Space Radiation Environment and Effects: From Earth to Jupiter

LABORATÓRIO DE INSTRUMENTAÇÃO E FÍSICA EXPERIMENTAL DE PARTÍCULAS

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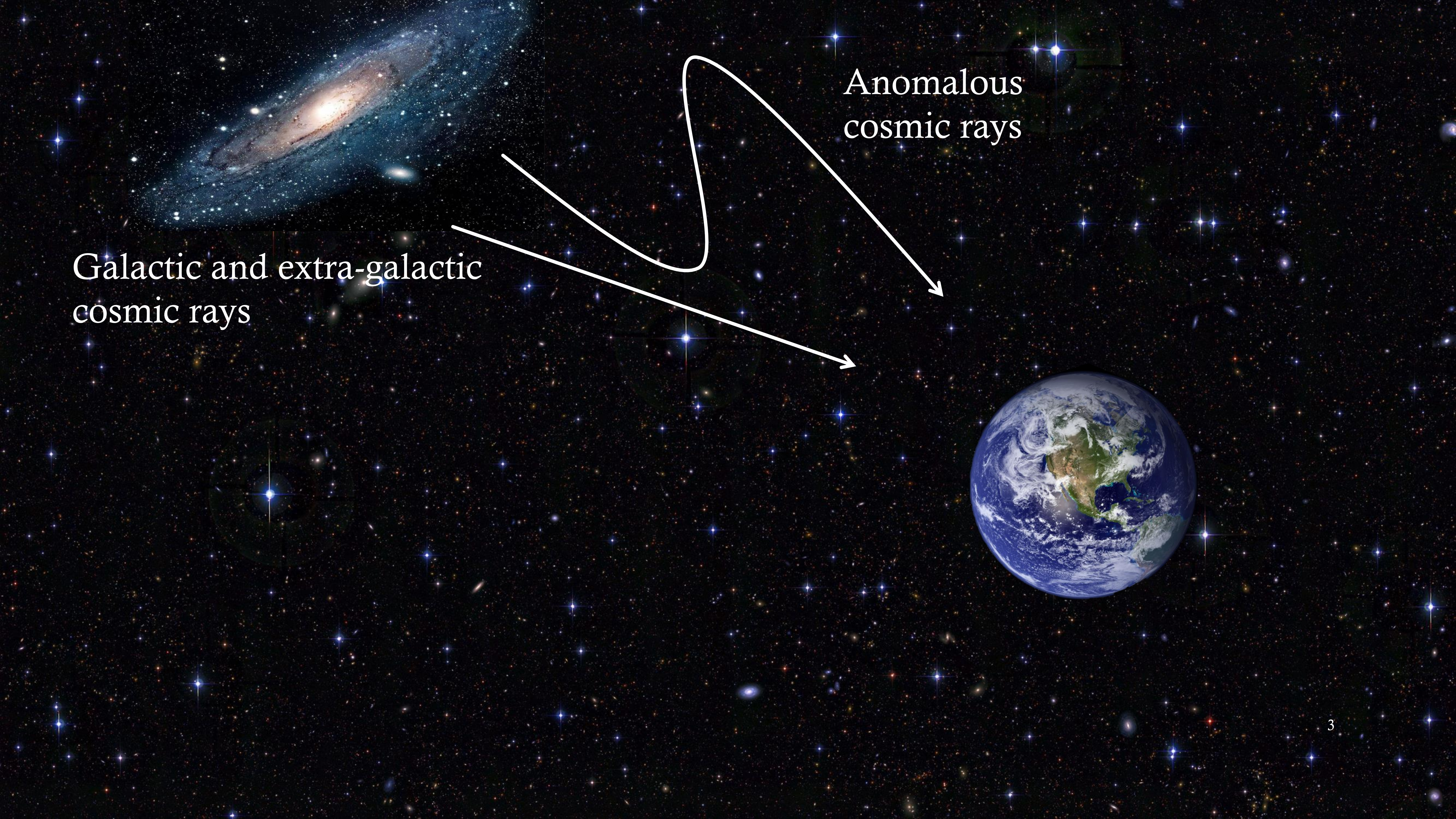
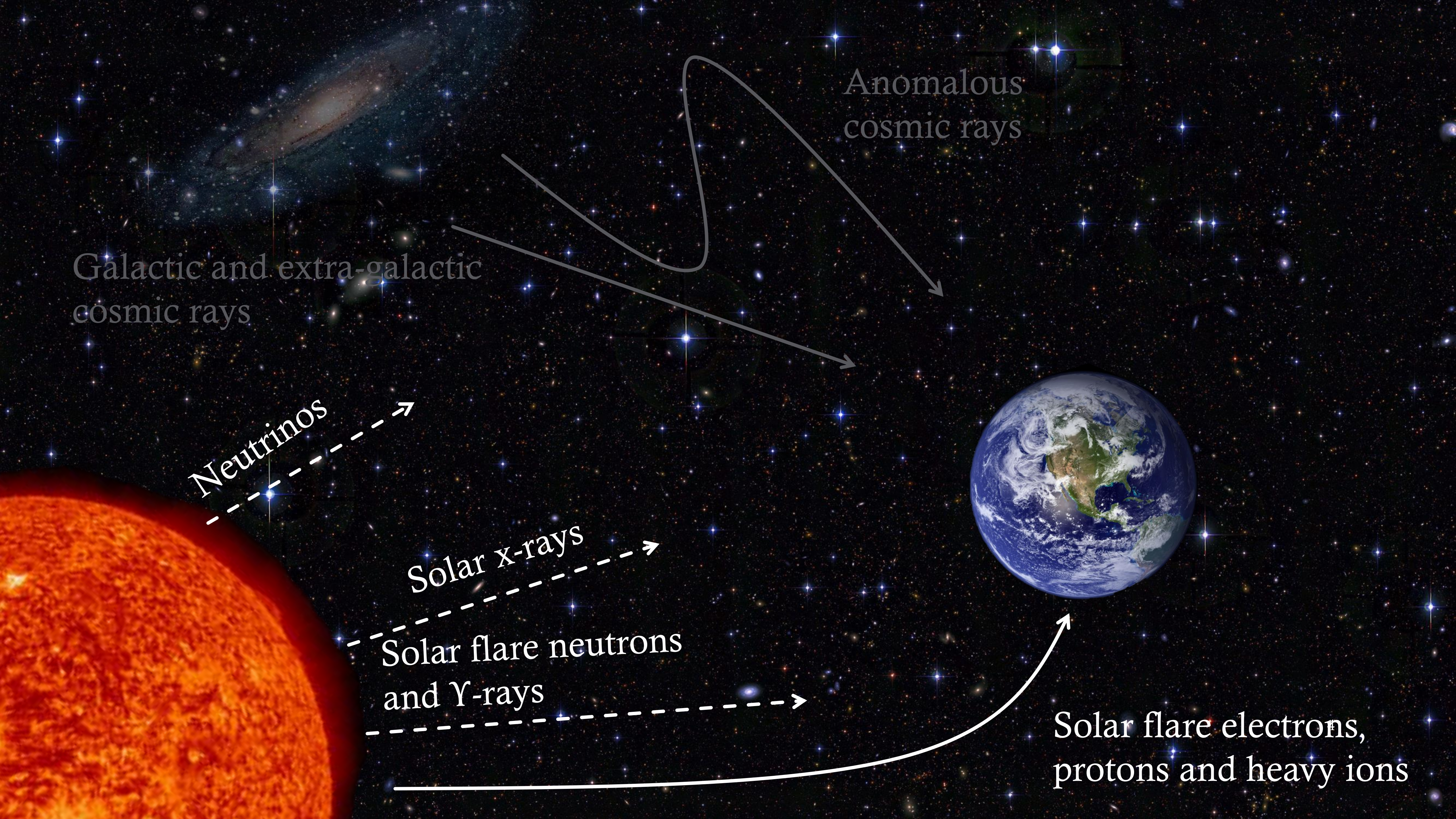
