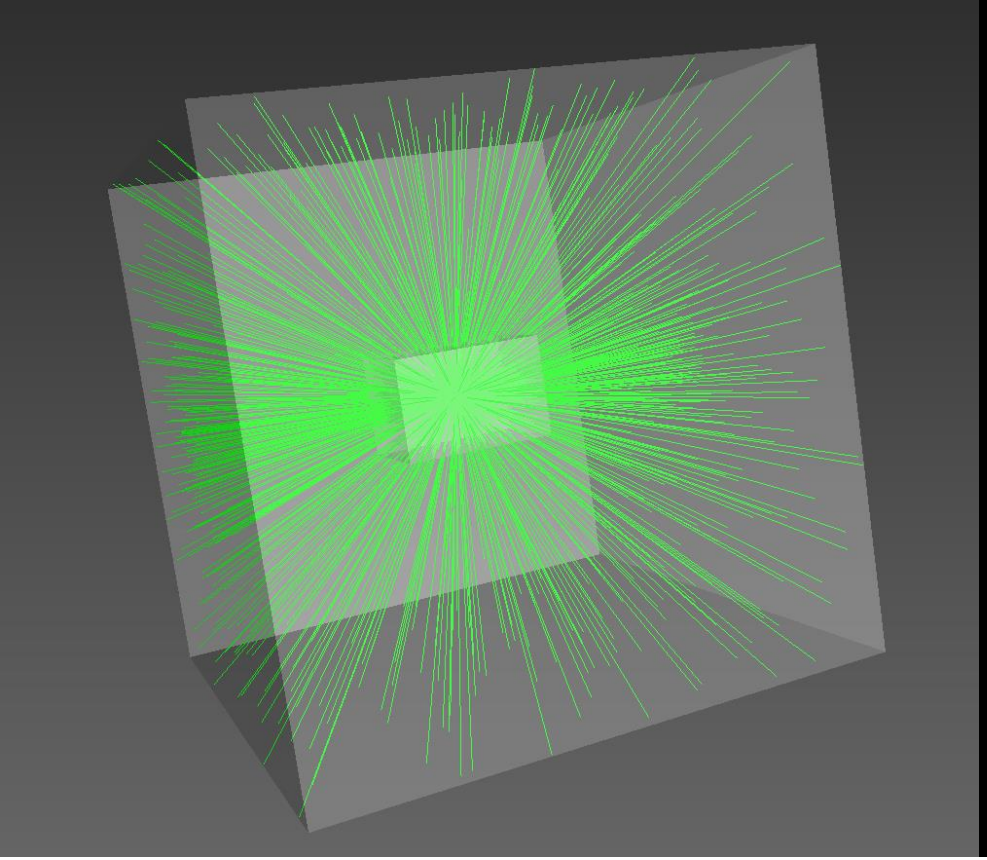


Radiation studies in support of the design of space mission instruments

Neophytos Messios & Erwin De Donder

STCE Annual Meeting, 29 June 2023

Royal Belgian Institute for Space Aeronomy

Outline

- A brief introduction to space radiation environments and its effects
- Performing radiation analysis for space mission instruments
- Study 1 - Lunar XRF Spectrometer
- Study 2 - Venus Spectrometer with High resolution

The space environment

- Any space mission planning involves the analysis of the potentially encountered environments

Neutral gaseous environments

- planetary atmospheres

Micro-particles

- micro-meteoroids
- space debris

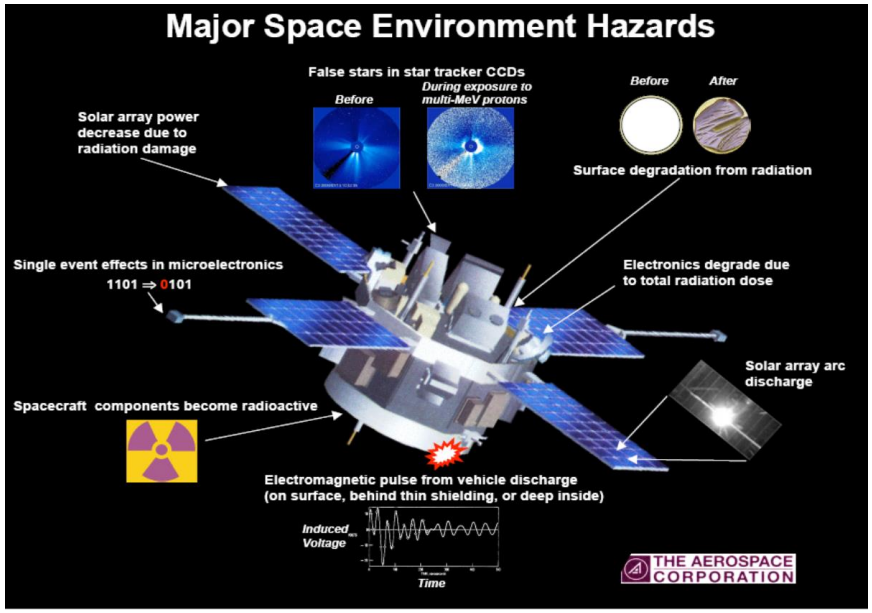
Plasma environments

- hot plasmas
- ionospheric plasmas

Radiation environments

- trapped particles
- solar energetic particles
- galactic cosmic rays
- secondary particles

Radiation environment & effects



Overview of relevant radiation environment for different missions and specific effects

Mission type	Effect	Space radiation environment			
		trapped protons	trapped electrons	solar particles	GCRs
LEO	TID				
	TNID				
	SEEs				
MEO	TID	low MEOS			
	TNID				
	SEEs				
GEO	TID	low energy			
	TNID	very low energy			
	SSEs				
Interplanetary	TID				
	TNID				
	SEEs				

TID: Total Ionising Dose
TNID: Total Non-Ionising Dose
SEEs: Single Event Effects)

