# Space Rad Activities @ LIP

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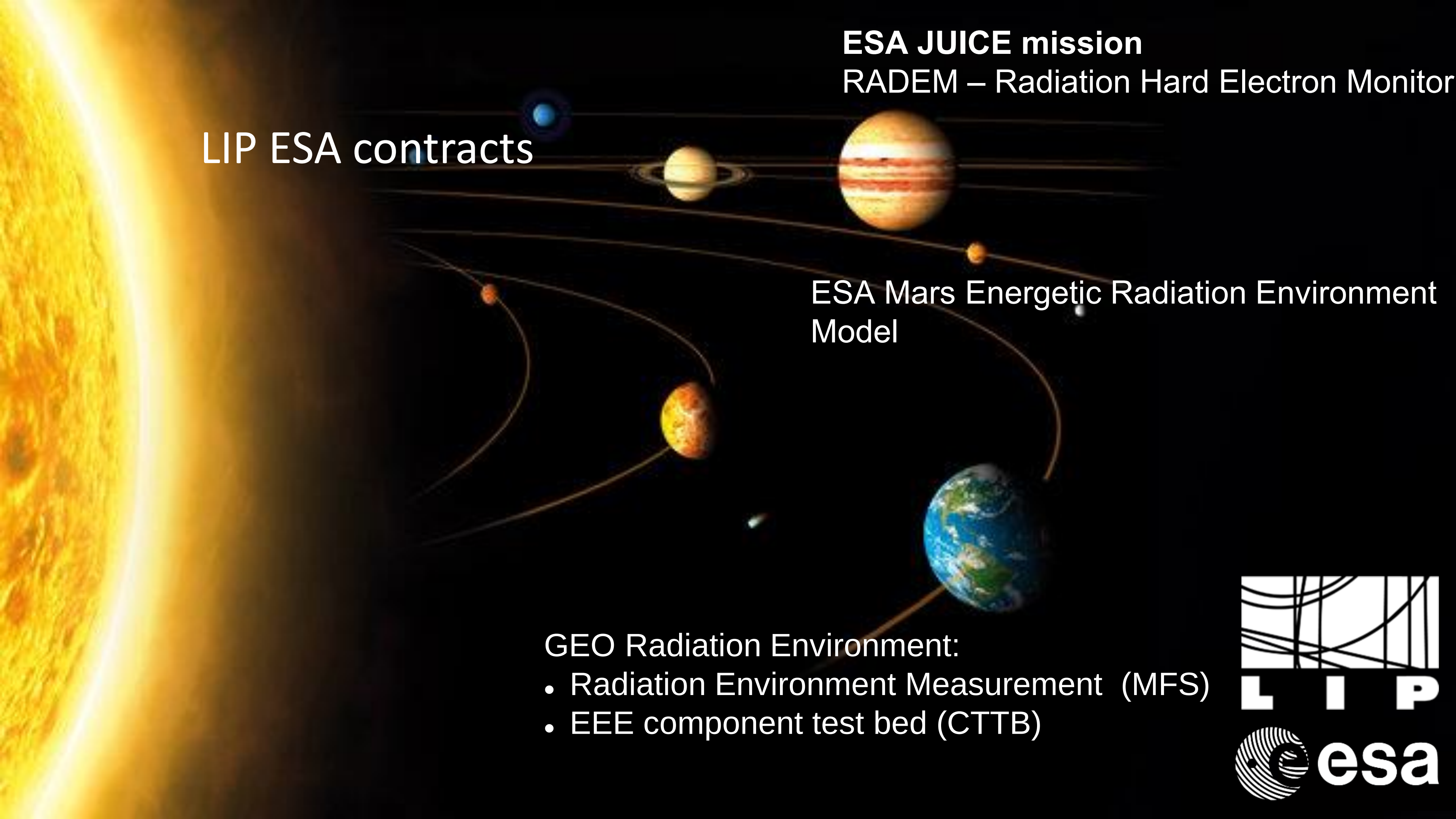
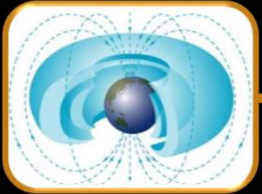
Patrícia Gonçalves, Jorge Sampaio,
Luís Sintra

LIP Jornadas 14-16 Feb 2020, Braga


LIP ESA contracts
ESA JUICE mission
RADEM – Radiation Hard Electron Monitor
ESA Mars Energetic Radiation Environment Model
GEO Radiation Environment:
• Radiation Environment Measurement (MFS)
• EEE component test bed (CTTB)
LIP
esa

# Space Radiation Environment

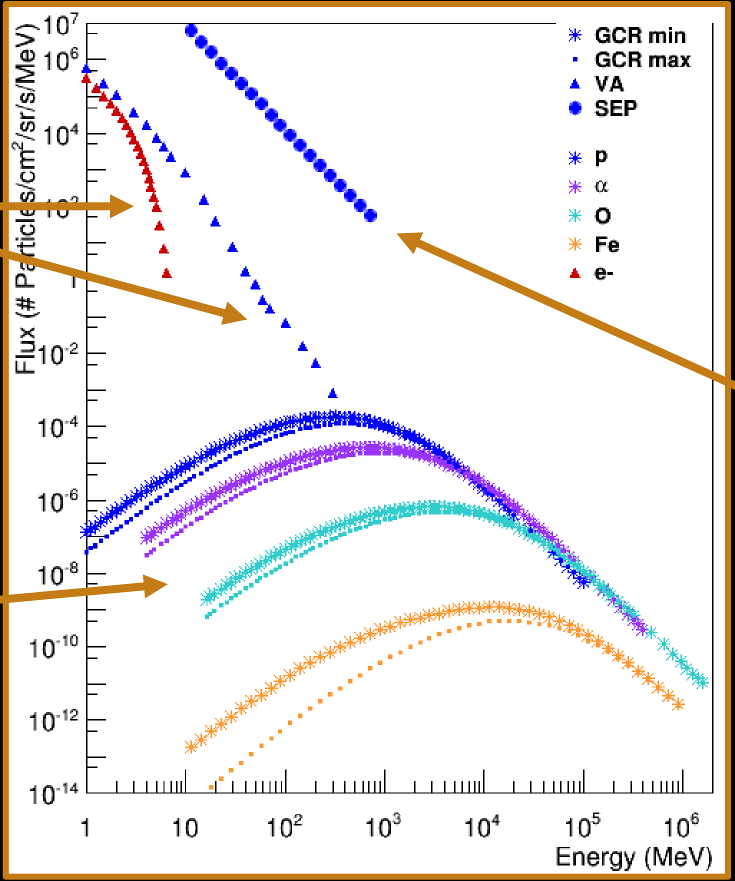
## Van Allen Radiation Belts



**Protons** and **electrons**
**AP-8** and **AE-8** models

## Galactic Cosmic Radiation (GCR)

**p,α, O and Fe**
**ISO 15390**
**Solar min: 30 Jan 2009**
**Solar max: 30 Jan 2014**
**1 AU from Earth**

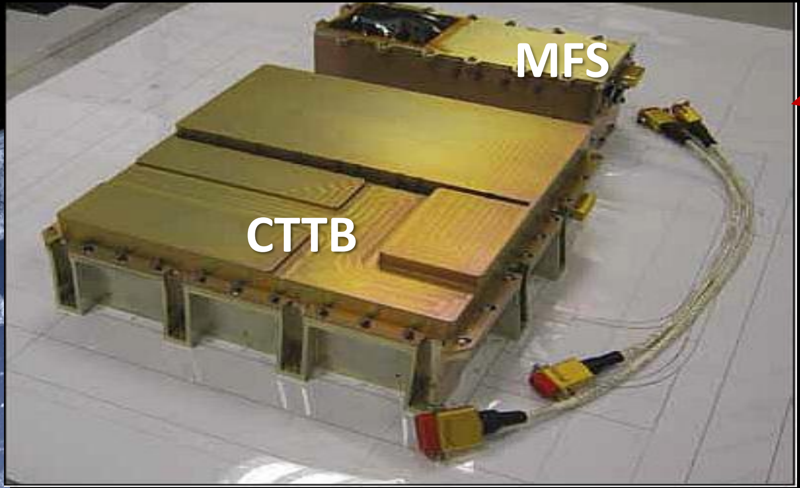


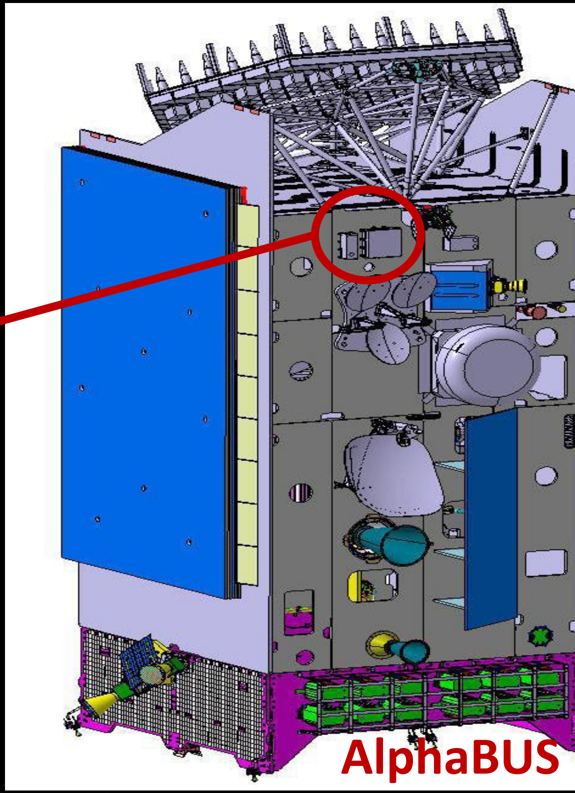

## SEP event

**Protons**
Integrated 14 day
SEP event of
**December 2006**

# Data Analysis & Tools
## The MFS & The CTTB on ALPHASAT

- The Alphasat launched to GEO July 2013 carrying the AEEF
- AEEF (TDP8) = MFS + CTTB
- Both installed on X-panel of the Alphasat




MFS: MultiFunctional Spectrometrer
CTTB: Component Technology Test Bed

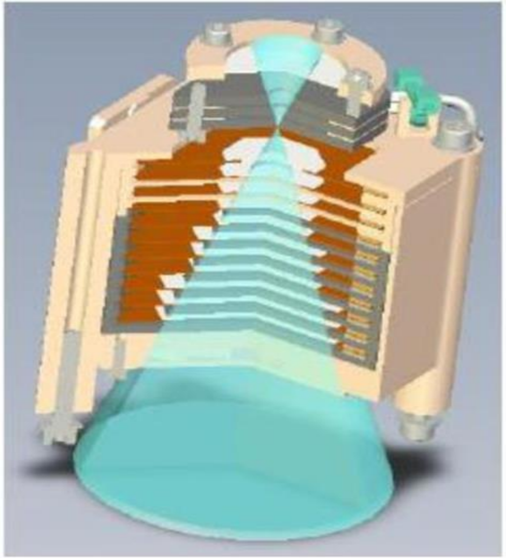
# The MultiFunctional Spectrometer

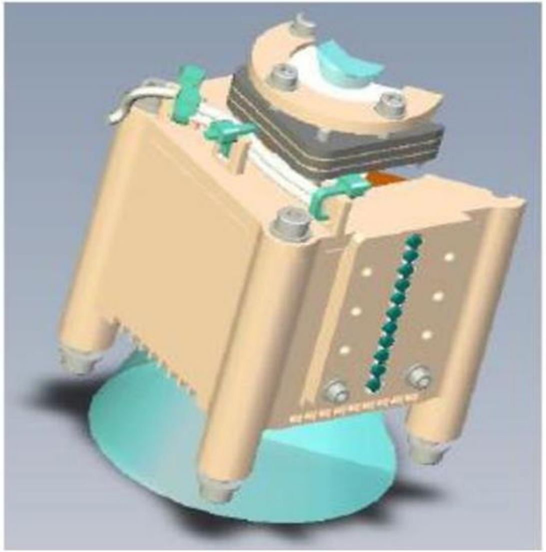
**ALPHASAT TDP-8 MFS PARTICLE SPECTROMETER DATA ANALYSIS**

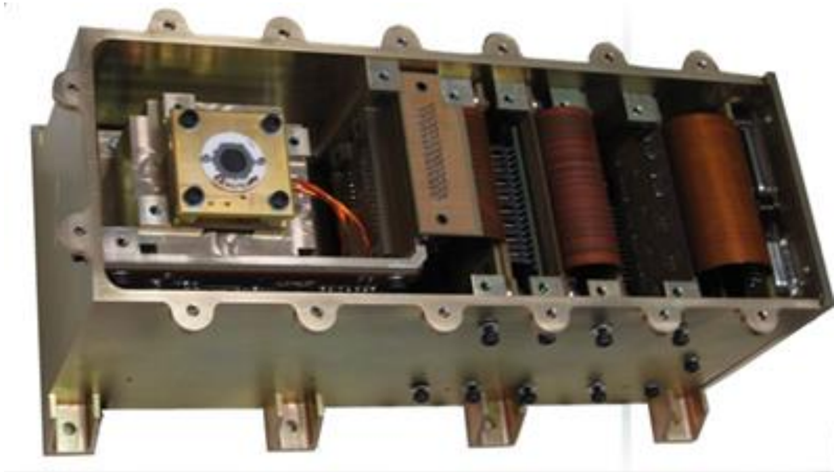
ESA/ESTEC CONTRACT 3-14025/13/NL/AK with EFACEC and LIP

## MFS requirements

| | |
|---|---|
| • Electrons | 300 KeV– 7 MeV |
| • Protons | 1 MeV – 200 MeV |
| • Alpha particles | 5 MeV – 200 MeV |
| • Heavy Ions | 5 MeV/nuc – 50 MeV/nuc |



