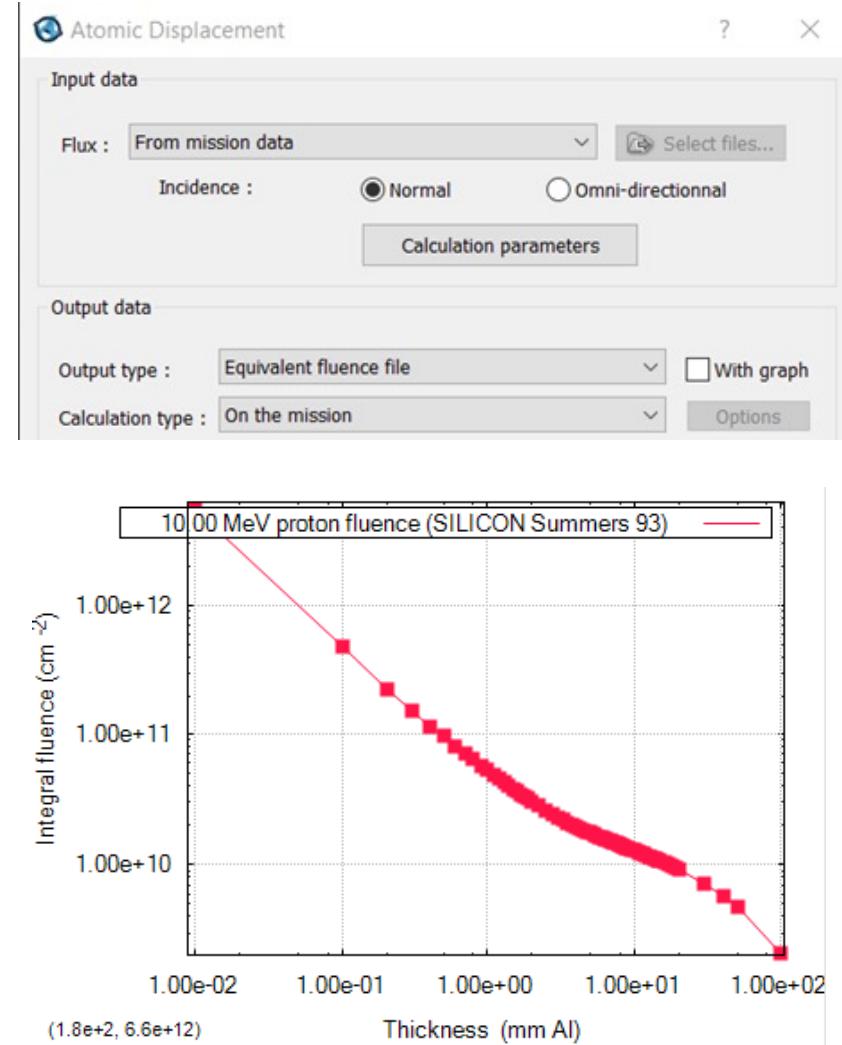
☐ Inputs: energy spectra

- *From mission*: the spectra are calculated considering the mission and models selected in the environment tools.
- *From files*: user directly inputs the spectra

☐ Output:

- The result can be expressed in terms of displacement dose or equivalent fluence*

*Correspond to the fluence that a monoenergetic beam of a given particle must have to deposit the same Displacement Damage Dose (DDD) as the mission



Solar cells

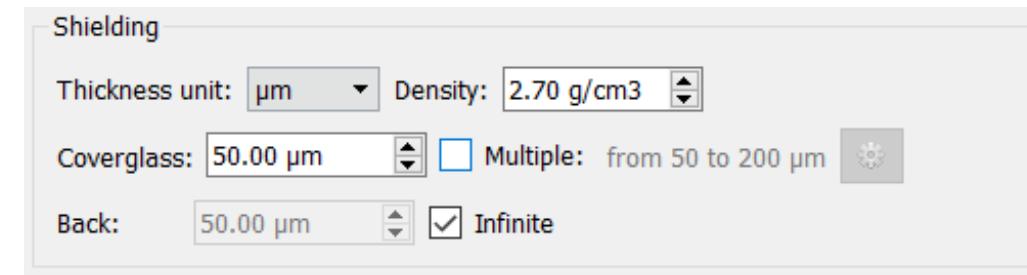
□ Two models:

- **JPL**: estimates the equivalent fluence for three electrical parameters: Pmax, Voc, Isc.
- **NRL**: estimates the EOL (End Of Life) performances via displacement damage.