Standardisation

European Cooperation for Space Standardization (ECSS)

https://ecss.nl/

esa

ECSS standards

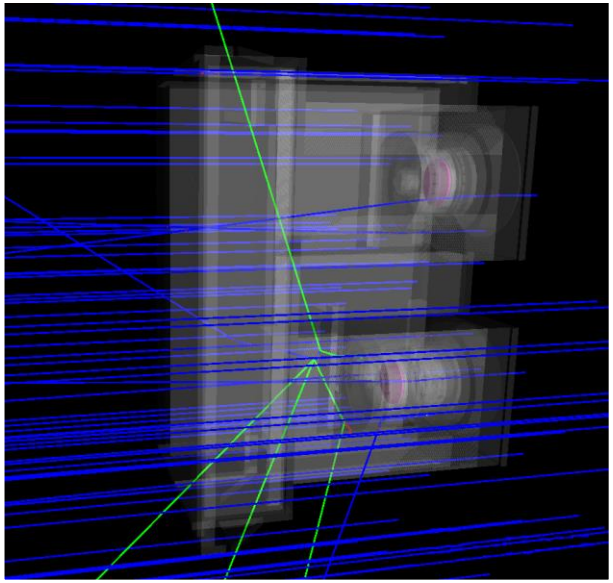
Standards are needed to aid the development process;
ensure people work in the same way and account properly for all issues

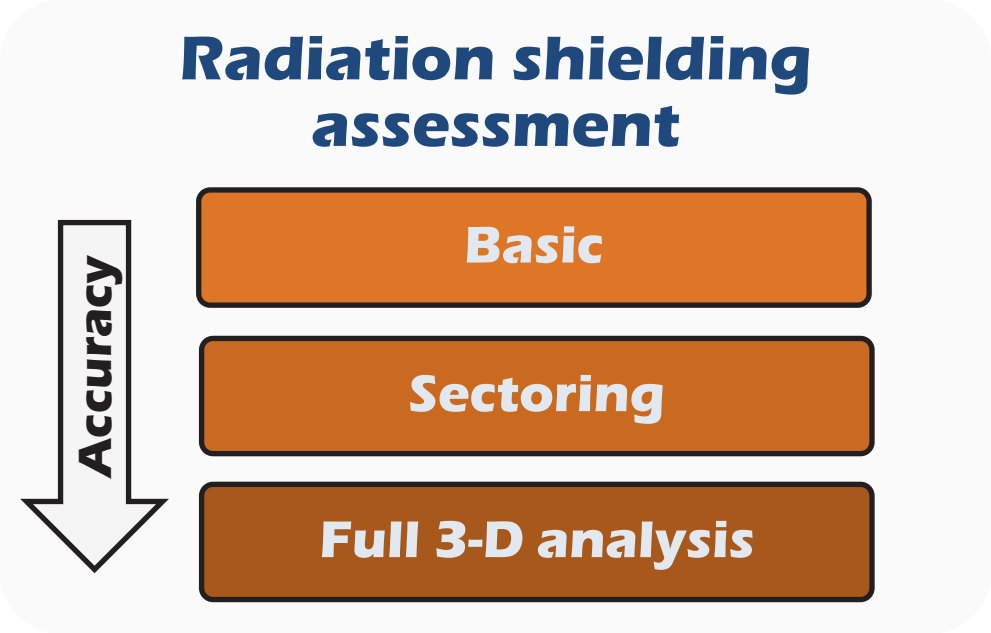
- Space Environment
  ECSS-E-ST-10-04C
- Method for calculation of radiation effects and a policy for margins
  ECSS-E-ST-10-12C
- Spacecraft Charging (= Spacecraft Plasma Interactions)
  ECSS-E-ST-20-06C
- Radiation Hardness Assurance - EEE Components
  ECSS-Q-ST-60-15C
- Handbook on Methods for Calculation of Radiation Effects
  ECSS-E-HB-10-12
- Q-ST-60-15c
  Radiation Hardness Assurance
- Others:
  - Materials
  - Human Factors