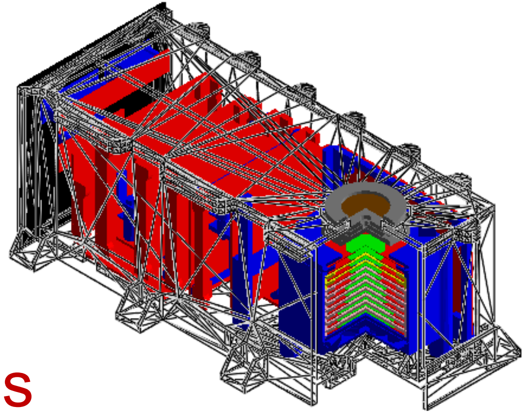




# The MultiFunctional Spectrometer

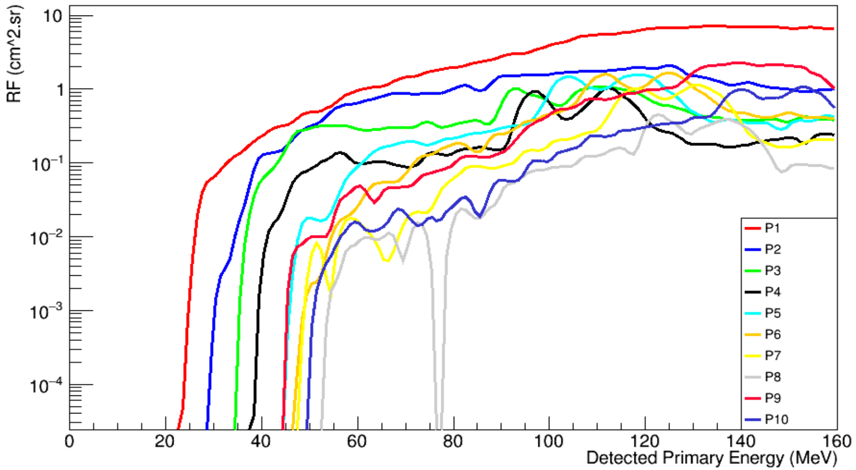
## Response Functions

MFS Geant4 Mass Model
Generated with GUIMesh*

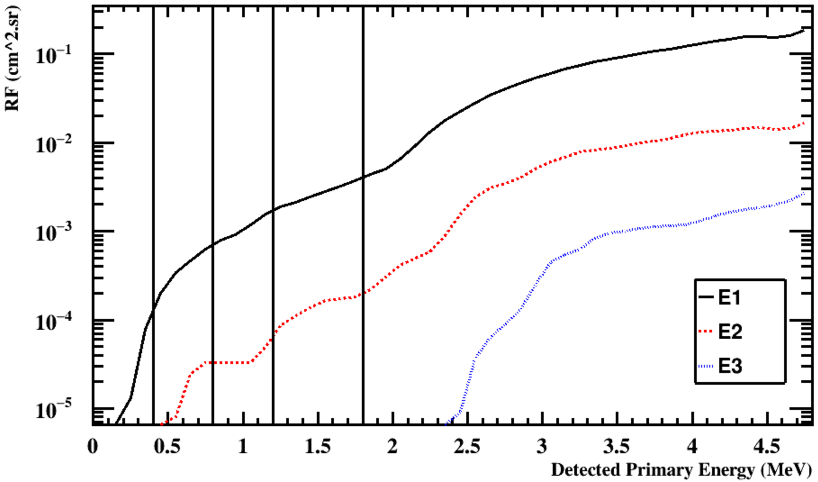


Obtained with Geant4 detailed simulation and analysis of the MFS response

### Protons




### Electrons



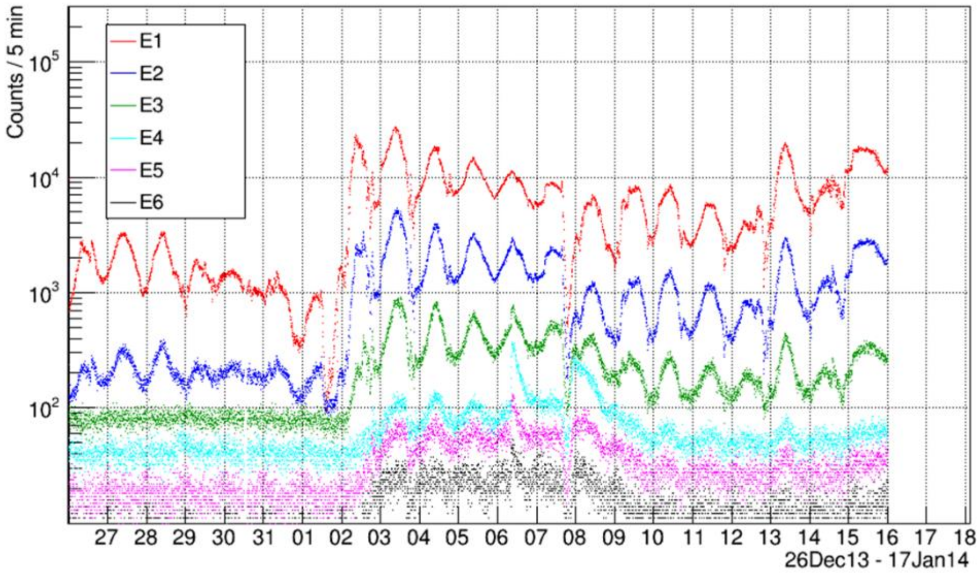

*(M. Pinto and P. Gonçalves, DOI: https://doi.org/10.1016/j.cpc.2019.01.024)

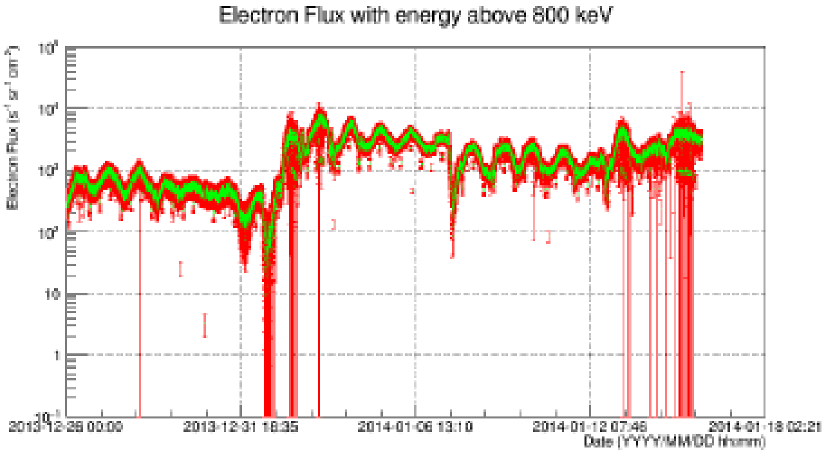
# MFS Flux Spectra Reconstruction

## Jan 2014 Electron SEP

$$C_i = \sum_{q=p,e} C_{i,q} = \sum_{q=p,e} \left[ \int_0^{\infty} f_q(E) RF_{i,q}(E) dE \right]$$

$f_q(E)$ differential omni-differential fluxes [$cm^{-2}MeV^{-1}s^{-1}$]
$RF_{i,q}(E)$ *MFS* response functions for $q=p,e$.




Flux unfolding using the maximization of a Likelihood function

***Master Thesis Filipe Máximo, IST, July 2019***

# MFS Flux Spectra Reconstruction

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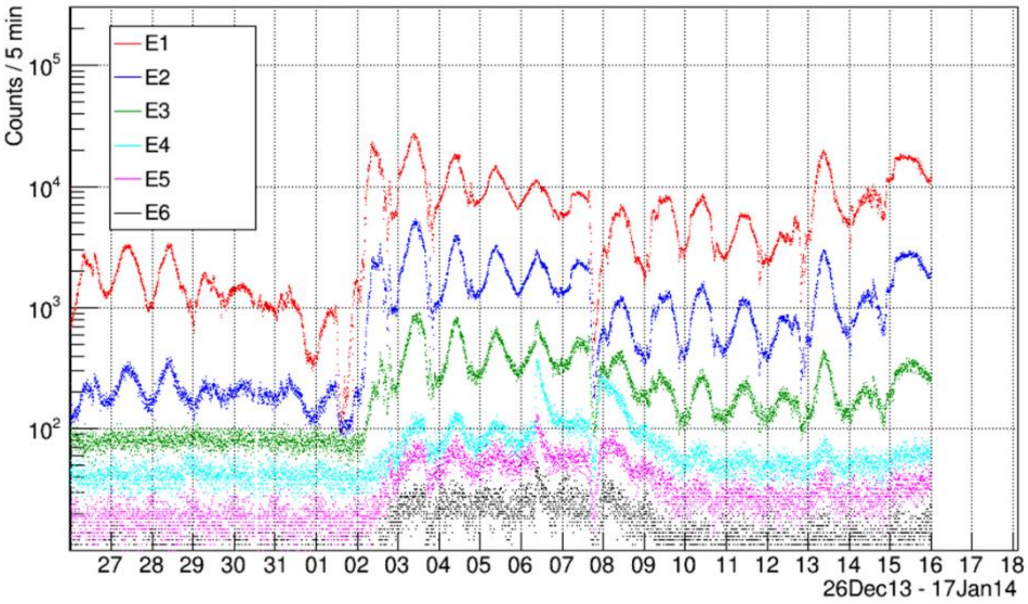



New
Flux unfolding using Machine Learning Techniques

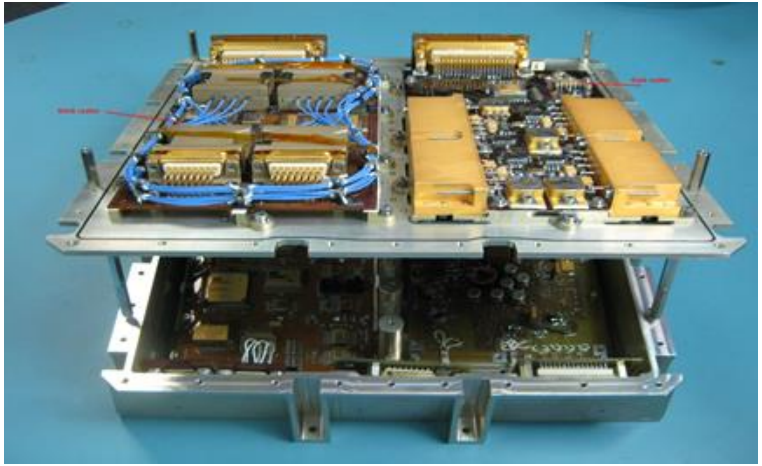
***See L. Sintra Poster!***

# CTTB Data Analysis

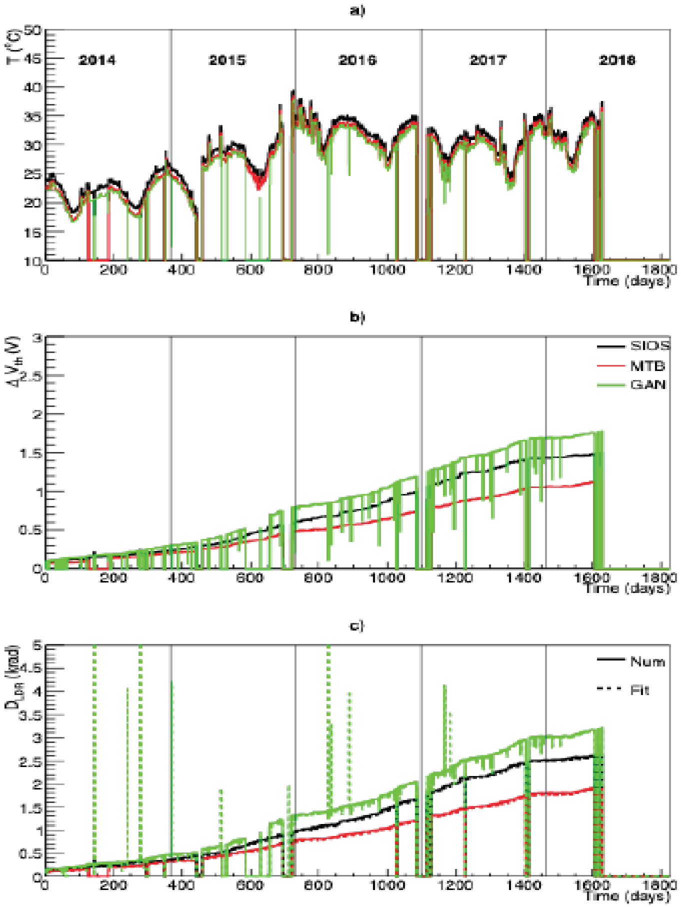
## FLIGHT DATA ANALYSIS OF TDP-8 RADIATION EXPERIMENTS ON-BOARD ALPHASAT

ESA/ESTEC CONTRACT 4000115004/15/NL/RA/ZK

Component Technology Test Bed



3 experiments:
- GaN transistors (Aveiro)
- Optical Links (Valencia)
- Memories

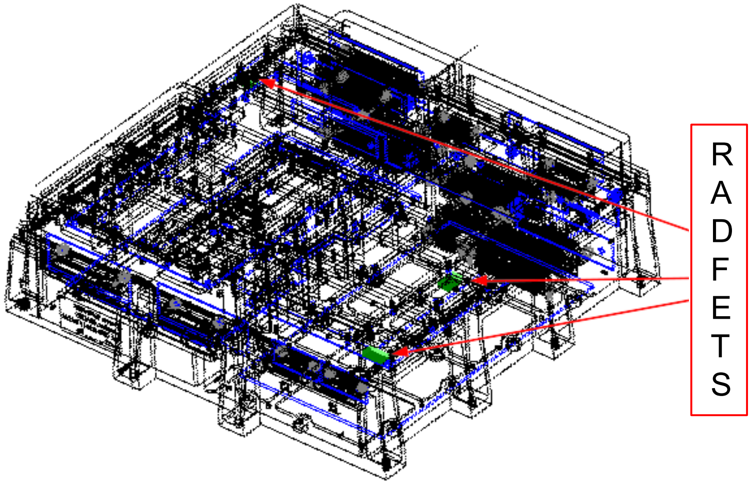



RADFET TID
Jan 14-Jul 18

# CTTB Dose Assessment

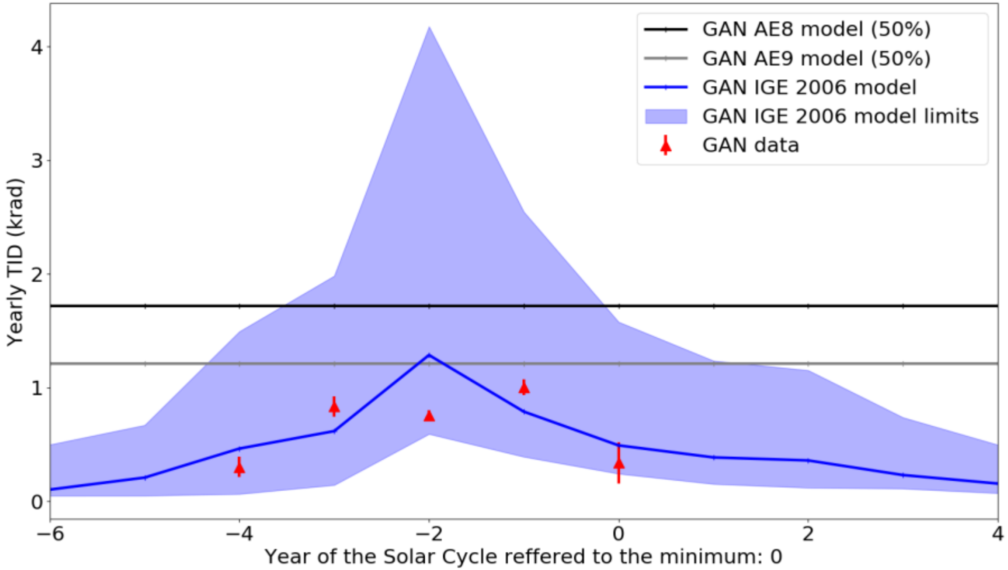
- In-flight data compared with Geant4 results

- Standard radiation models were evaluated




CTTB Geant4 Mass Model

Generated with GUIMesh (M. Pinto and P. Gonçalves, DOI: https://doi.org/10.1016/j.cpc.2019.01.024)