□ Two types of shielding:

- Simple: only one value of shielding is considered
- Multiple: the degradation is estimated for several values of shielding



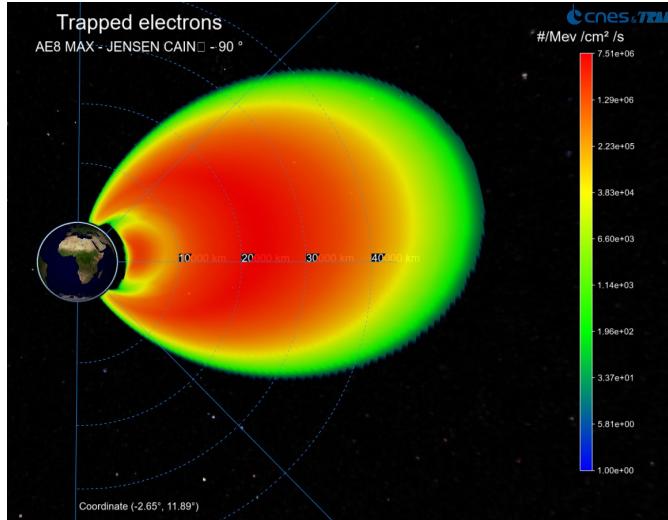
□ Output:

- Output file with EOL performance for each source of particle

# Back Shielding: Infinite	Displacement Damage Dose (MeV/g)			EOL Performance (%)
# Coverglass	Electrons	Protons	Total	
# Thickness (um)	5.000e+01	1.712e+09	3.218e+09	4.931e+09
#				7.854e+01