Assessing the radiation impact

Requires accurate knowledge of

1. external space environment
2. shielding effect of material

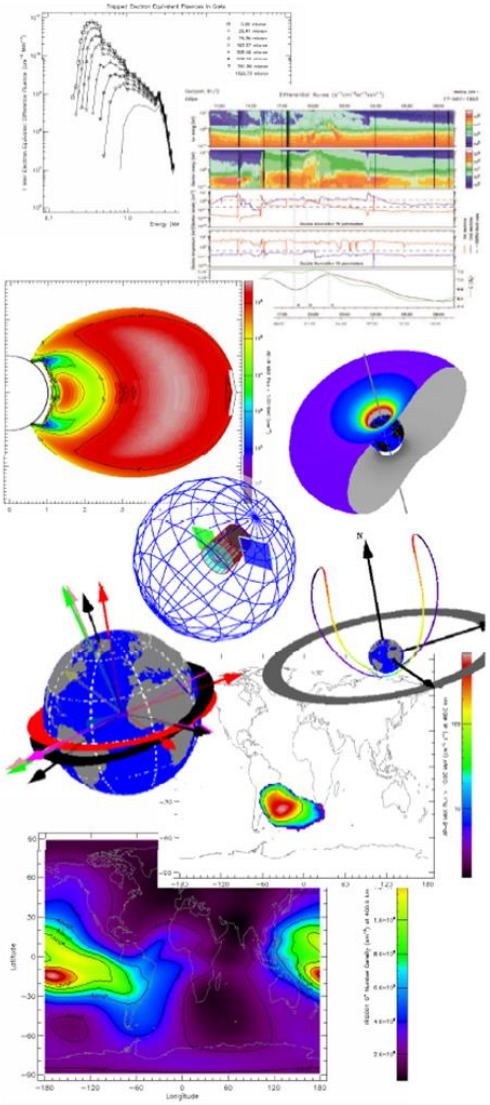




Tools - ESA's SPENVIS system

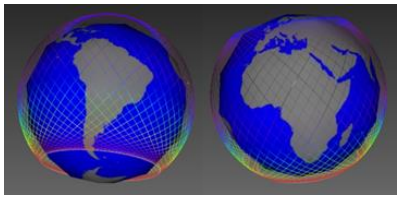
https://www.spenvis.oma.be

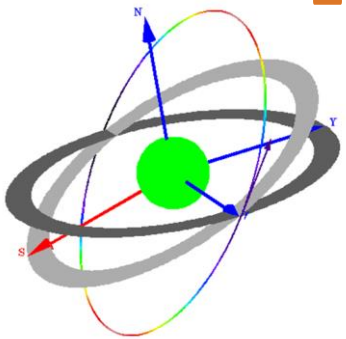
- Operational software with large user community
- Web interface to models of the space environment & its effects
- Developed & maintained by BIRA-IASB since 1996
- Publicly available since 1998

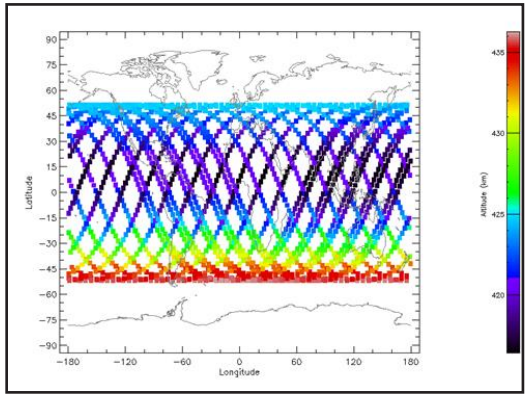


Typical workflow

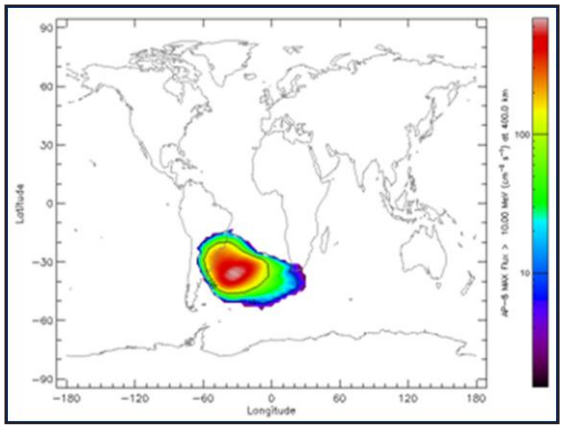
1. Mission

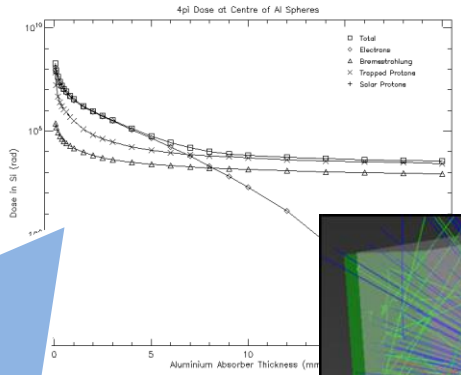




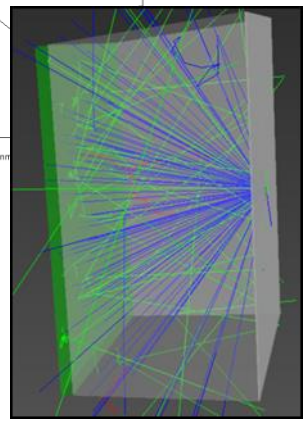


2. Environments





3. Effects



STUDY 1 » Lunar XRF Spectrometer

BIRA•IASB

Royal Belgian Institute
for Space Aeronomy

The context

- ESA project to develop an X-ray fluorescence (XRF) spectrometer for a lunar mission led by CSL (Belgium)

- Tasked to performed a radiation environment specification and analysis assuming the following mission profile:
  - ✓ one year duration
  - ✓ only lunar surface operation

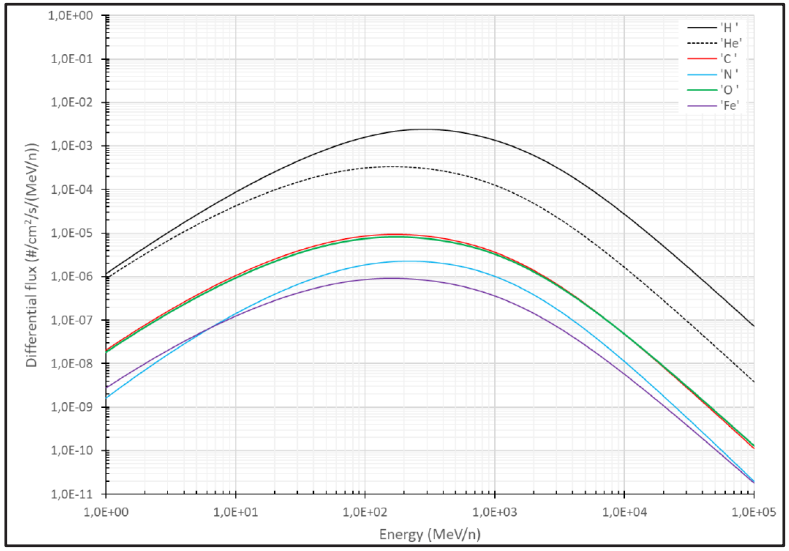
Specifying the radiation environment

- Primary radiation environment specification (worst case)
  - ✓ GCR flux spectrum using **ISO standard 15390** model (solar minimum)
  - ✓ SEP fluence spectrum using the **ESP** (Emission of Solar Protons) model and the **PSYCHIC** (Prediction of Solar particle Yields for CHaracterizing Integrated Circuits) model (worst event with a 95% confidence level during 1 year of solar maximum activity)