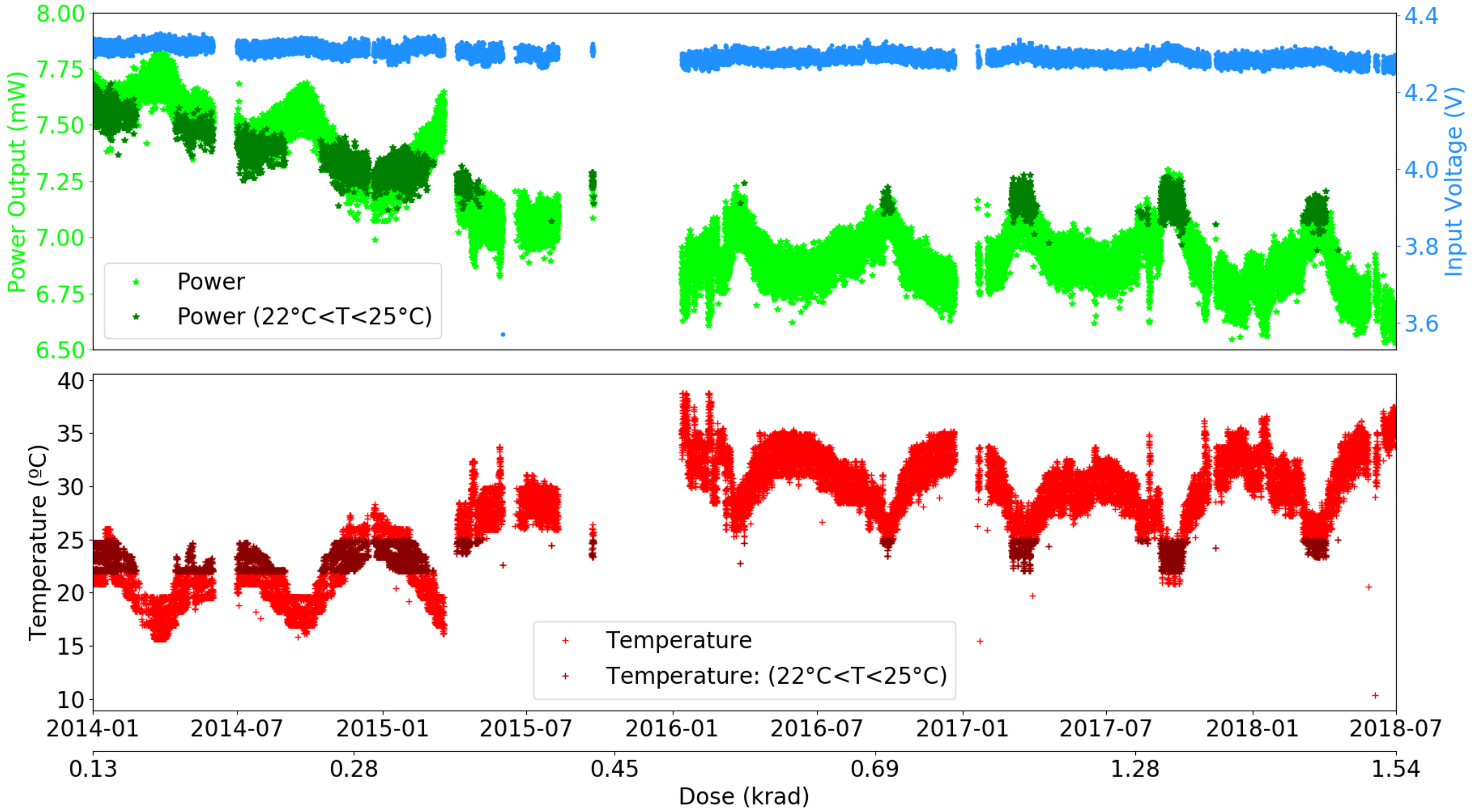

Submitted to IEEE-TNS

Dose measurements and simulations of the RADFETs response onboard the Alphasat CTTB experiments

J. M. Sampaio, P. Gonçalves, M. Pinto, J. Silva, V. Negîrneac, L. Sintra, C. Pinto, T. Sousa, P. Ribeiro, and C. Poivey

# CTTB: Radiation Effects

## First analysis of a GaN device in GEO

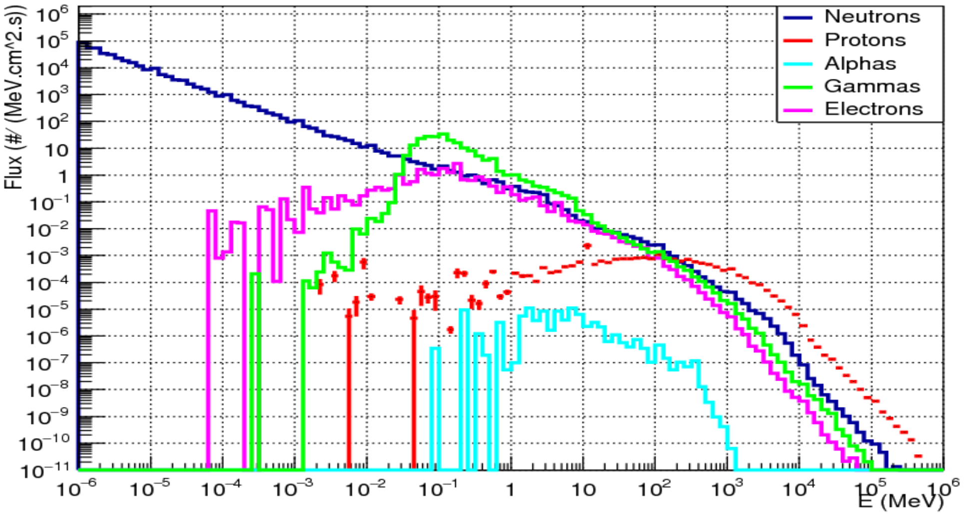


# Mars Radiation Environment: dMEREM

LIP developed **dMEREM (**ESA contract 19770/06/NL/JD)

- ❑ **Geant4 based model for the radiation environment of Mars, Phobos and Deimos**
- ❑ Includes local treatment(5 x 5 degree grid and season)
  - Surface topography composition
  - Atmospheric composition
  - Density
  - Local magnetic fields
- ❑ Diurnal + annual variations

GCR-p

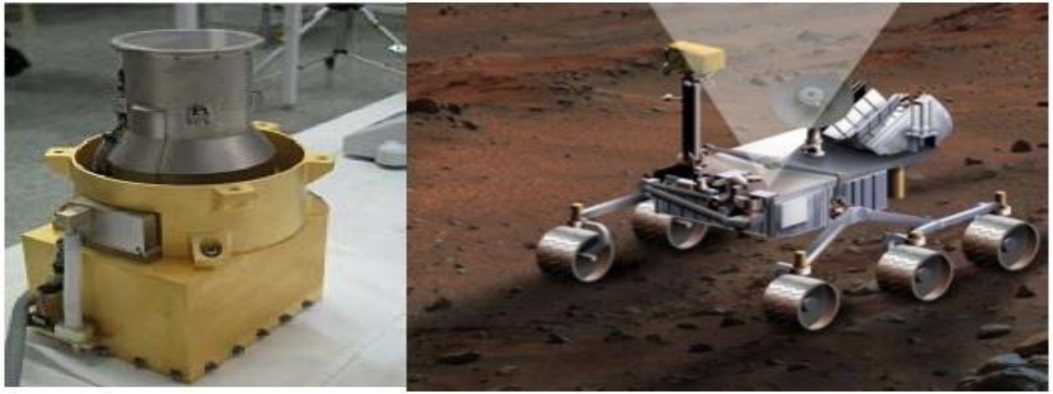



# Mars radiation environment

For **future human missions to Mars**, it is important to study the **surface radiation environment** during **extreme** and **elevated conditions.**

RAD (Radiation Assessment Detector) measuring and identifying high-energy radiation at Mars surface since Aug 12

RAD

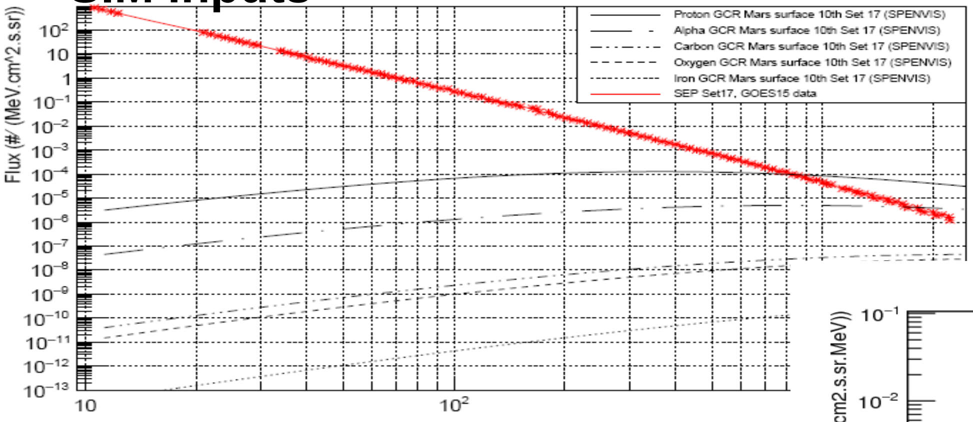


First in-situ data to validate radiation environment models at Mars surface

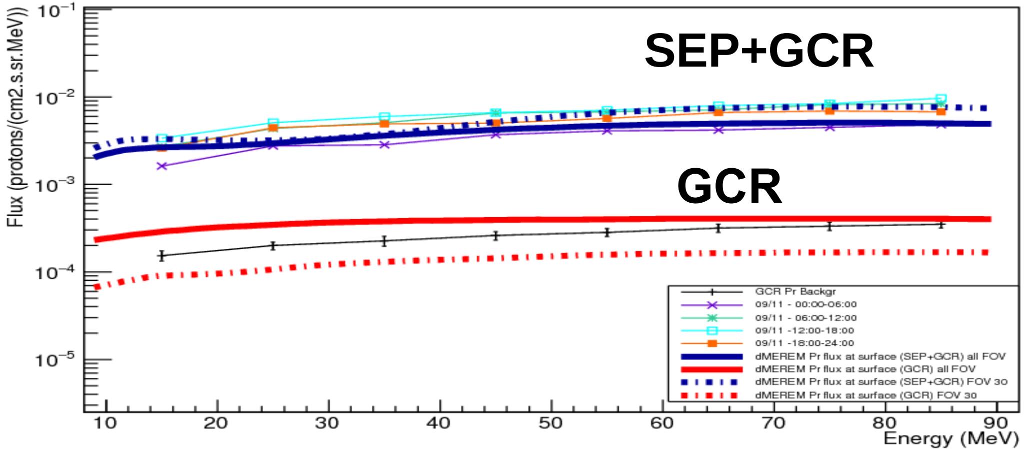
# dMEREM validation

## SEP Set 17 and GCR measured by RAD

### SIM inputs




### Proton fluxes at Mars surface




***Paper to be submitted***

Validation of the ESA detailed Mars Energetic Radiation Environment Model with *Curiosity* Rover measurements from Mars surface

L. Arruda, P. Gonçalves

# FUTURE WORK FOR MARS

- ❑ Radiological risk assessment on manned missions to Mars
- ❑ Modelling Mars radiation environment underground and study its astrobiological implications
  - ❑ Geant4-DNA studies
- ❑ Project to be submitted to on-going PTDC call

# Radiation Hard Electron Monitor (RADEM) for the JUICE mission

ESA/ESTEC Contract 1-7560/13/NL/HB

Cosmic Vision
L-class Mission

What are the conditions for planet formation and emergence of life?

- Emergence of habitable worlds around gas giants

How does the Solar System work?

- Jupiter system as an archetype for gas giants

First mission dedicated to the Icy moons

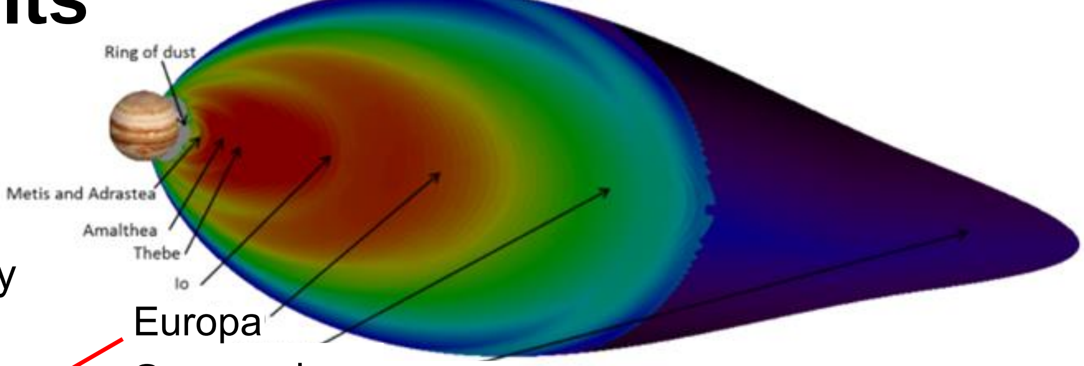
Launch 2022 → Cruise 7.6 years → Transfer to Europa 458 days → Europa Flybys 38 days → High Latitude with Callisto 38 days → Transfer to Ganymede 311 days → Ganymede orbit 5000 km 152 days → Ganymede orbit 500 km 148 days

# Jupiter Radiation Belts

- Intense electron population
  - Electron data up to 11 MeV
  - Long-term proton data up to 1.25 MeV

- Region dependent angular variability
  - Consequence of particle dynamics

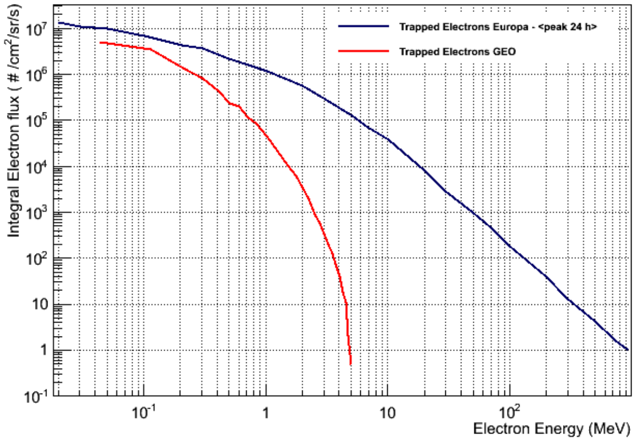
- Many Open Questions

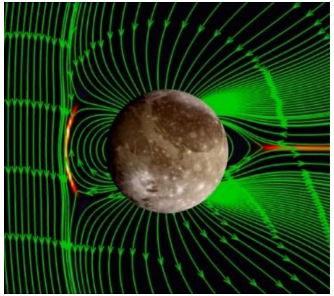


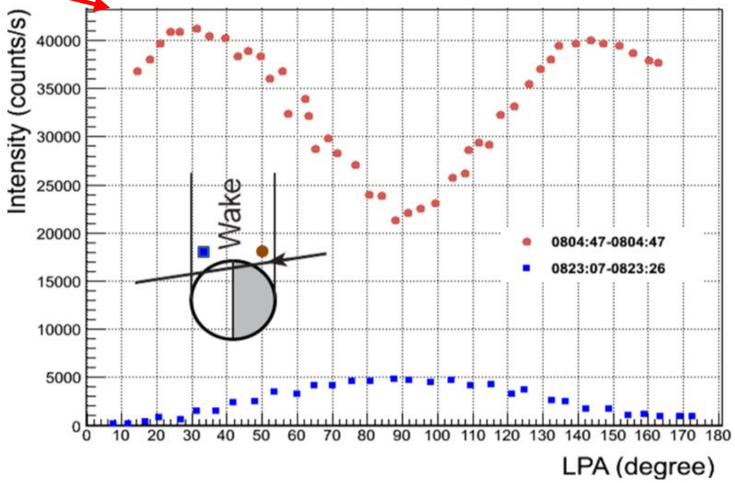

Europa

Ganymede

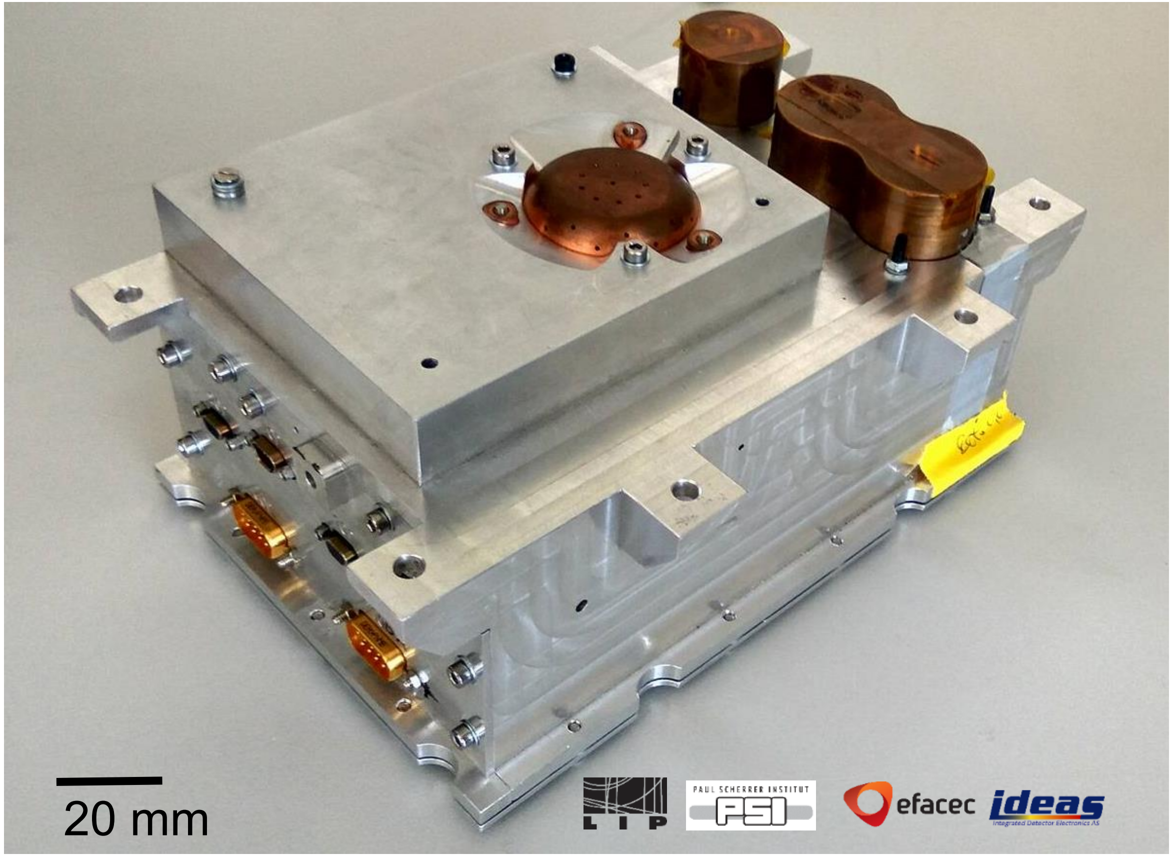
Callisto





# RADEM - Requirements




- Measure electron flux
  - Spectral range 300 keV – 40 MeV
  - Peak Flux $10^9$ e/cm$^2$/s
  - Electron Directional Distribution