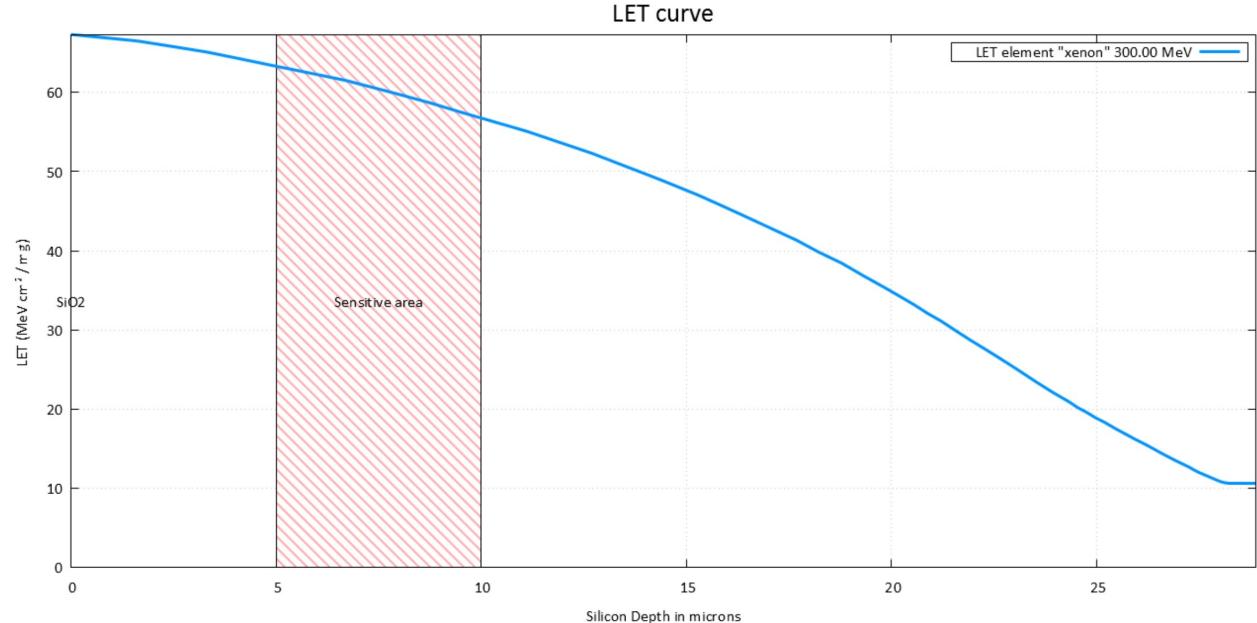
Other features

□ Flux and magnetic field mapping

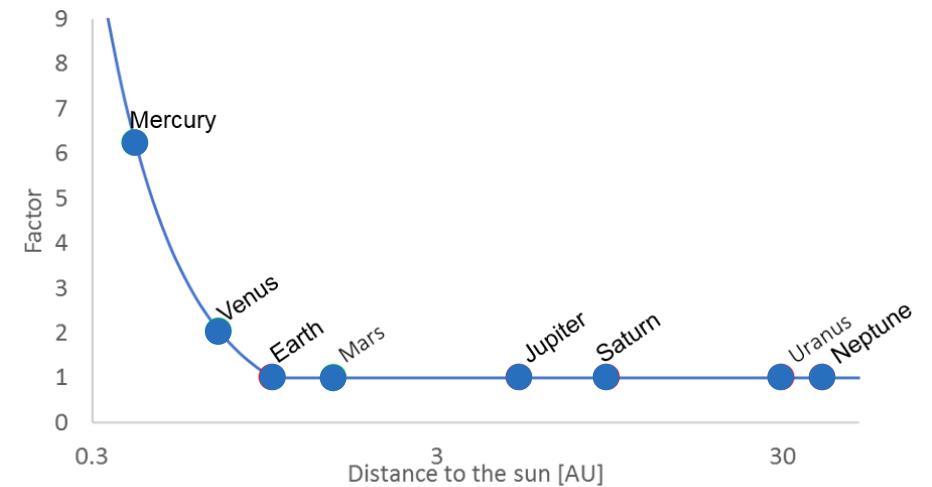