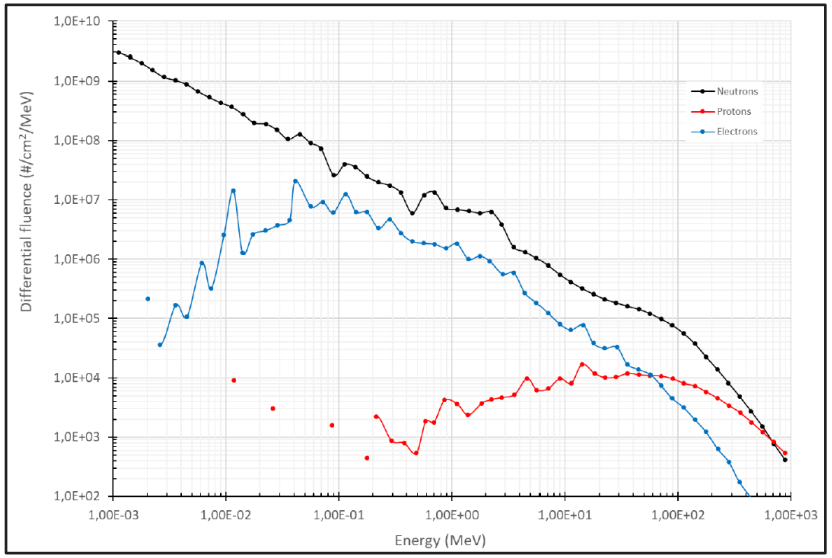
- Additional assumptions
  - ✓ isotropic and omnidirectional flux/fluence
  - ✓ shielding effect of the lunar body

Specifying the radiation environment

- Lunar albedo secondary particles
  - ✓ interaction of incident high-energy particles with lunar soil
  - ✓ secondary proton, electron and neutron spectra



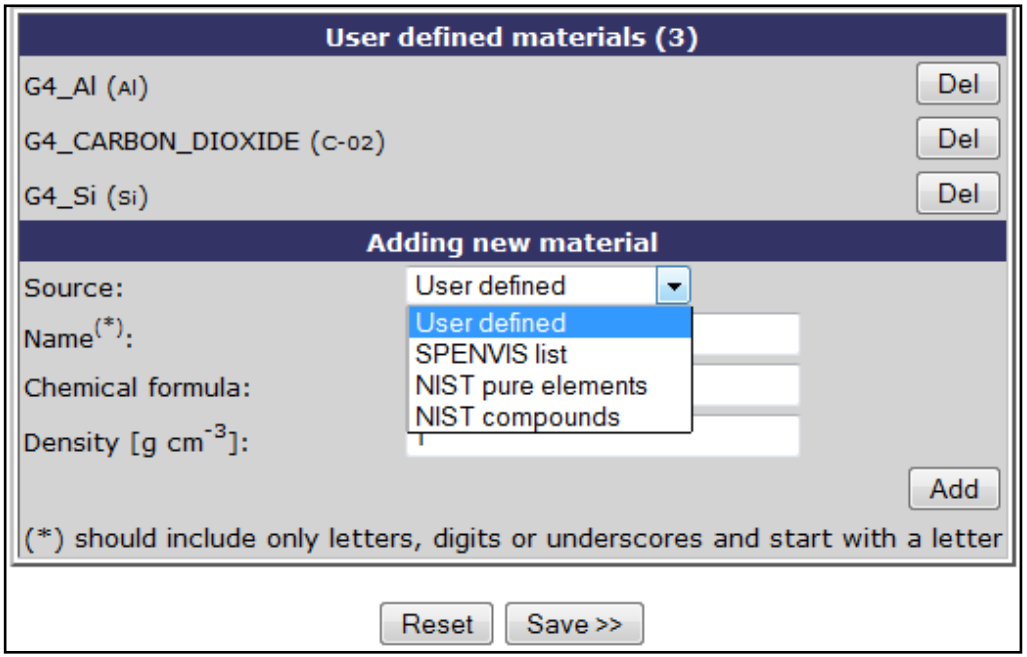
Omnidirectional GCR flux spectra during solar minimum (1996) at 1 AU



Secondary particle fluences generated by GCR proton interaction with the lunar surface