- Measure proton flux
  - Spectral range 5 MeV– 250 MeV
  - Peak Flux $10^8$ p/cm$^2$/s

- Measure Heavy Ion population
  - From Helium to Oxygen
  - 8 to 670 MeV

- In-flight dose calculation

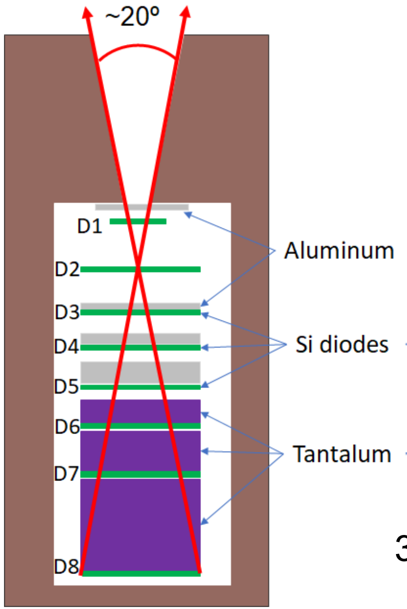
- Low power
- Low mass (~3 kg currently)
- Rad-Hard

# RADEM – Detector Overview

Based on traditional Stack Detectors SREM, MFS, BERM, etc

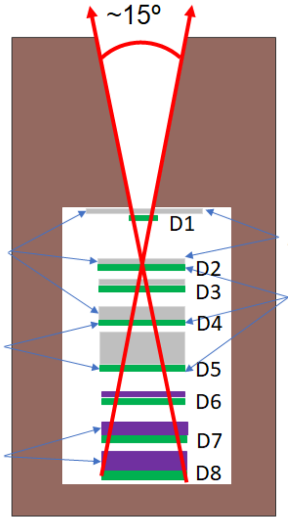
New concept fully developed at LIP

## Proton Detector (PDH)



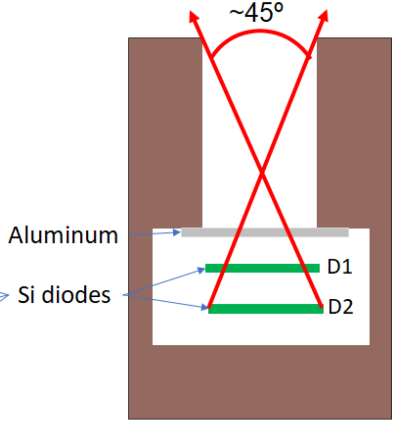

5 MeV– 250 MeV

## Electron Detector (EDH)



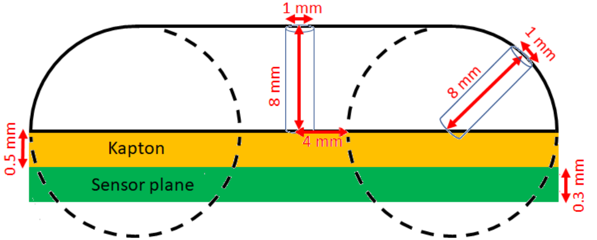

300 keV – 40 MeV

## Heavy Ion Detector (HIDH)



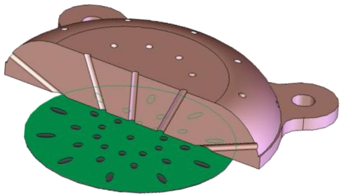

8 MeV - 670 MeV
Helium to Oxygen

## Directional Detector (DDH)




Electrons >300 keV
Measures 28 directions
- 4 zenithal directions
- 9 azimuthal directions

3 background sensors

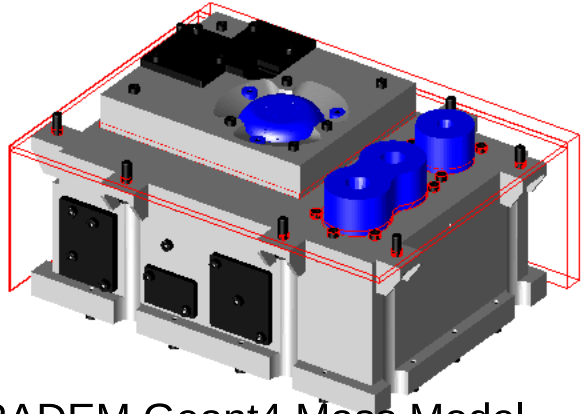


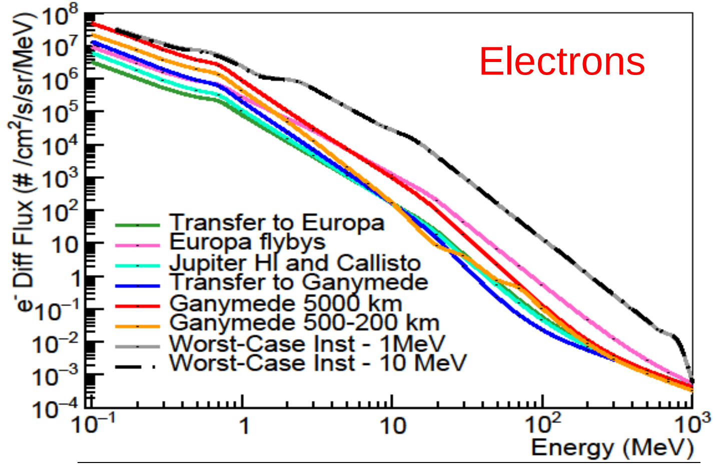
# RADEM – Directionality Detector

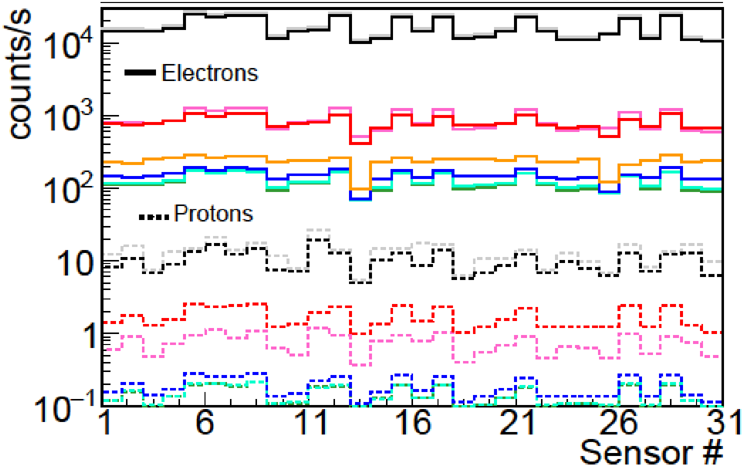
## Proof-of-Concept

Studied with Geant4 simulations

- ❑ Considered each zenithal direction
  - Same cutoff
  - Same sensor area
  - Average over the 9 sensors
- ❑ Different mission phases analyzed
  - Phase average fluxes
  - Omnidirectional flux






RADEM Geant4 Mass Model

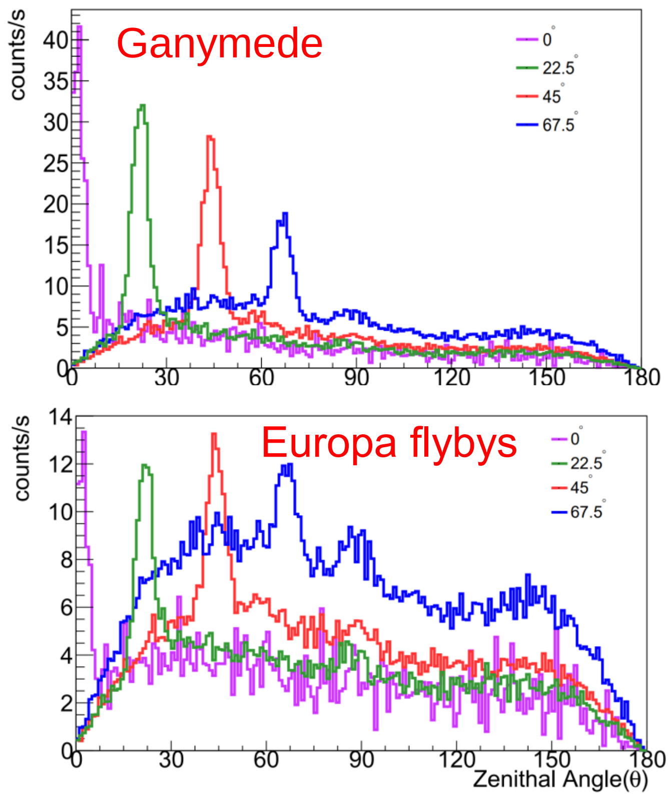
Generated with GUIMesh (M. Pinto et al, DOI: https://doi.org/10.1016/j.cpc.2019.01.024)

# RADEM – Directionality Detector

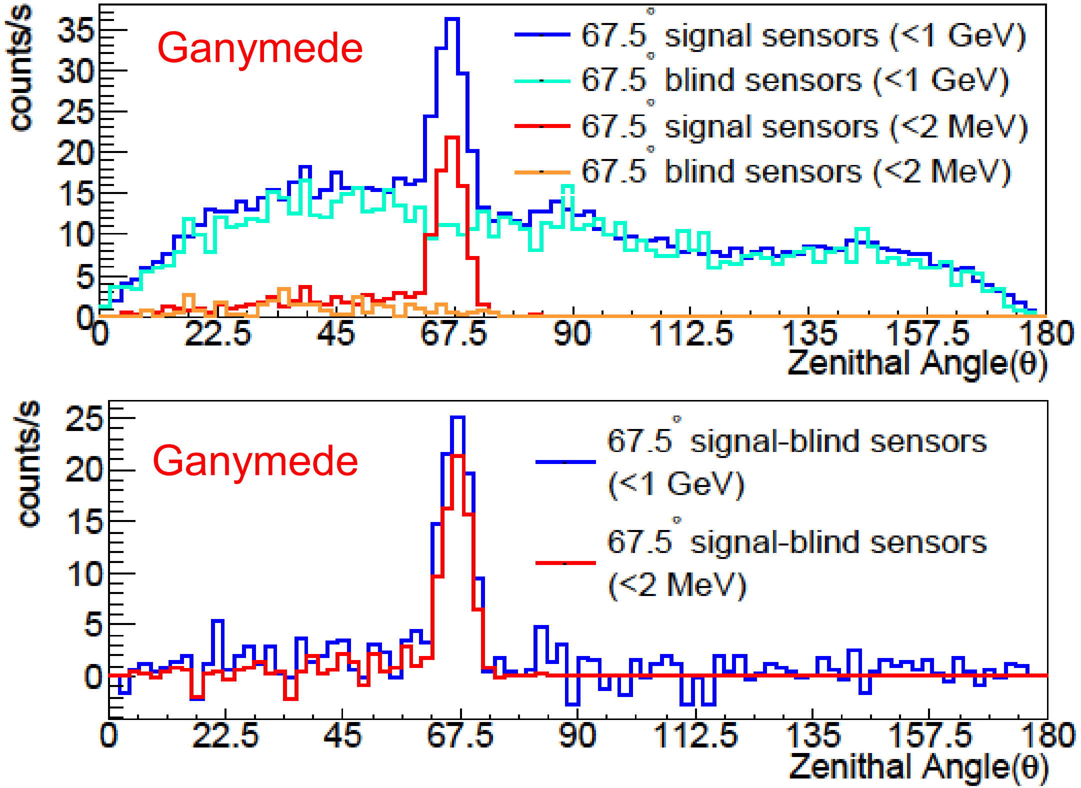
## Angular Response

(M. Pinto et al., DOI: 10.1109/TNS.2019.2900398)

### Directional response




### Background removal



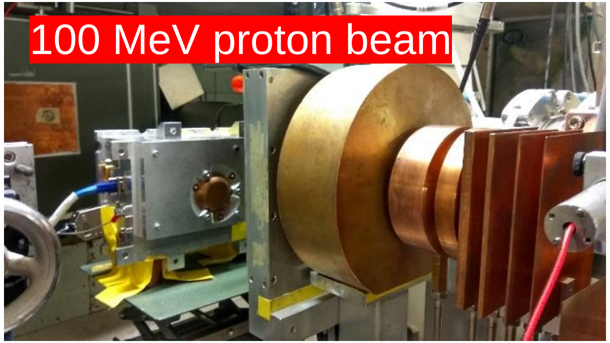
# RADEM – Current Status

(M.Pinto et al.: https://doi.org/10.1016/j.nima.2019.162795)

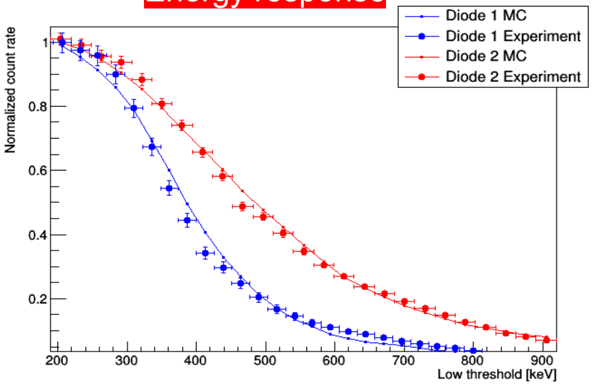
BreadBoard Model
Tested in 2016

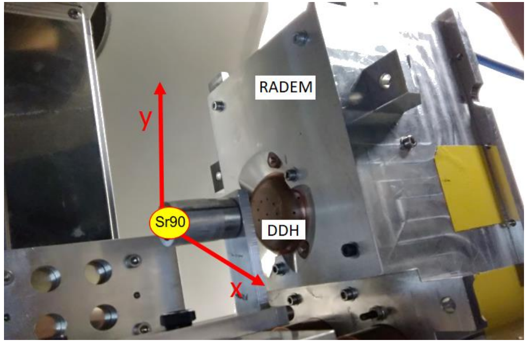
Engineering Model
Tested in 2018/2019

Engineering Qualification
Model / Flight Model
Calibration schedulled for 2020!