□ Many others:

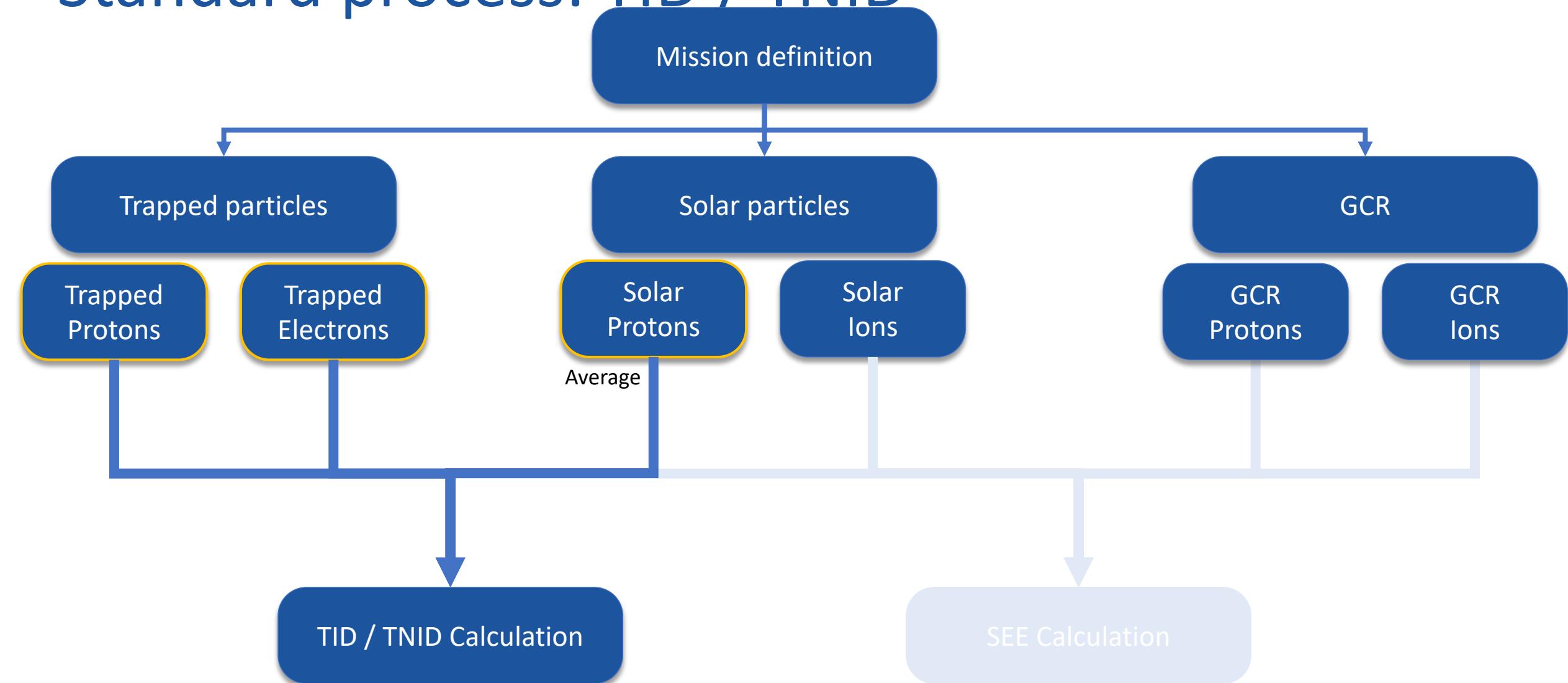
- Ion LET vs range in material (ion test)
- Interplanetary missions
- ...