Modelling the lunar regolith

SPENVIS material definition tool

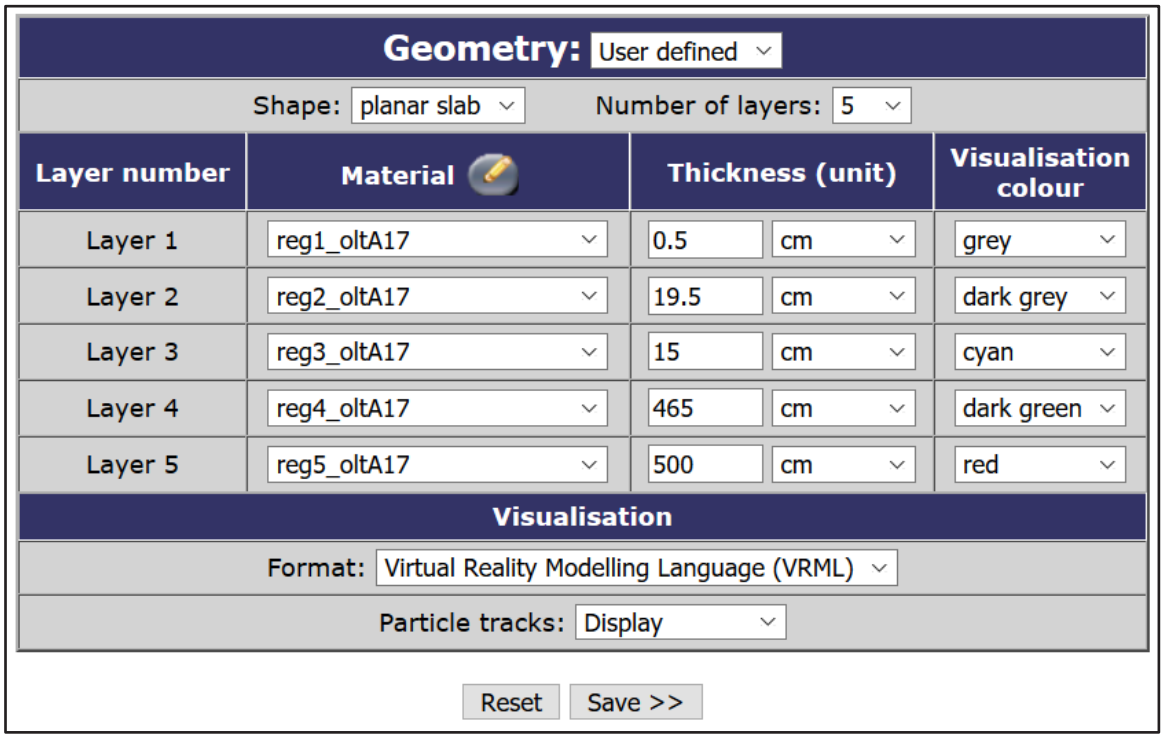


Compound	%
SiO_2	39.9
K_2O	0.078
CaO	10.7
Na_2O	0.38
O	0.352
P_2O_5	0.07
S	0.12
TiO_2	9.6
Al_2O_3	10.9
Cr_2O_3	0.46
FeO	17.7
MnO	0.24
MgO	9.5

On-Line Tool for the Assessment of Radiation In Space (OLTARIS) – Apollo 17

Lunar soil geometry settings

SPENVIS Geant4/MULASSIS geometry



Layer	Thickness (cm)	Density (g/cm3)
1	0.5	0.6
2	19.5	1.2
3	15.0	1.5
4	465.0	2.0
5	500.0	3.4

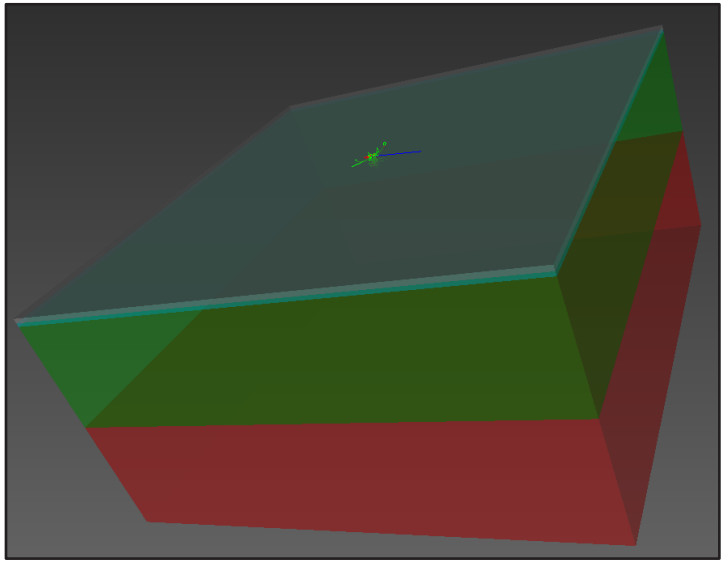
Denisov et al., Acta Astro. 68, 1440–1447, 2011

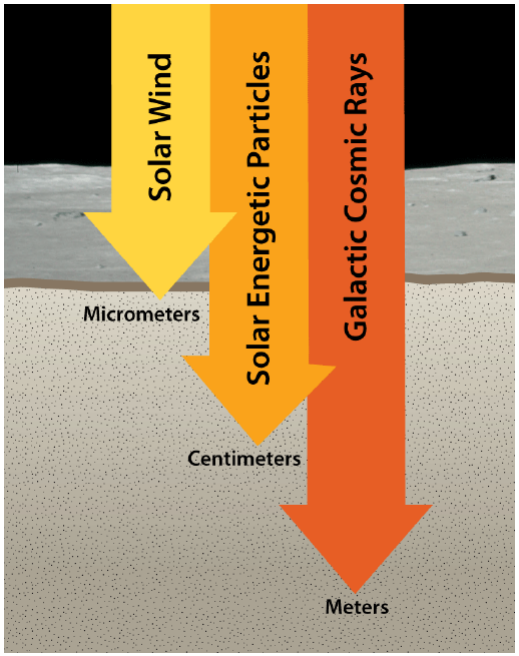
Geant4: GEometry ANd Tracking v.4

MULASSIS: Multi-Layered Shielding Simulation

Geant4 simulations for the Moon

- Propagation of energetic particles into the lunar soil using e.g. MULASSIS or GRAS
- Calculation of deposited dose and backscattered particle spectra