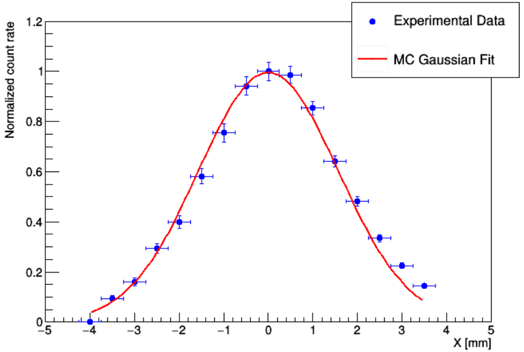



Energy response

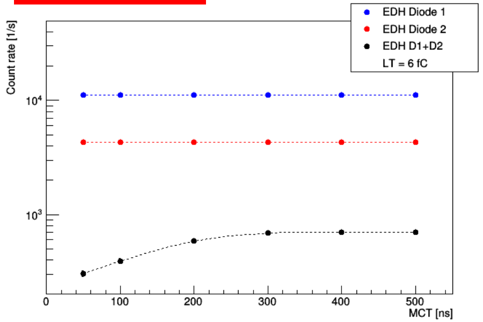


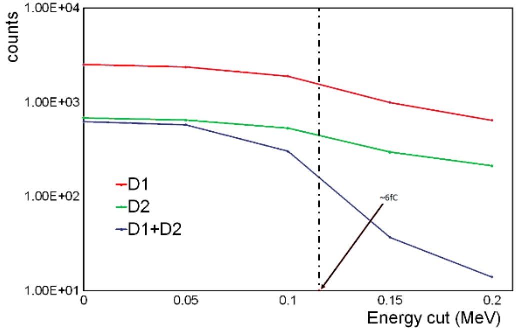




DDH pixel alignment

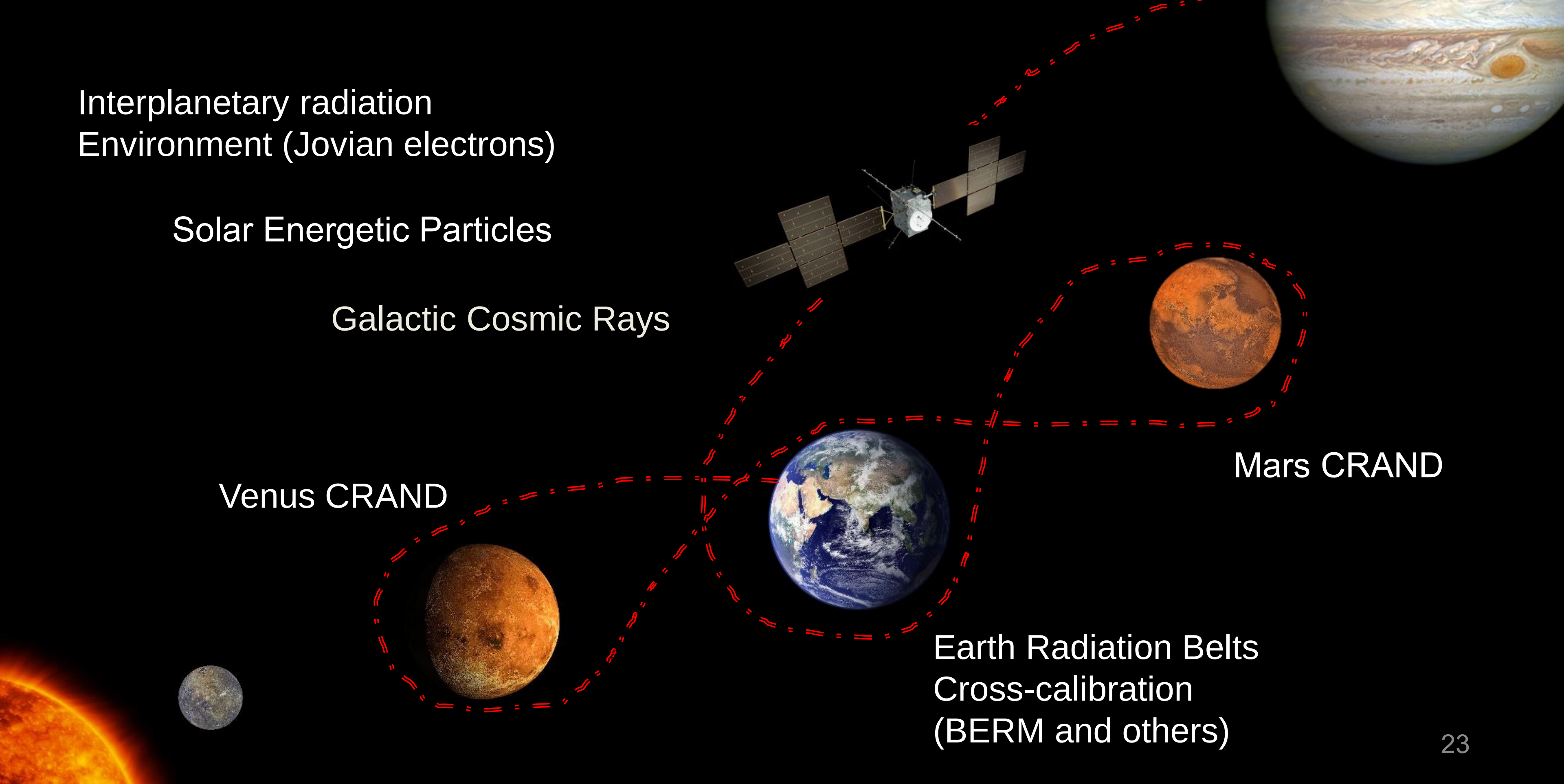



Coincidences



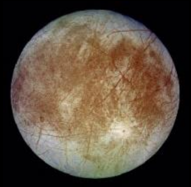



# RADEM – Scientific Opportunities

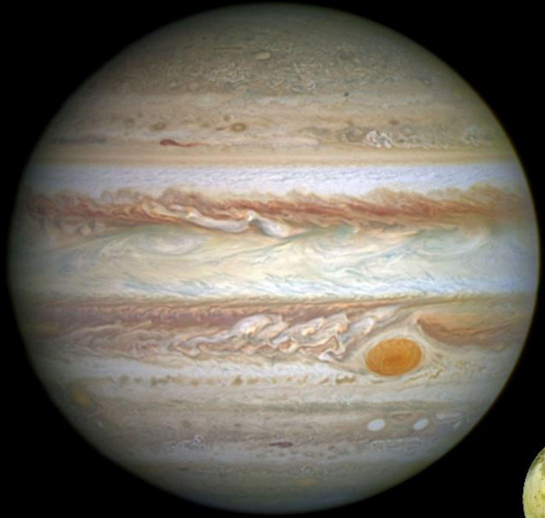


# RADEM – Scientific Opportunities

Jupiter CRAND as a source of protons



Jupiter-Moon interactions



Constrain Acceleration Mechanism

Improve Radiation models

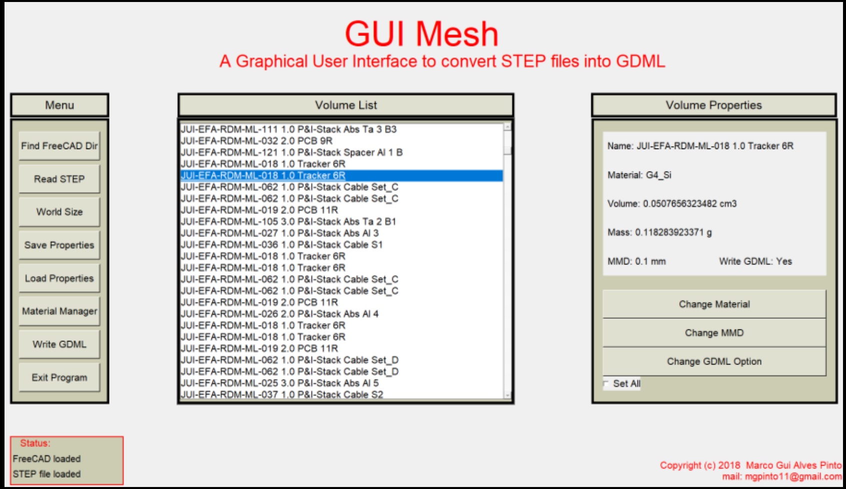
Astrobiological implications of radiation

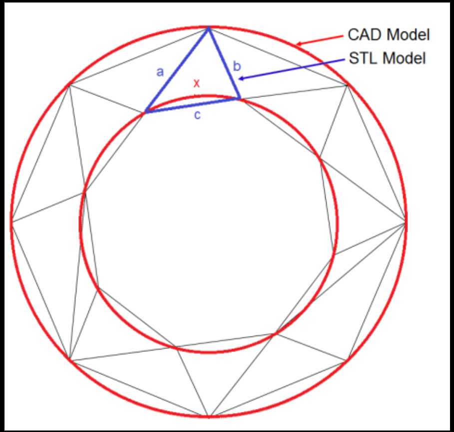
# GUIMesh

New method – fully developed by LIP

STEP → 1. Interpret STEP file; 2. Assign materials; 3. Mesh solids; 4. Write GDML → GDML

1. Interpret STEP file
2. Assign materials
3. Mesh solids
4. Write GDML




Mesh format

Leverages on the mesh format

- Effect on computation studied

Precision and materials customable

Application extends to other relevant fields

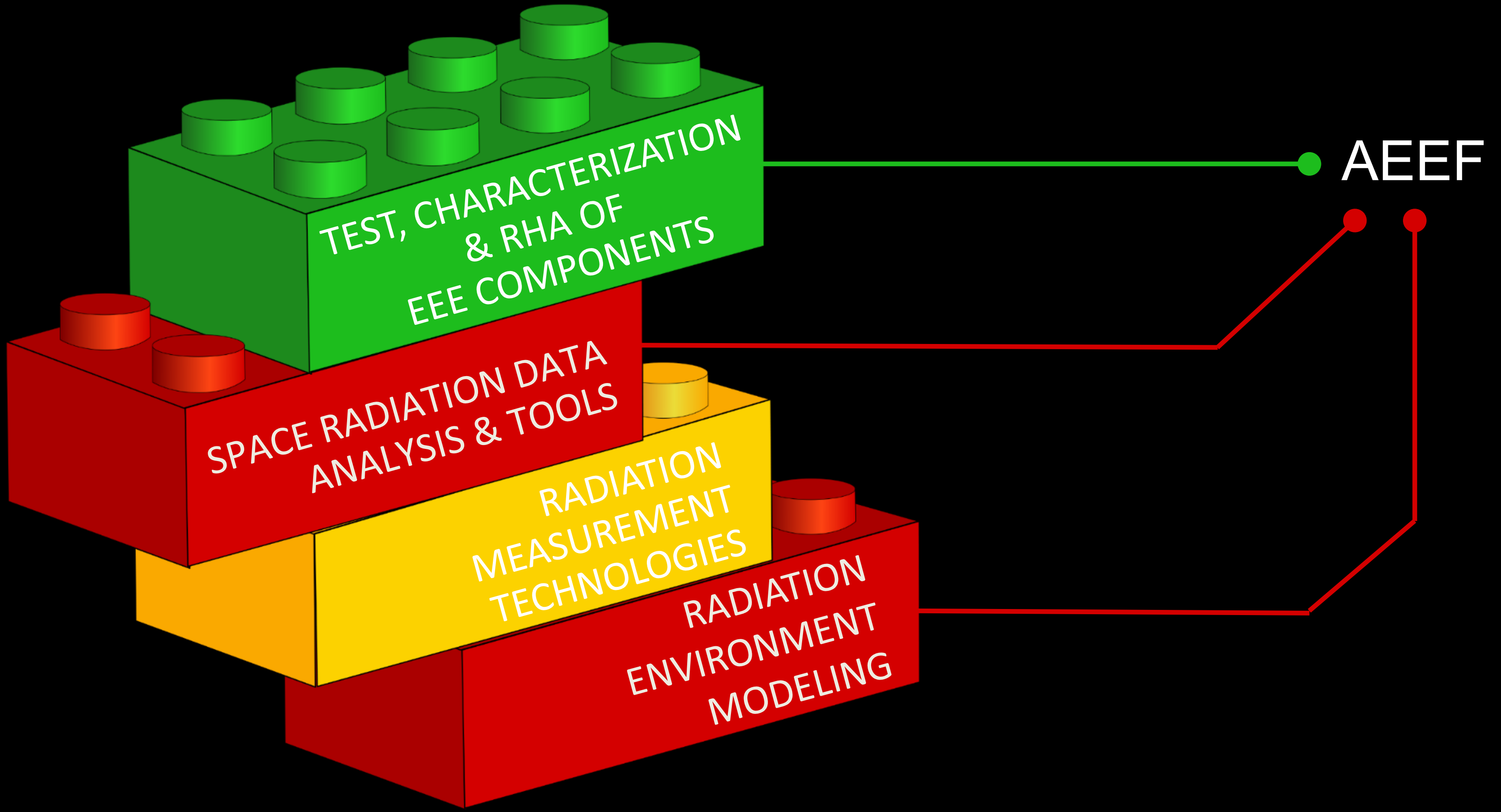
- Space
- Nuclear Physics
- Medical Physics
- High Energy Physics

Open source

(M. Pinto et al., DOI: https://doi.org/10.1016/j.cpc.2019.01.024)