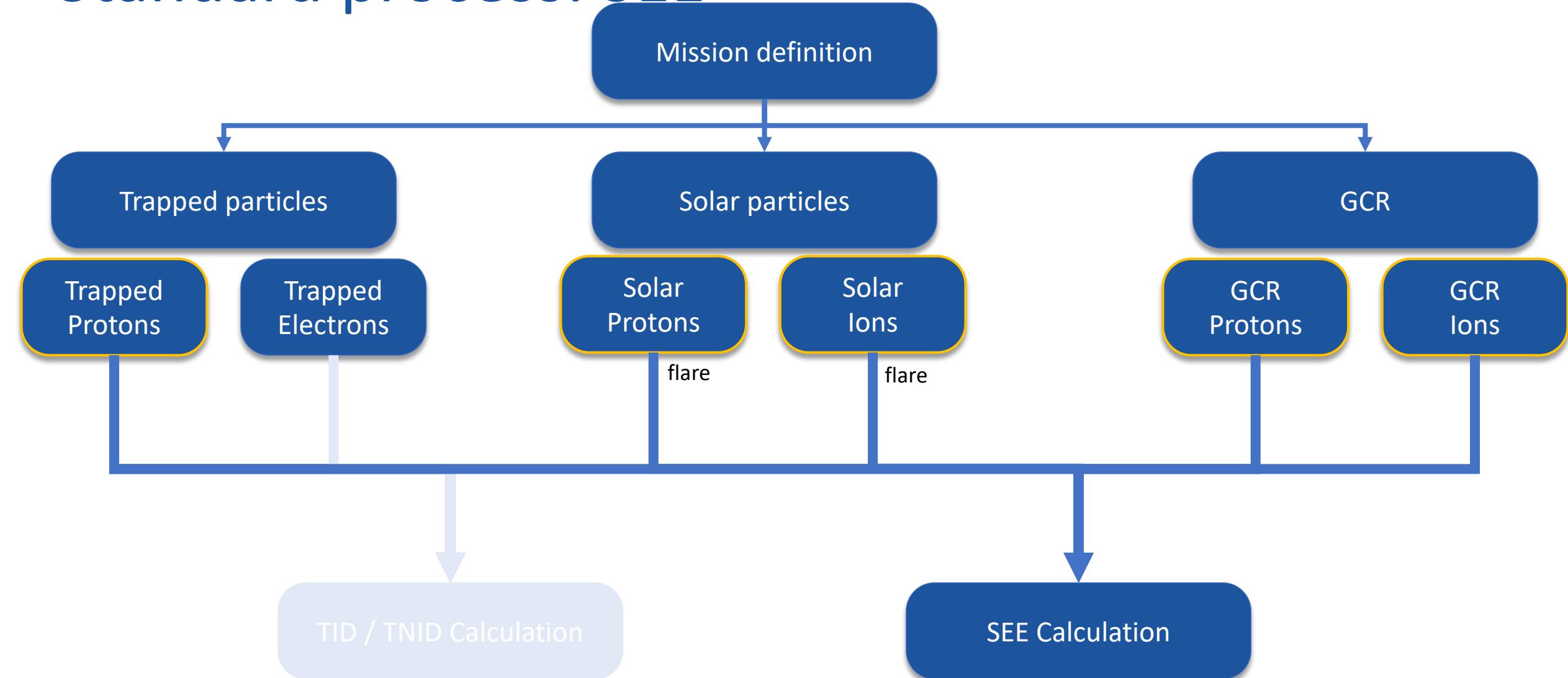
Solar particle flux attenuation law (ECSS)