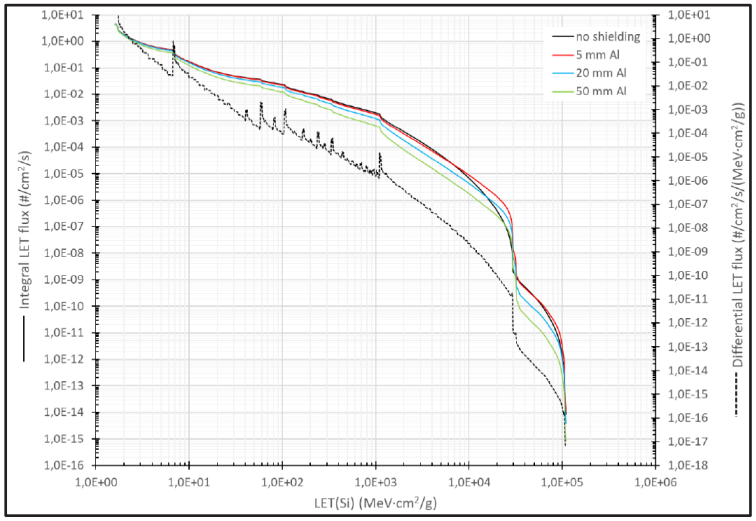


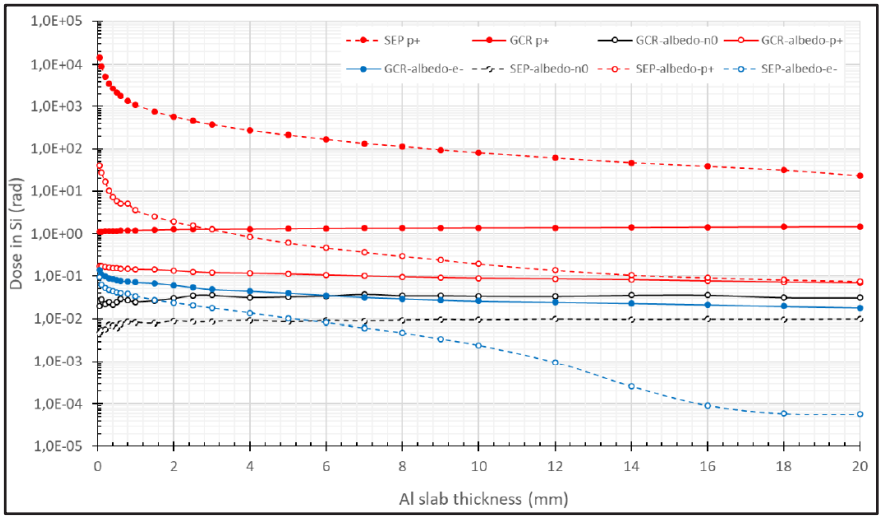
A. P. Jordan et al., 43rd Lunar and Planetary Science Conference, 2012

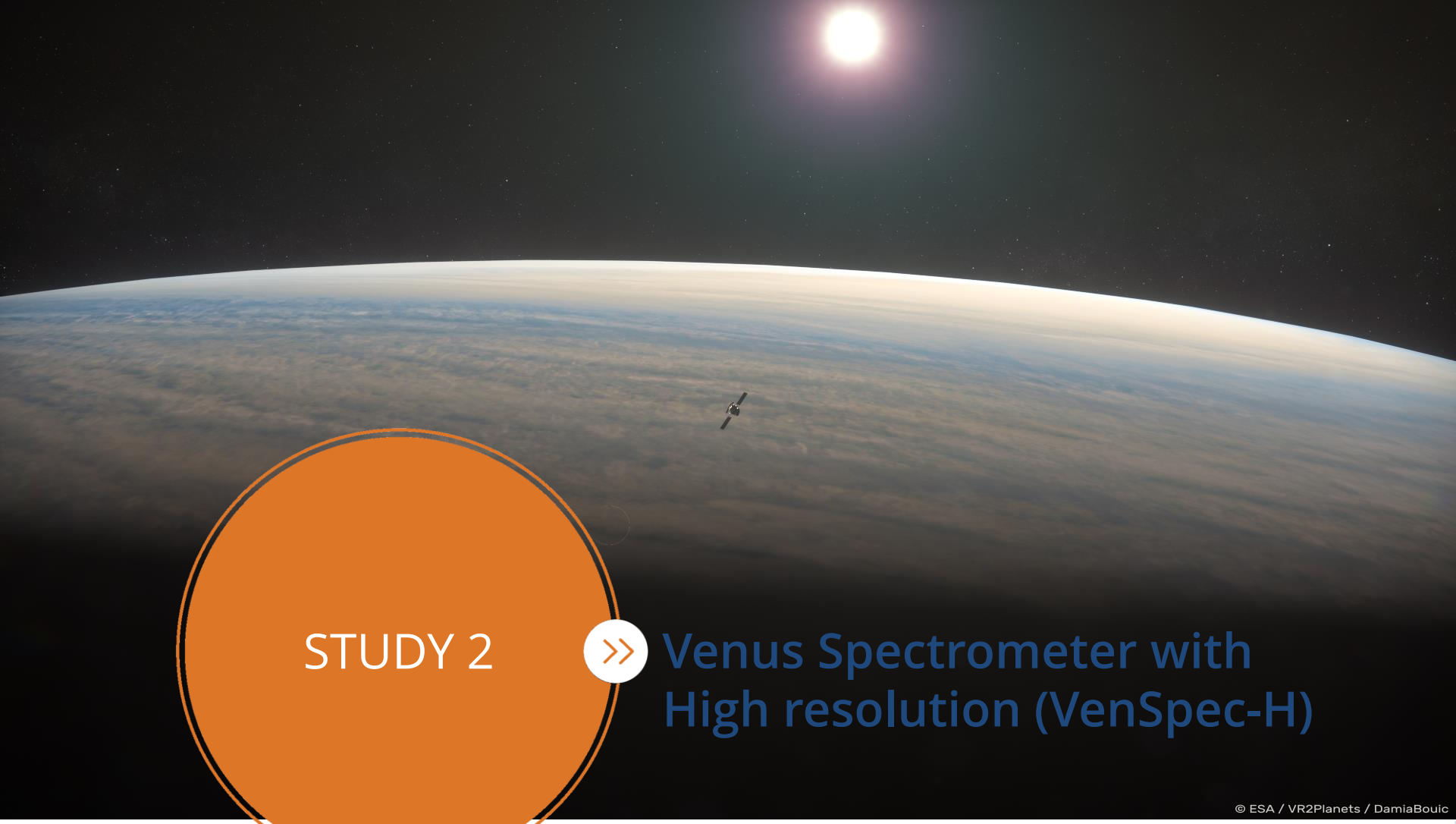
GRAS: Geant4 Radiation Analysis for Space

Radiation analysis results

- Linear Energy Transfer (LET) flux spectra
- Total ionizing dose (TID) in silicon device (100 µm) as function of planar Al shielding (thickness ranging from 0.5 to 20 mm)







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STUDY 2

Venus Spectrometer with High resolution (VenSpec-H)