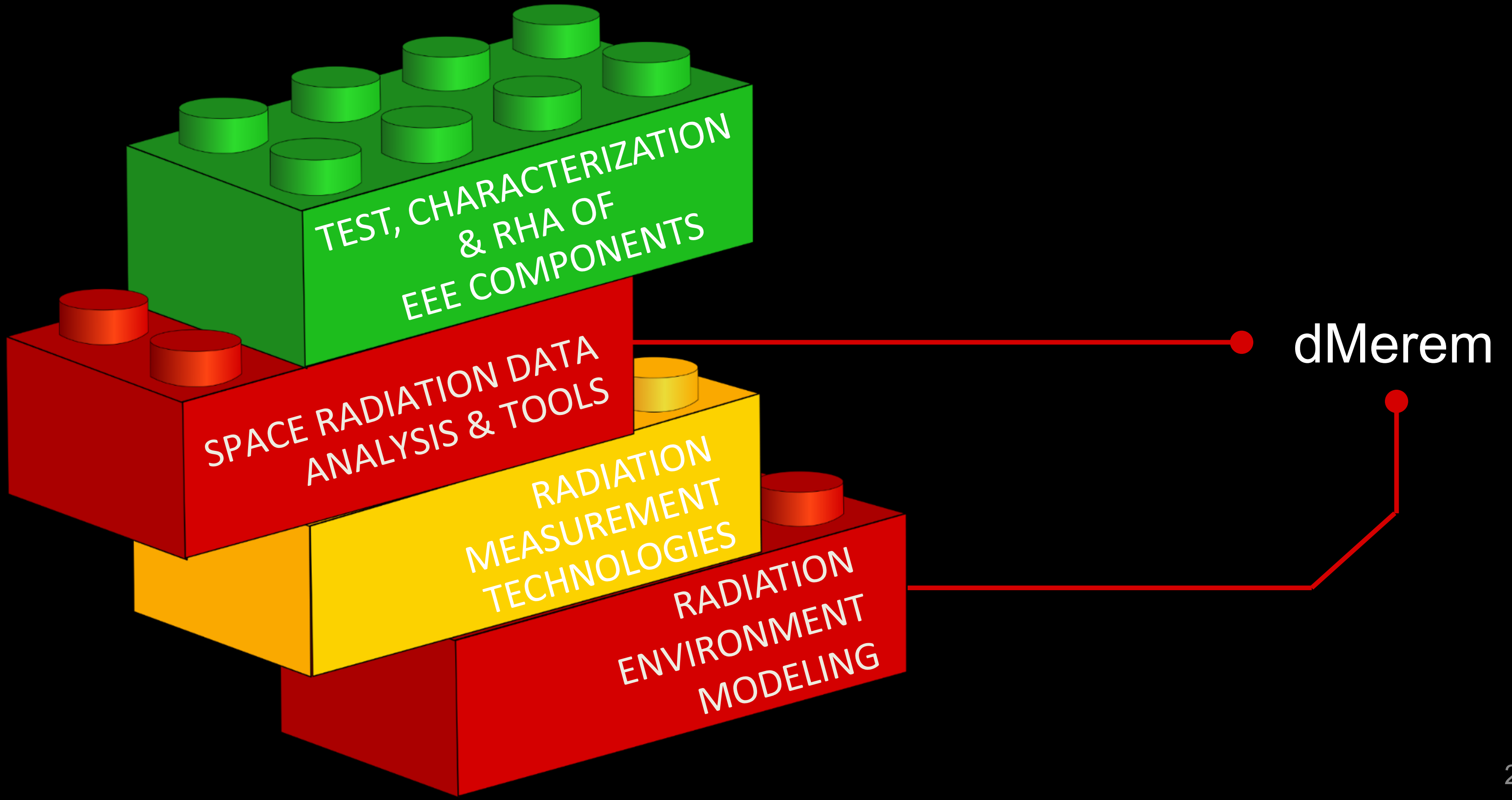
# Future of Space Rad

ESA ROADMAP



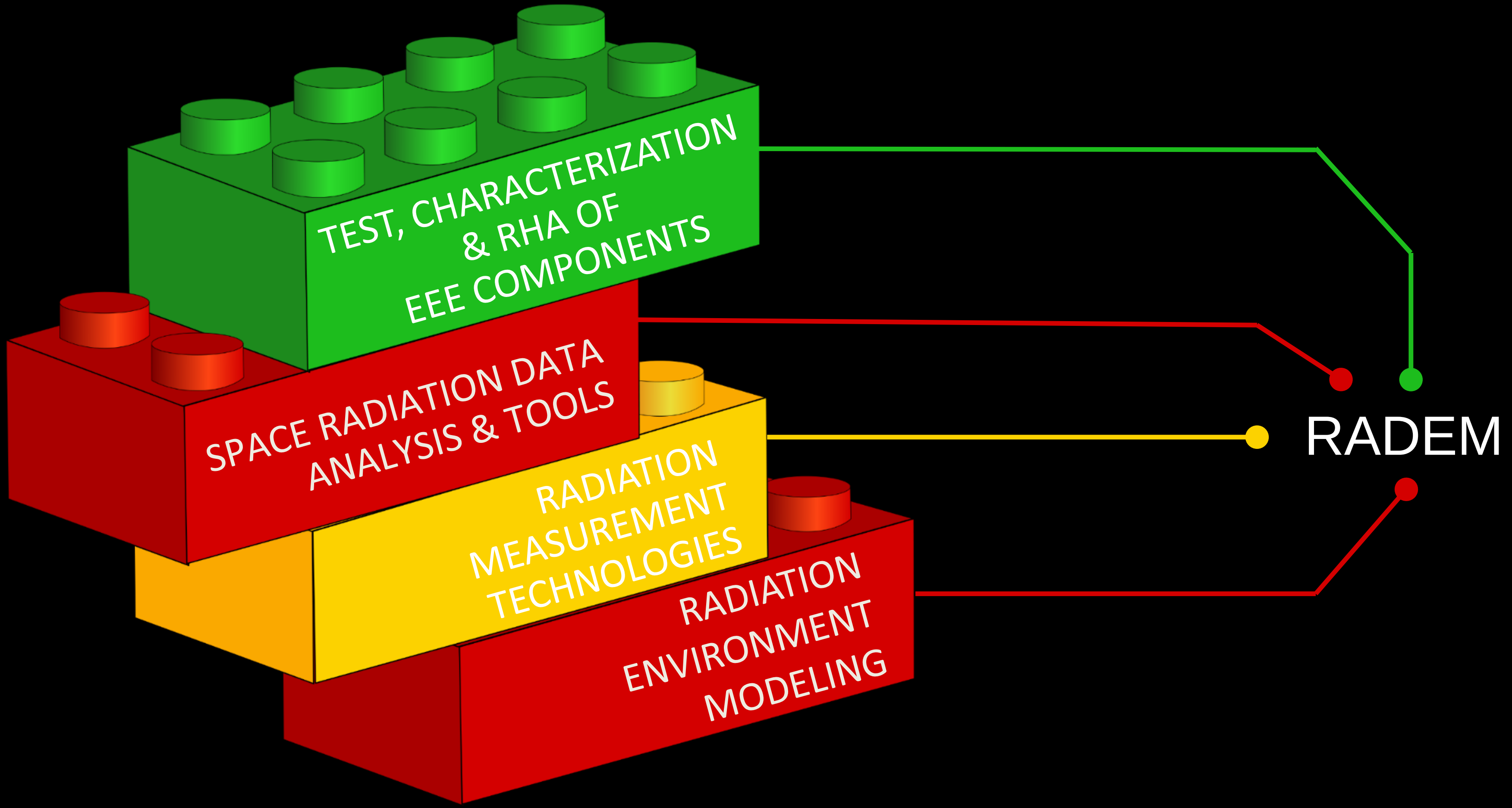
# Future of Space Rad

ESA ROADMAP



# Future of Space Rad

ESA ROADMAP

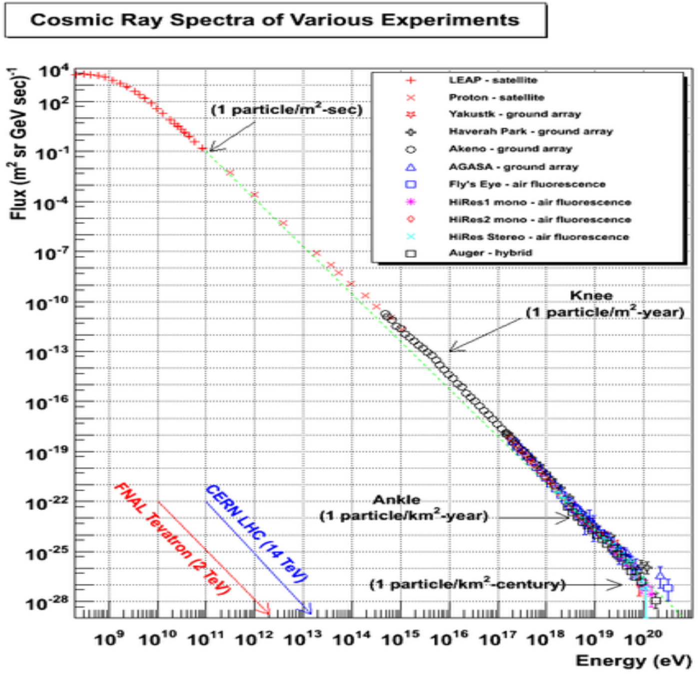


# *Backup Slides*

# *Future work with dMEREM*

- Radiological risk assessment on manned missions to Mars
- Modelling Mars radiation environment underground and study its astrobiological implications
  - Gent4-DNA studies
- Project to be submitted to on-going PTDC call

# *Radiation Environment in the Solar System*




Galactic Cosmic Rays

low flux but highly penetrating

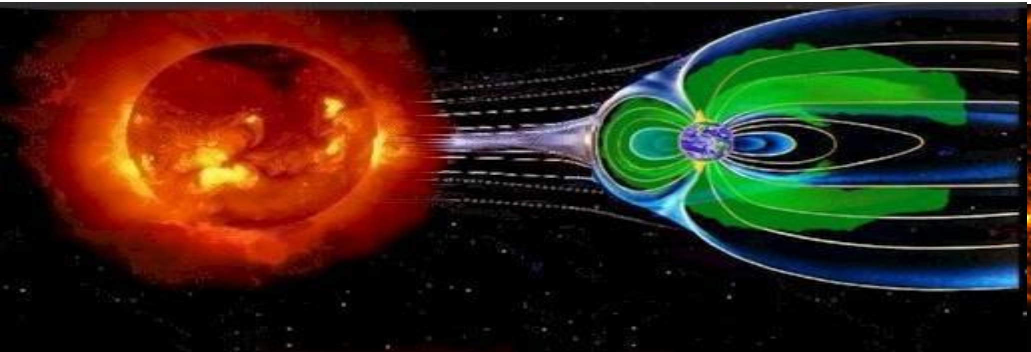
protons & nuclei

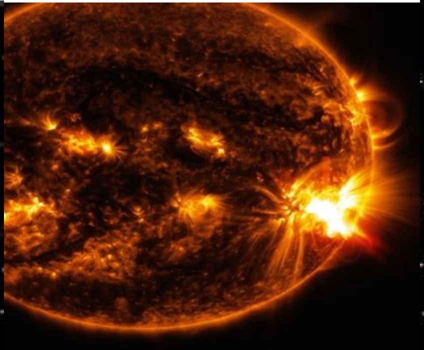
Solar Energetic Particles

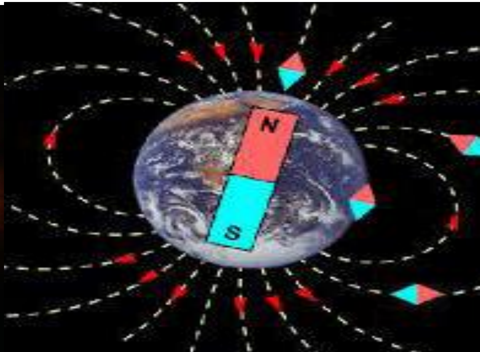
sporadic, intense & dangerous

electrons & protons

electrons , protons & ions





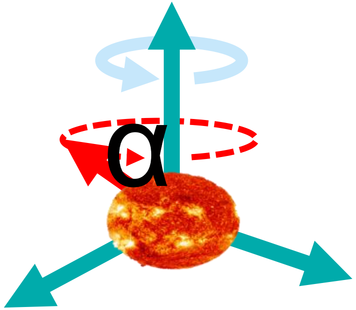


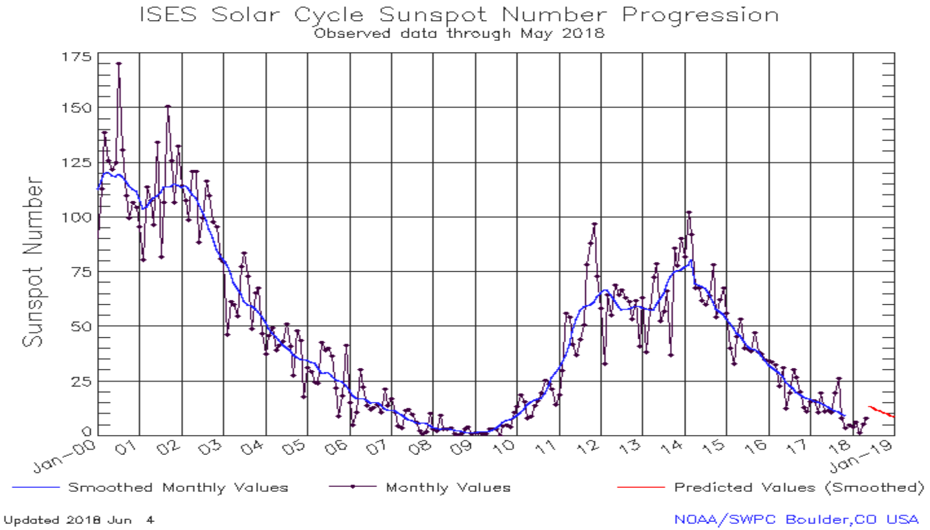
# GCR and Solar cycle activity

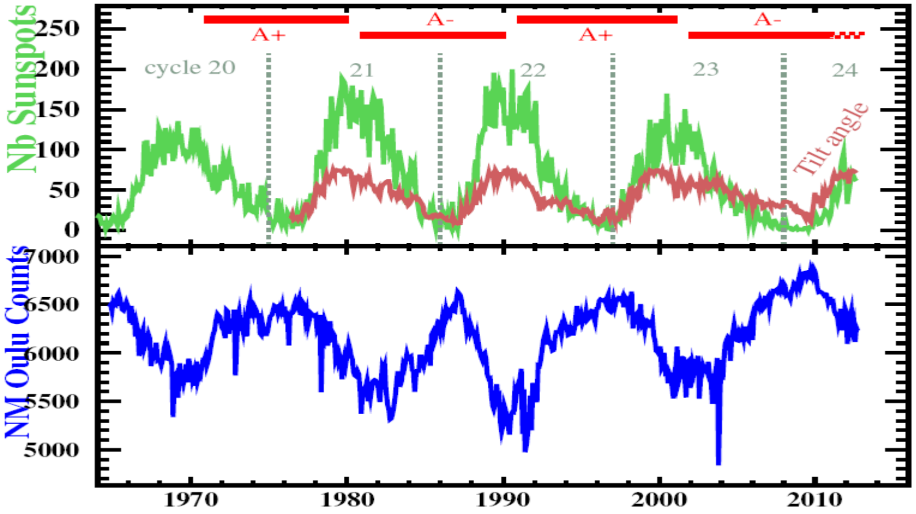
Modulation with solar activity – 11 yr cycle
Solar cycle modulated flux inversely proportional to the Sun's activity

**Maximum: solar storms and SEP**

**Minimum: more GCR**



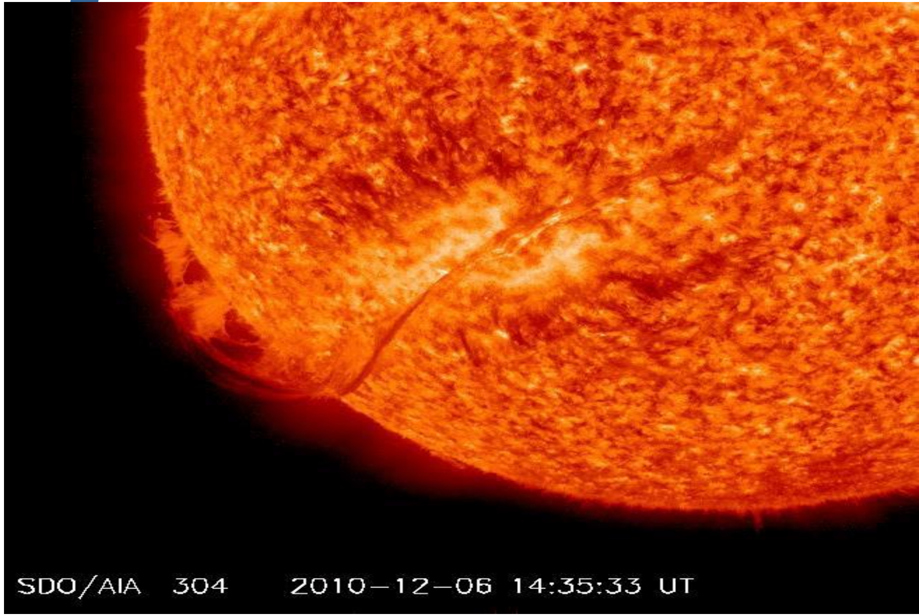
# SEP – Solar energetic particles

Associated to

- Solar flare
- Coronal mass ejections (CME)

- Mainly protons and electrons
- Energies from several hundred MeV/nuc to GeV/nuc

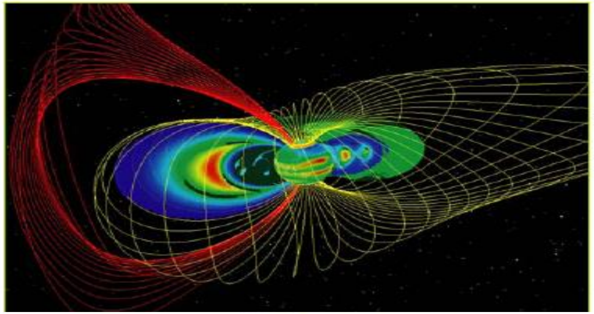
List from 1976-present @
*https://umbra.nascom.nasa.gov/SEP*

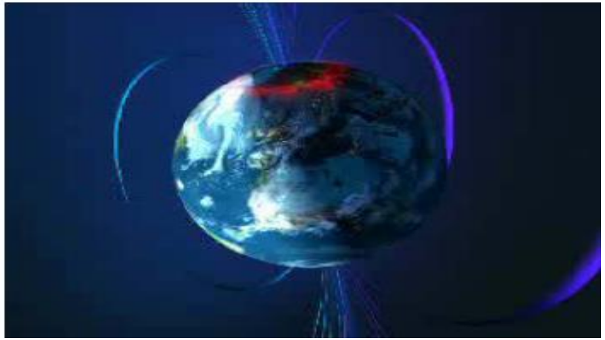


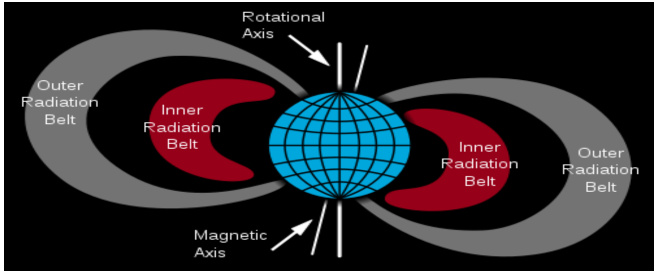

At **Earth's surface**, the **atmosphere** in conjunction with the **geomagnetic field** provides considerable protection against cosmic rays and solar particle events!