Standard process: TID / TNID



Standard process: SEE



OMERE demo

Calculation example

Environment and dose calculation

Mission	Orbit Name	Altitude	Eccentricity	Inclination	Duration
	LEO1	800	0 (circular)	98	10 years
	LEO2 ISS	400	0 (circular)	51.5	10 years

Trapped Particles	Particle type	Model	Solar condition
	Trapped Electrons	AE8 (ECSS Standard)	Max (Worst-case)
	Trapped Protons	AP8 (ECSS Standard)	Min (Worst-case)

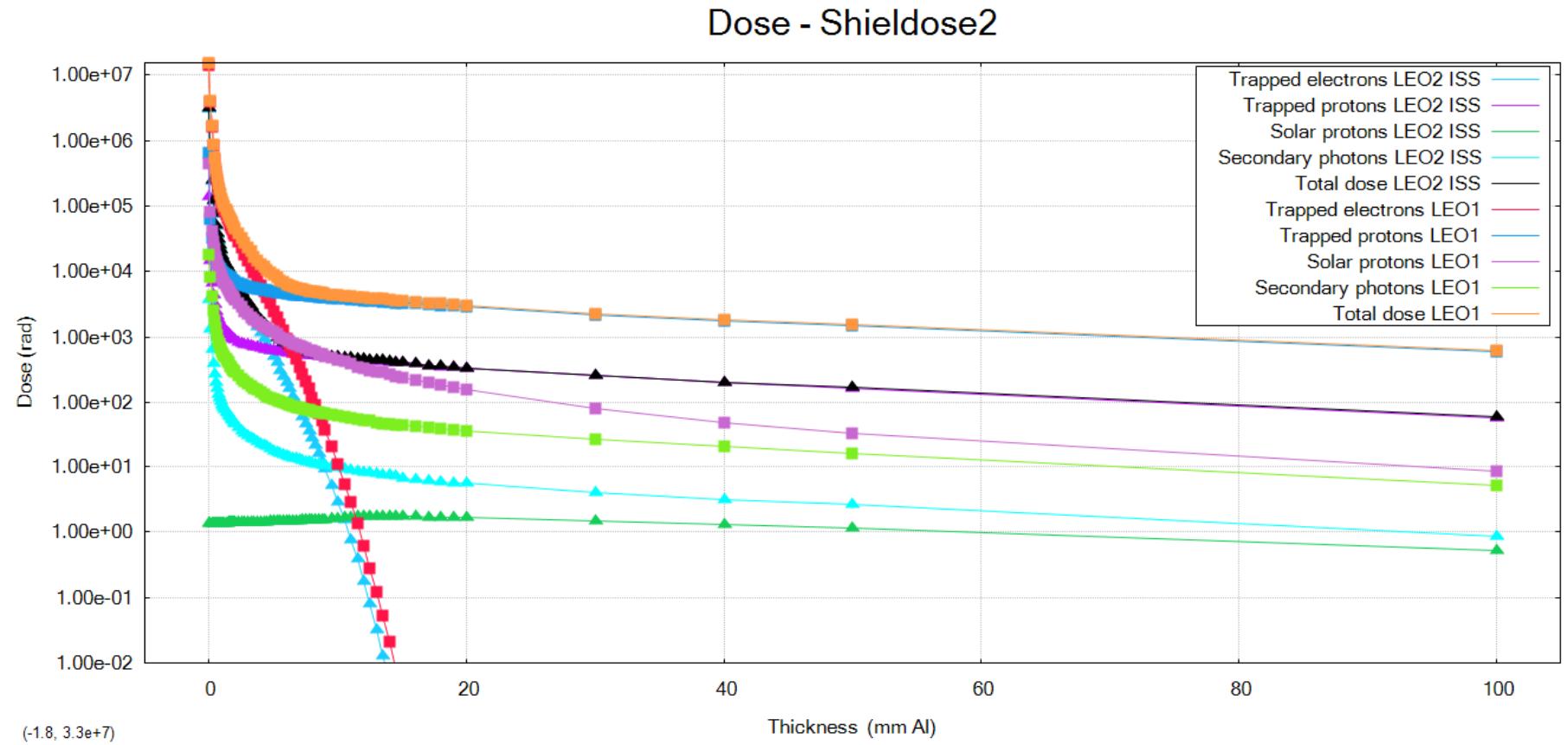
Solar particles	Particle type	Model	Confidence level	Solar active period
	Solar Protons	ESP (ECSS Standard)	80%	Worst case