BIRA•IASB

Royal Belgian Institute for Space Aeronomy

The context

- The VenSpec-H instrument is developed at BIRA-IASB
- It will be part of an ESA medium-class science mission to Venus (EnVision)
- Asked to perform radiation analysis for the main instrument and its electronic box
- Assumed mission profile (baseline launch date of 2033)
  - ✓ launch into HEO (310 - 100000 km, 7 deg inclination)→ transfer phase → aero-braking phase → final orbit (220-470 km, nearly polar)
  - ✓ 4 years nominal science mission duration

Specifying the radiation environment

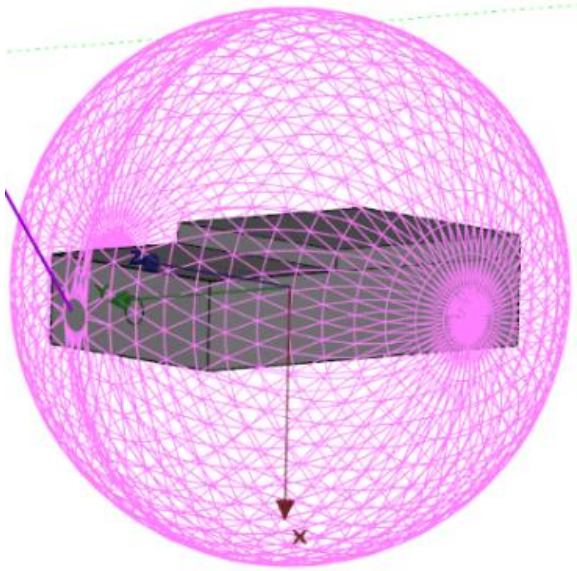
- Defined using SPENVIS based on the recommendations given in the ESA's EnVision Environment Specification document

- Only long-term (i.e., mission average) energetic particle spectra were considered
  - ✓ solar energetic particle environment from SAPPHIRE total fluence model at 0.74 AU over 1 solar cycle (with 7 years in solar max and 1.6 years in solar min).
  - ✓ GCR proton spectrum from ISO-15390 model with no magnetic shielding and using the solar minimum (May 1996) data as input for the solar activity data

Creating the geometry models

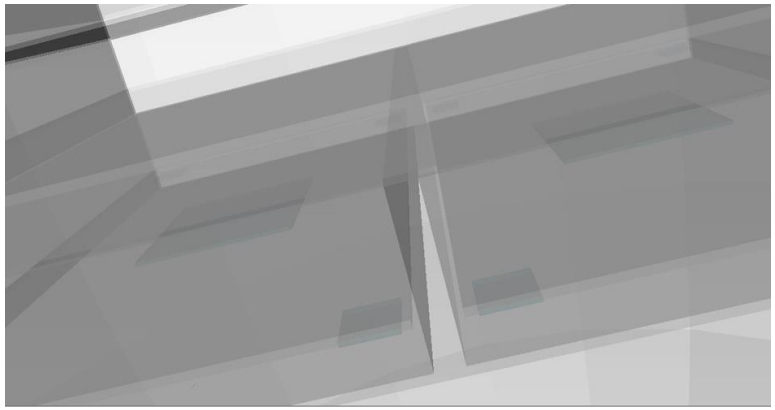
- This study required only a simplified geometry model for the main instrument and its electronics box
- Original models were designed using some computer-aided design (CAD) software and then converted in GDML (Geometry Description Markup Language) format

Creating the geometry models



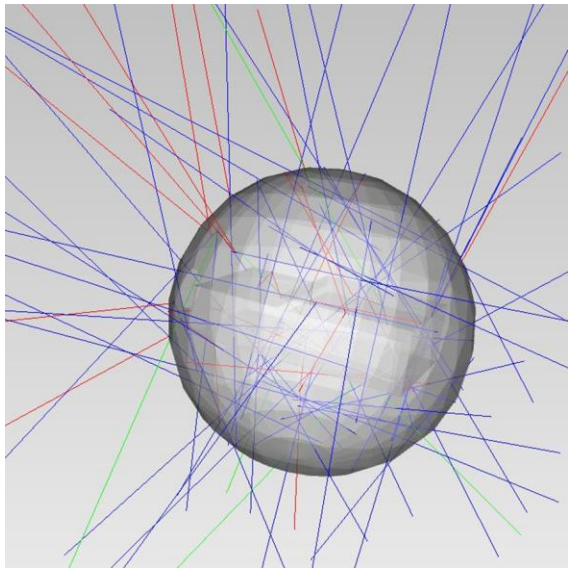
- A hollow Al sphere (400 mm radius & 1 mm thickness) placed around the instrument to model the spacecraft shielding

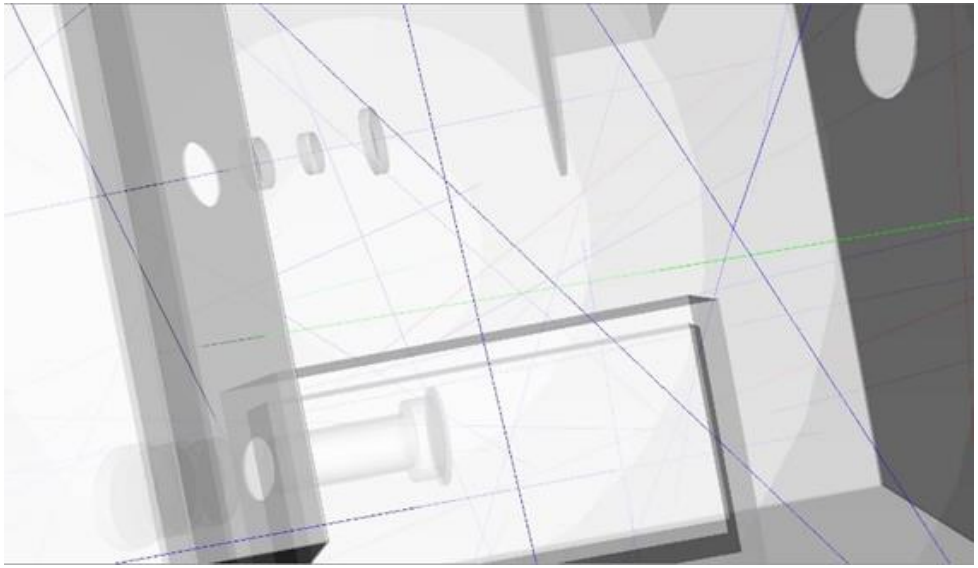
- Some manual inspection & manipulation of the models
  - solving some issues related to name attributes introduced during the file conversion
  - adding box detectors to serve as scoring volumes for the simulations