In **Space**, SEPs are responsible for spacecraft system and component hazard and damage and **impose strict constrains on human space exploration**

# *Earth radiation belts*








- Particles coming from Space depending on their **R** may be trapped by the **geomagnetic field** and form the **Earth's radiation belts**.

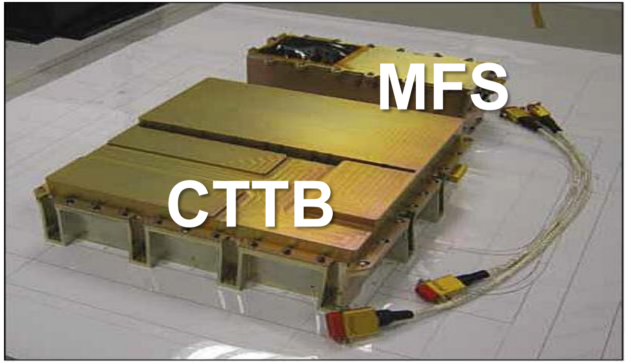
- In Earth's orbits the radiation belts containing

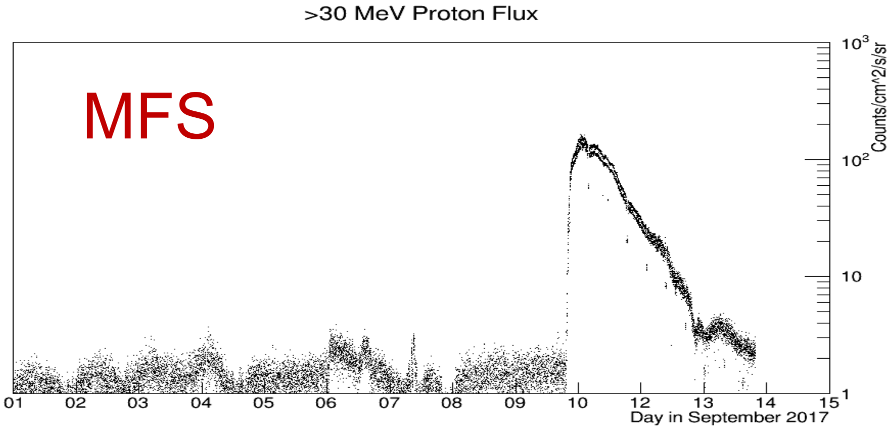
• **Inner belt** (700-10000km)
Dominated by **p**
Product of CR Neutron Decay
E~100's MeV

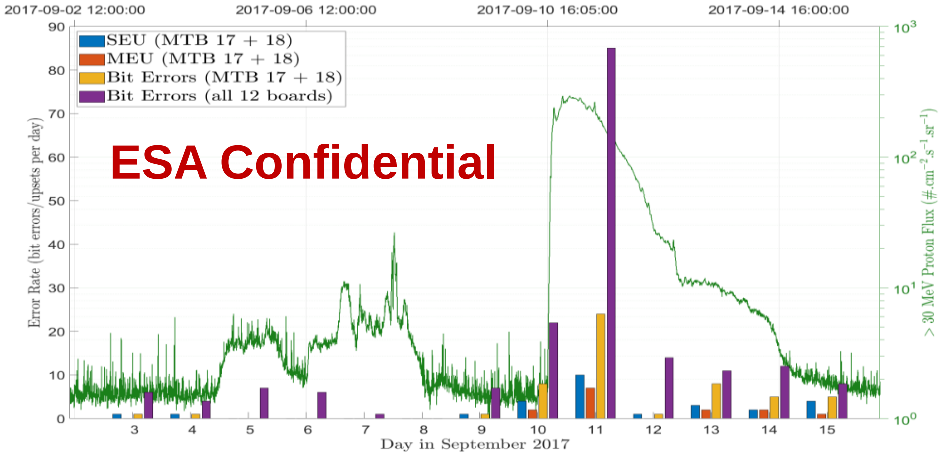
• **Outer belt** (~20000-70000km)
Dominated by **$e^-$**
Controlled by "storms"
Dominates GEO environment &
Navigation (Galileo, GPS) orbits

# MFS data analysis

- ➢ Correlation with eventual variations in CTTB EEE measurements



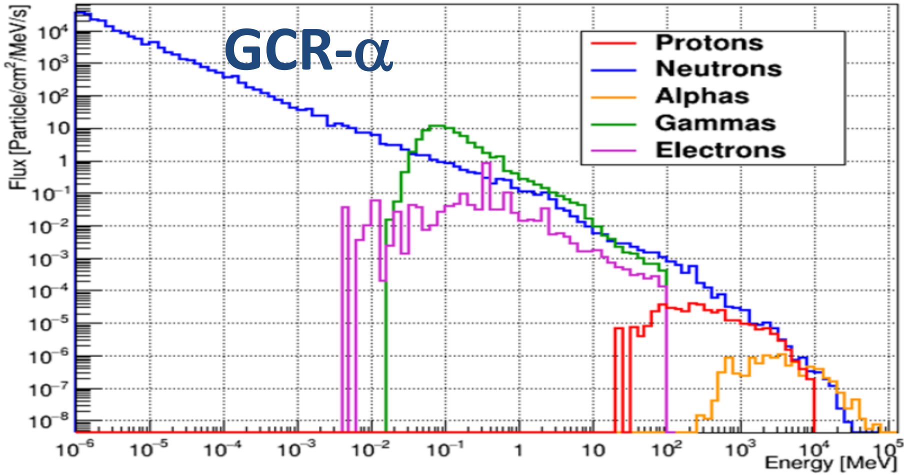



# *Mars Radiation Environment: dMEREM*

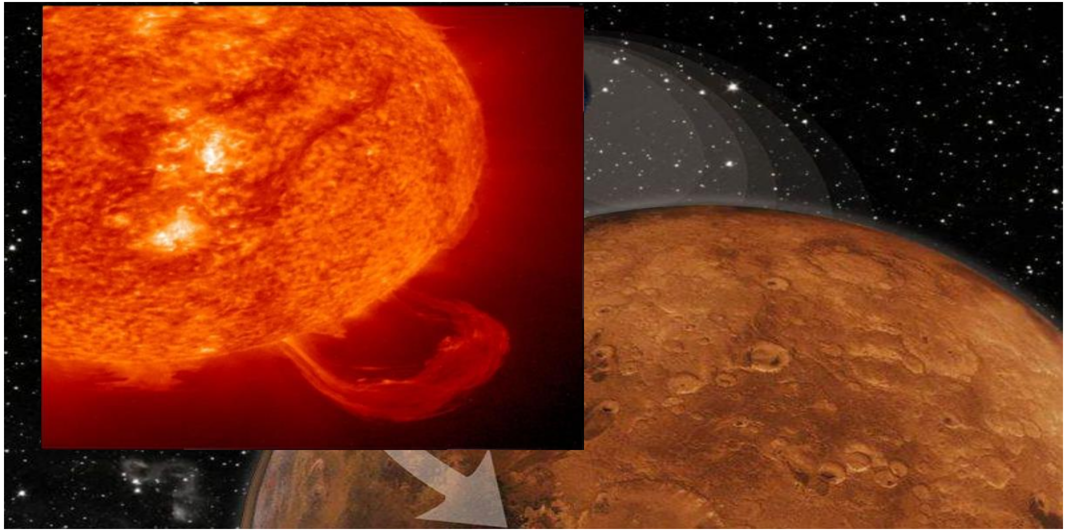
LIP developed **dMEREM** (ESA contract 19770/06/NL/JD)**,** a **Geant4 based model for the radiation environment on Mars, Phobos and Deimos**, including local treatment of surface topography and composition, atmospheric composition and density (including diurnal + annual variations) and local magnetic fields.

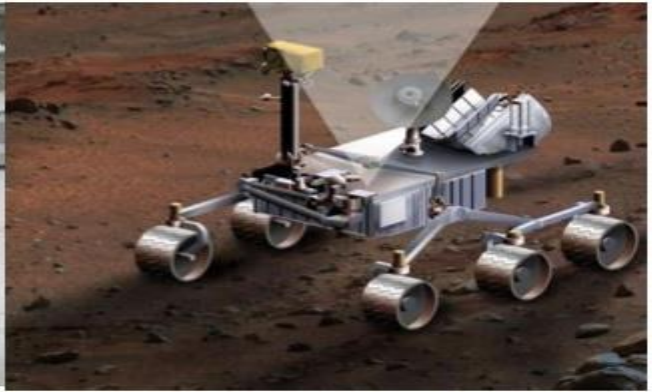
Inputs given as a function of latitude, longitude, in a 5 x 5 degree grid, and season




- Co- supervision of Master Thesis by P. Magalhães: "Radiation Environment and its Effects on the Martian Surface and Underground"

# *Mars radiation environment*



For **future human missions to Mars**, it is important to study the **surface radiation environment** during **extreme** and **elevated conditions.**

RAD (Radiation Assessment Detector) measuring and identifying high-energy radiation at Mars surface since Aug 12

**On going PhD thesis at LIP on Mars Radiation environment study and RAD detector simulation by A. Casimiro.**

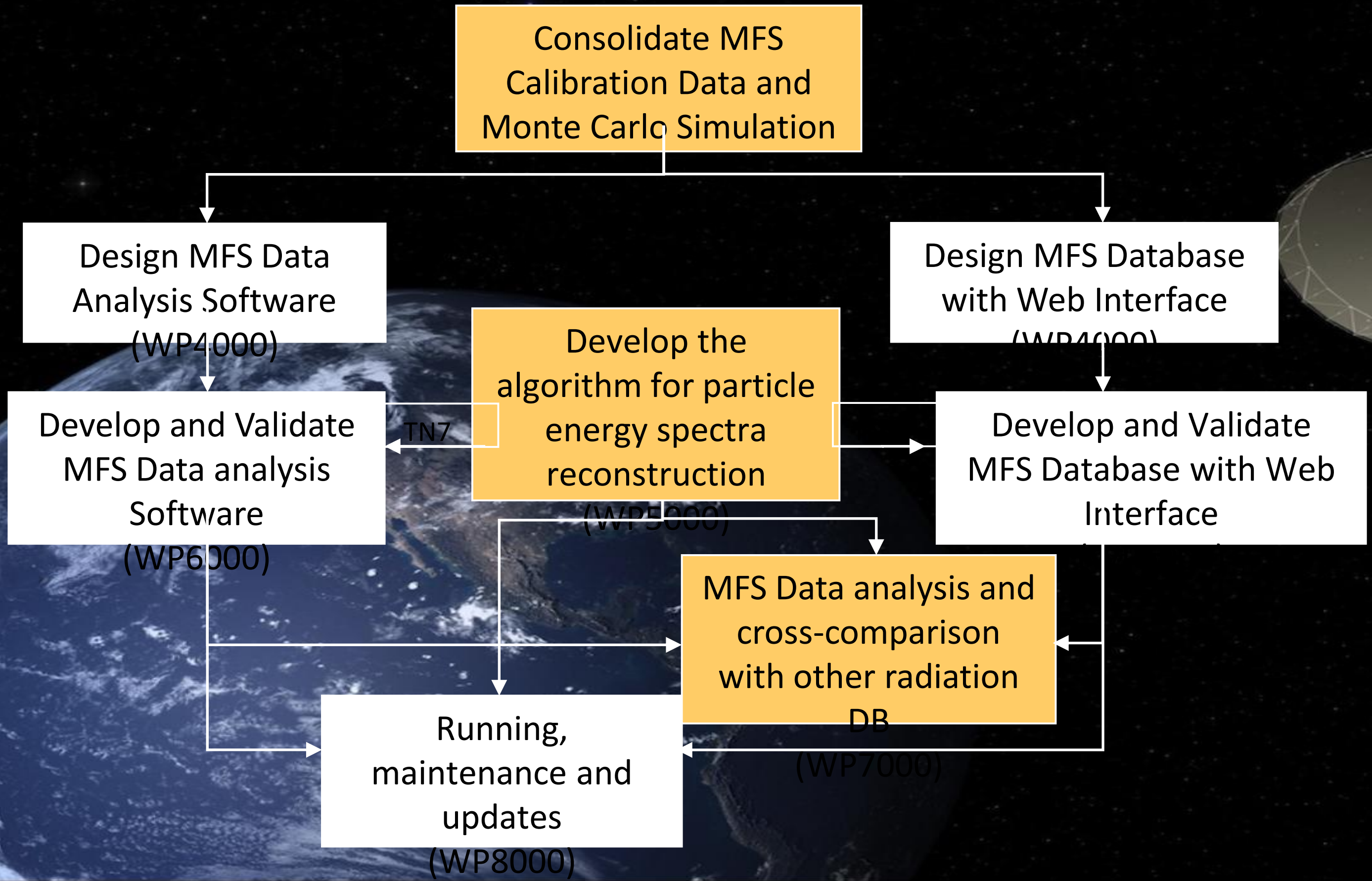
# *Improving Mars radiation environment models*

- Update dMEREM with different inputs
    - atmosphere composition
    - soil composition (available from measurements on MSL/Curiosity)
- Introduce granular information on the arrival directions of all particles reaching a specified location: simulate RAD FOV
- Update to Geant4.10.04 or higher
- Introduce more appropriate physics lists to describe the hadronic and electromagnetic processes.

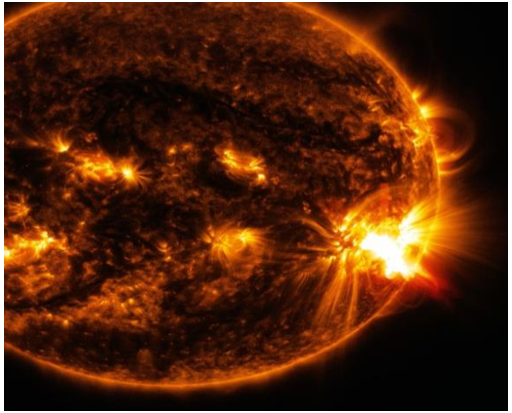
**The ground-level radiation environment will be simulated with dMEREM at possible landing exploration sites.**

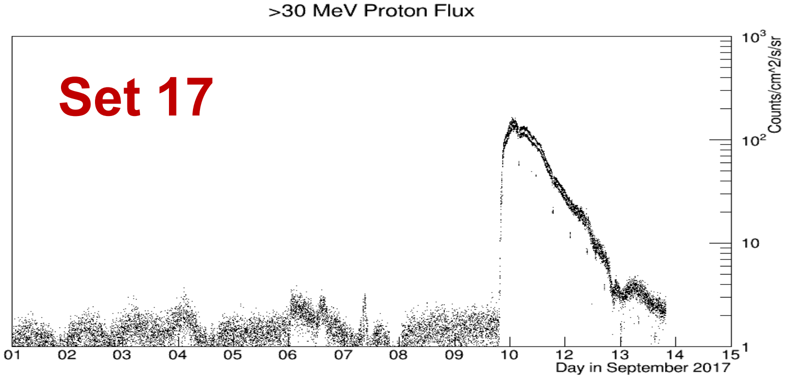
- Different contributions to the radiation environment:

# MFS data analysis



# *MFS data analysis*






- Monitor p and e⁻s fluxes

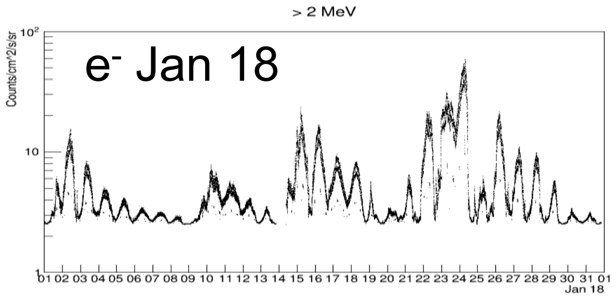
- Flux **unfolding method** need to be revised in order to have a more precise flux measurement specially for the e⁻s.
  - SVD and/or ANN methods

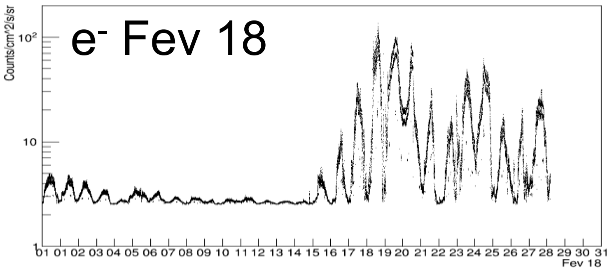
- Unfolded fluxes will be made available to the scientific community.