1. Compare the dose as a function of the thickness for the two missions.
2. Compare the average trapped proton flux for each orbit.
3. Compare the solar proton flux >10 MeV along each orbit.
4. Conclude

Calculation example solution

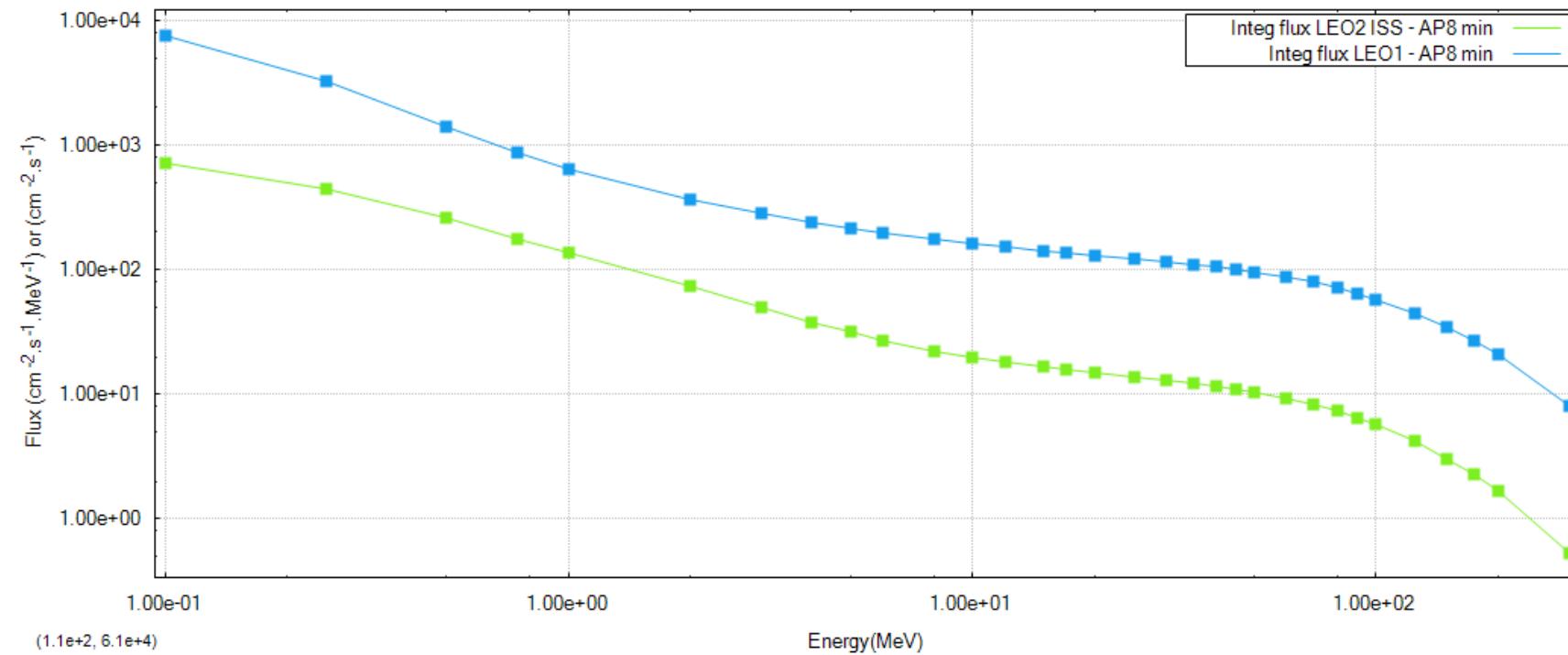
Solution

□ Main differences found in : Solar protons & Trapped protons



Solution : Trapped particles

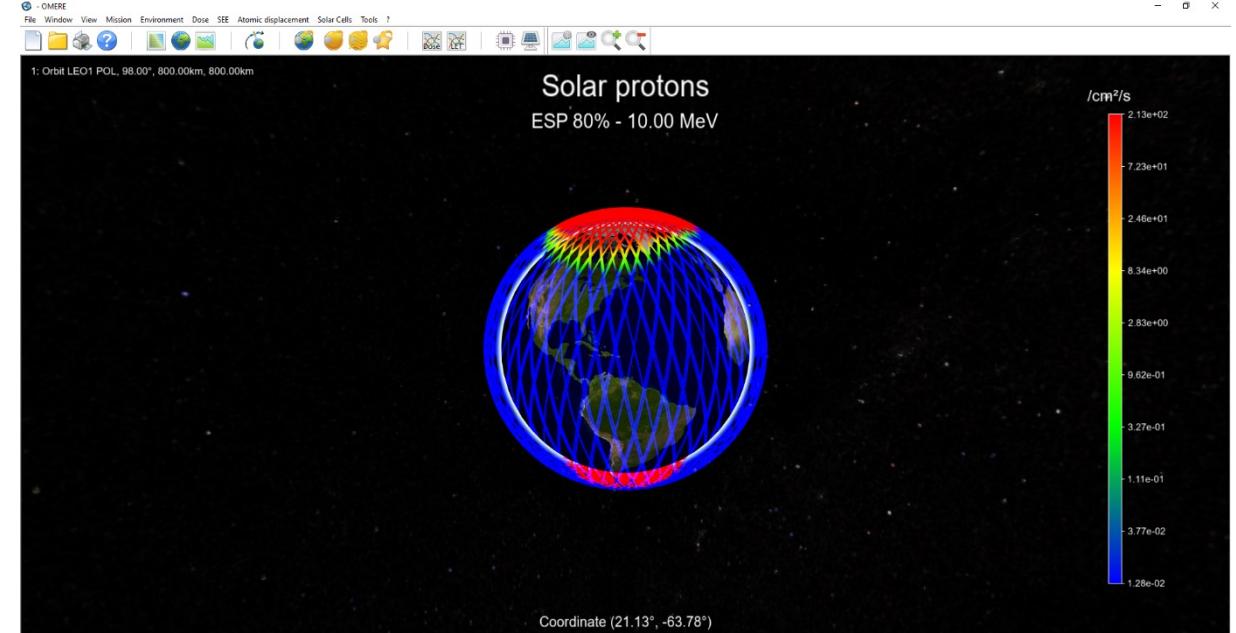
- LEO1 : High altitude → Deeper in Trapped proton belt
- LEO2 ISS: Lower altitude



Solution : Solar particles

□ LEO1 : Polar orbit → High inclination

- Less protected
- Higher solar proton fluence



□ LEO 2 : Low inclination

- More protected
- Lower solar proton fluence