Geant4 simulations

- Performed radiation analysis for selected volumes using the Geant4 Radiation Analysis for Space (GRAS) tool
  - ✓ total ionising dose (TID)
  - ✓ total non-ionising dose (TNID)





Radiation analysis results

- Solar protons have a more prominent contribution on the expected doses while GCR protons have lower fluxes and contribute less to the estimated doses

- Nevertheless, GCR protons can penetrate deeper, interact with various components and generate significant secondary particles

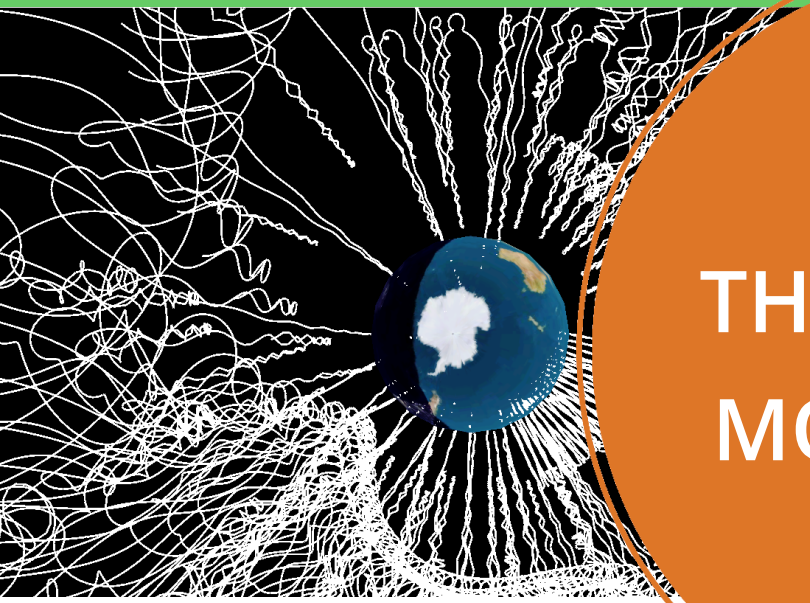
- In general, the results show that the detector readout circuit and the detector array are relatively well shielded

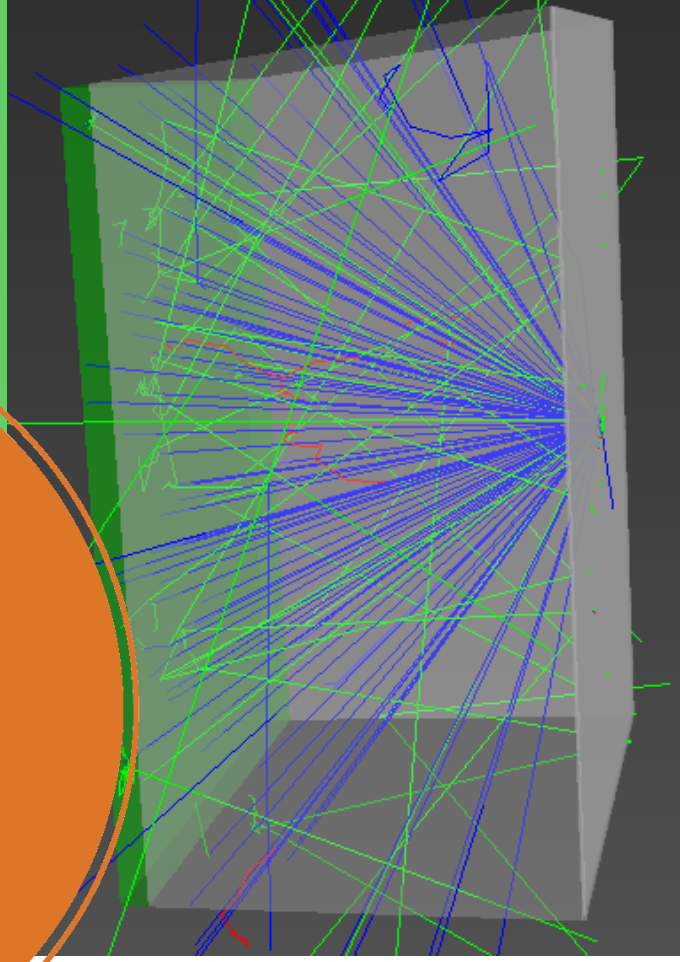
Radiation analysis results

- Preliminary SEU analysis
  - ✓ no available info about devices to compute the SEU rate (i.e. cross sections or critical charge/LET threshold and sensitive volume dimensions)
  - ✓ general analysis → discrete set of LET values in combination with some arbitrarily chosen sensitive volumes
  - ✓ short-term upset rates (per bit per second) and long-term mission upsets (per bit)

Some final remarks…

- Good knowledge of models used and their limitations
  - ✓ SEP fluence spectra are based on probability functions that change (non-linearly) with the mission duration → Doses cannot be scaled linearly with time
- Geant4 simulations can be computationally expensive
- Such studies can help engineering teams to
  - ✓ better understand potential radiation risk due to the mission environments
  - ✓ select appropriate electronic parts for their instruments





THANK YOU!
MORE INFO?

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