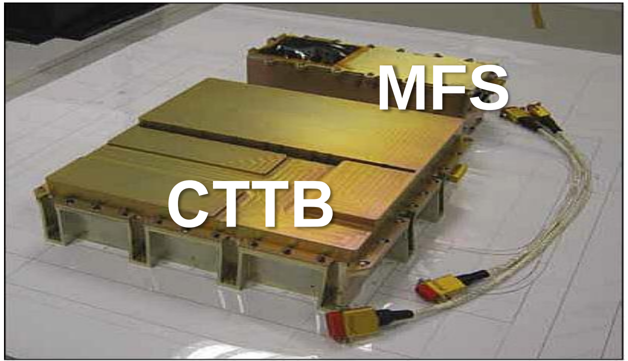
- Analysis of more **SEP events registered in GEO** with the MFS in the last solar cycle-24 and future occurrences

  **aim**: contribute to a better understanding on SEP

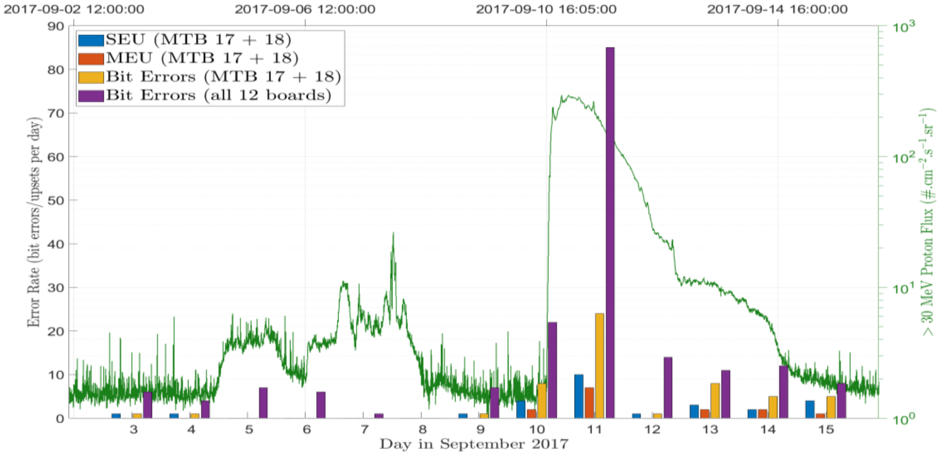
# MFS data analysis



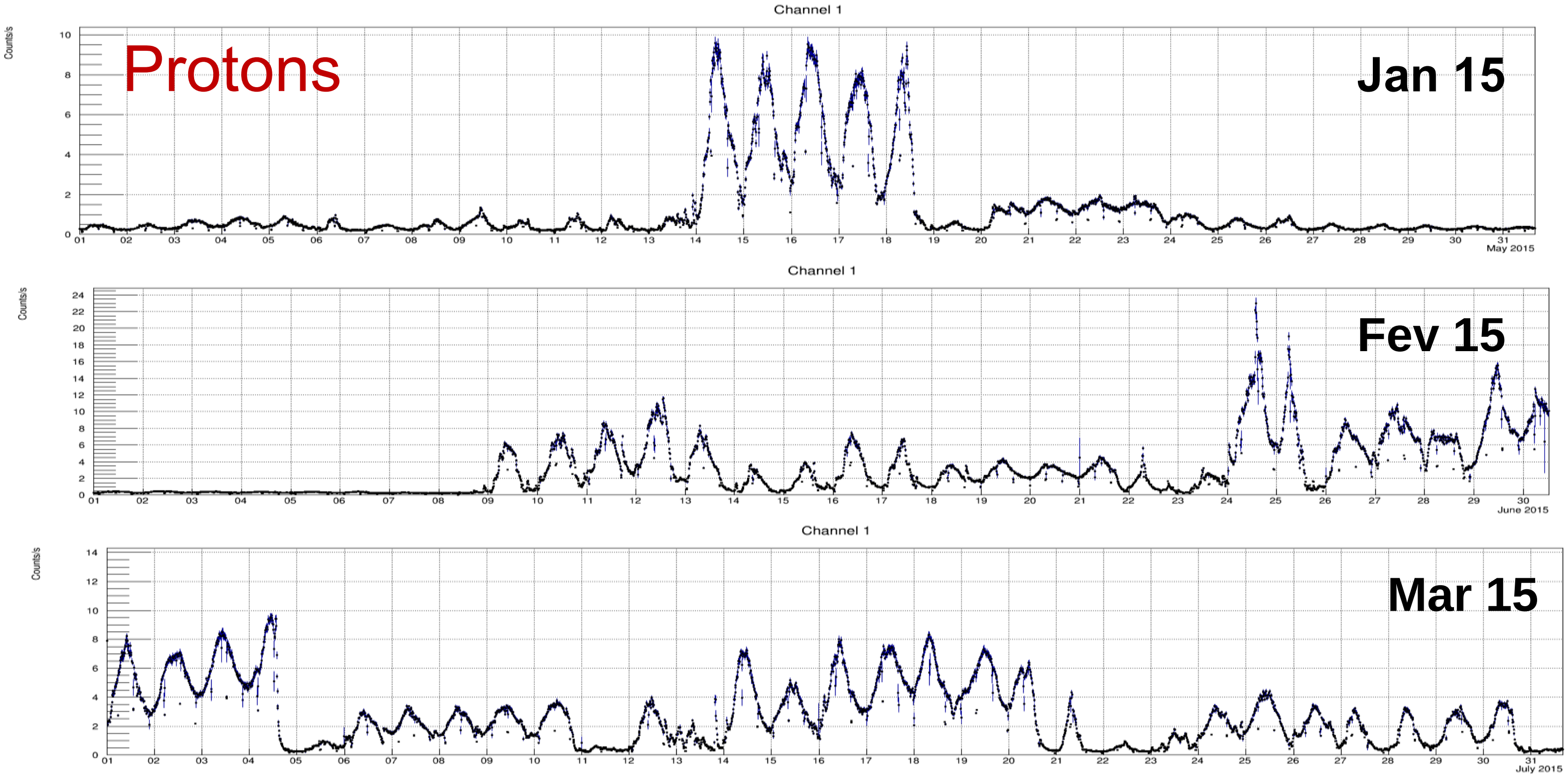




- Continuous monitoring of MFS data
    - MFS is the only ESA radiation monitor at GEO. Make it very interesting to study electron radiation belts.



# *Monitoring of MFS measurements*






**Correlation with eventual variations in CTTB EEE measurements**

# NOAA SPACE ENVIRONMENT SERVICES CENTER
## Solar Proton Events Affecting the Earth Environment

**Preliminary Listing**

**1976 - present**

A current listing can be found at:
ftp://ftp.swpc.noaa.gov/pub/indices/SPE.txt

| PARTICLE EVENT | | | | ASSOCIATED CME, FLARE, AND ACTIVE REGION | | | | |
|---|---|---|---|---|---|---|---|---|
| **Start (Day/UT)** | **Maximum (Day/UT)** | **Proton Flux (pfu @ >10 MeV)** | **Year** | **CME** | **Maximum (Day/UT)** | **Importance (X ray/Opt)** | **Location** | **NOAA SEC Region No.** |
| | | | **2014** | | | | | |
| Jan 06/0915 | Jan 06/1600 | 42 | | Asymm. Partial Halo/06 0800 | (Farside) | | | 11936 |
| Jan 06/0915 | Jan 09/0340 | 1033 | | Asymm. Partial Halo/07 1824 | 07/1832 | X1 | S15W11 | 11944 |
| Feb 20/0850 | Feb 20/0925 | 22 | | Asymm. Full Halo W. limb/20 0800 | 20/0755 | M3 | S15W67 | 11976 |
| Feb 25/1355 | Feb 28/0845 | 103 | | Asymm. Halo/25 0130 | 25/0049 | X4 | S12E82 | 11990 |
| Apr 18/1525 | Apr 19/0105 | 58 | | CME (C3)/18 1325 | 18/1303 | M7 | S16W41 | 12036 |
| Sep 11/0240 | Sep 12/1555 | 126 | | Asymm. Full Halo/10 1800 | 10/1745 | X1 | N16W06 | 12158 |
| | | | **2015** | | | | | |
| Jun 18/1135 | Jun 18/1445 | 16 | | Narrow SW limb event/18 0125 | 18/0127 | M1 | SW limb | 12365 |
| Jun 21/2135 | Jun 22/1900 | 1070 | | Full halo/21 0236 | 21/0236 | M2 | N13W00 | 12371 |
| Jun 26/0350 | Jun 27/0030 | 22 | | Asymmetric full halo/25 0836 | 25/0816 | M7 | N12W40 | 12371 |
| Oct 29/0550 | Oct 29/1000 | 23 | | Far-sided on W limb, S11/29 0236 | (Farside) | | | 12434 |
| | | | **2016** | | | | | |
| Jan 02/0430 | Jan 02/0450 | 21 | | SW limb event/02 2324 | 02/0011 | M2 | S21W73 | 12473 |
| | | | **2017** | | | | | |
| Jul 14/0900 | Jul 14/2320 | 22 | | Asymmetric full halo/14 0125 | 14/0209 | M2 | S06W29 | 12665 |
| Sep 05/0040 | Sep 08/0035 | 844 | | Asymmetric full halo/04 2042 | 04/2033 | M5 | S11W16 | 12673 |
| Sep 10/1645 | Sep 11/1145 | 1490 | | Asymmetric full halo/10 1600 | 10/1606 | X8 | S08W83 | 12673 |

# *Mars Radiation Environment: dMEREM update*

- Co- supervision of Master Thesis by P. Magalhães: "Radiation Environment and its Effects on the Martian Surface and Underground“ @IST, 7Jun 16

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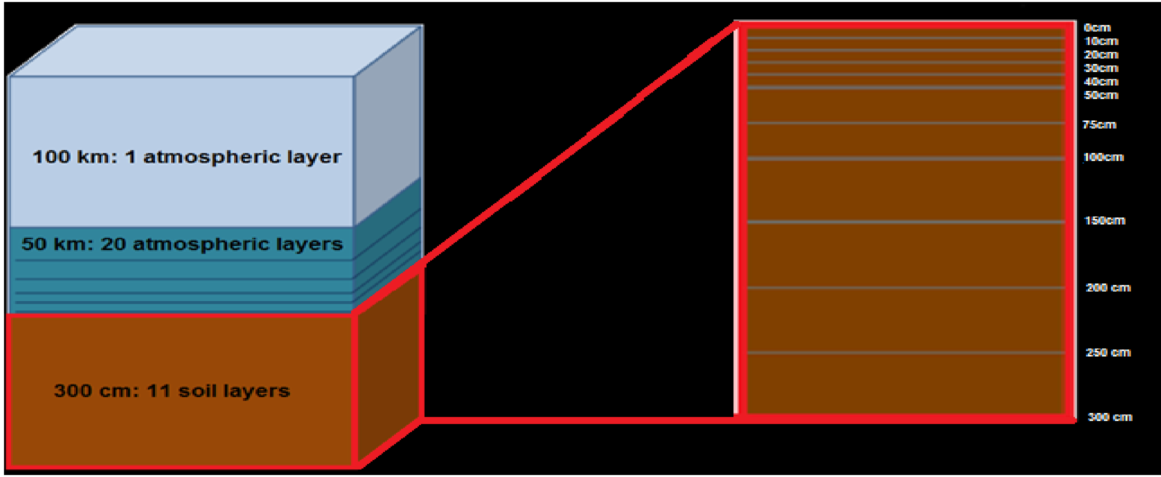
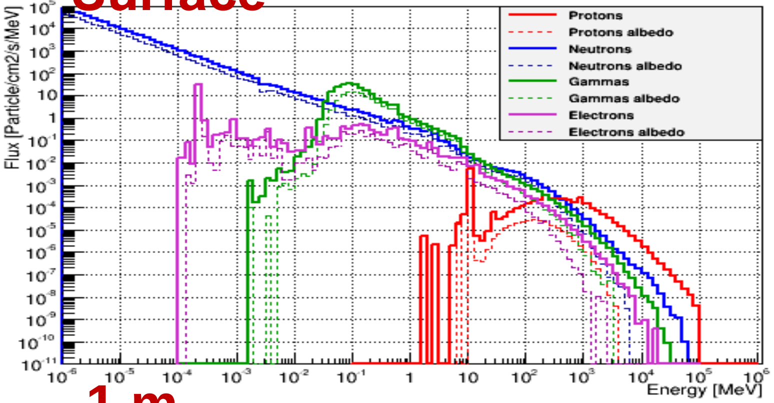
- atmospheric composition and density (including diurnal + annual variations) and local magnetic fields



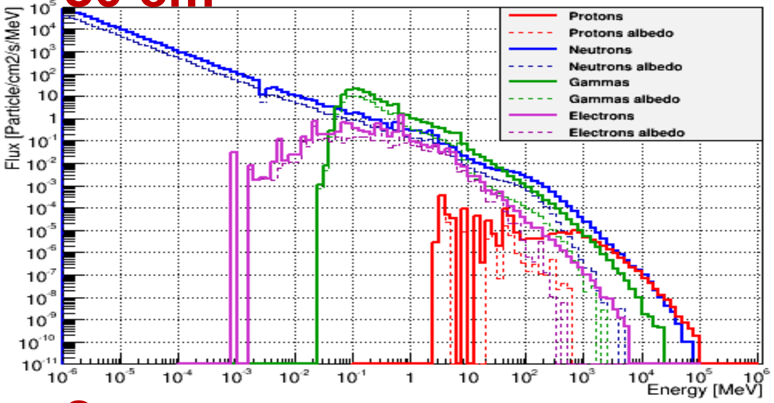

This model was updated to register the flux of energetic particles at **different soil depths. Interesting for astrobiological studies in Mars**

# *dMEREM results: Particle radiation arriving on Mars surface & underground resulting from GCR-proton spectrum*

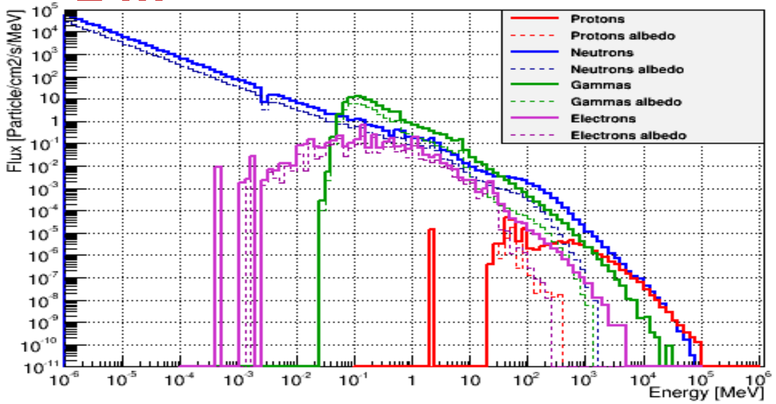
**Surface**




**50 cm**




**1 m**




**3 m**