28/10/2020

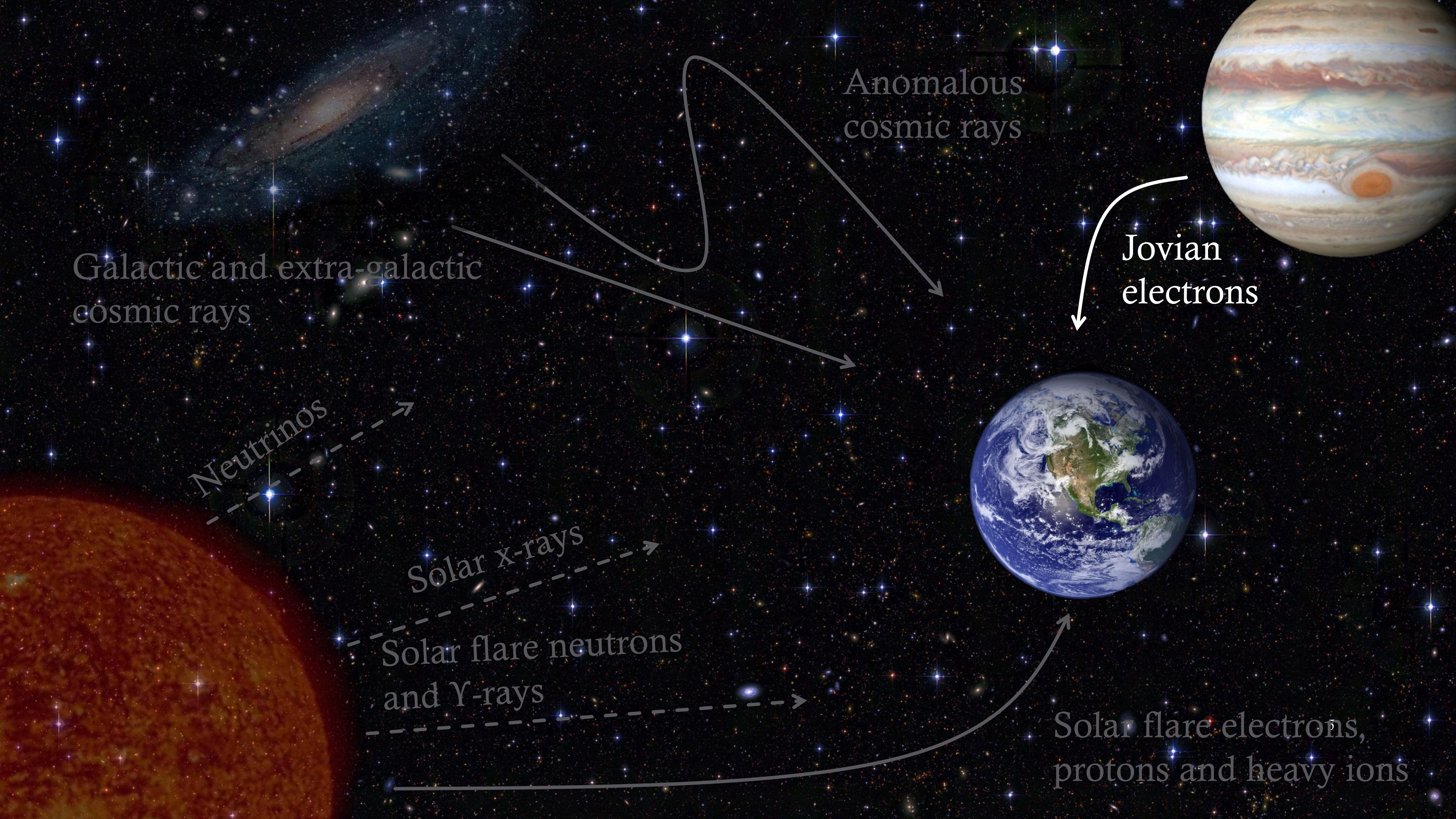
What constitutes the space radiation environment?

Its not all photons!

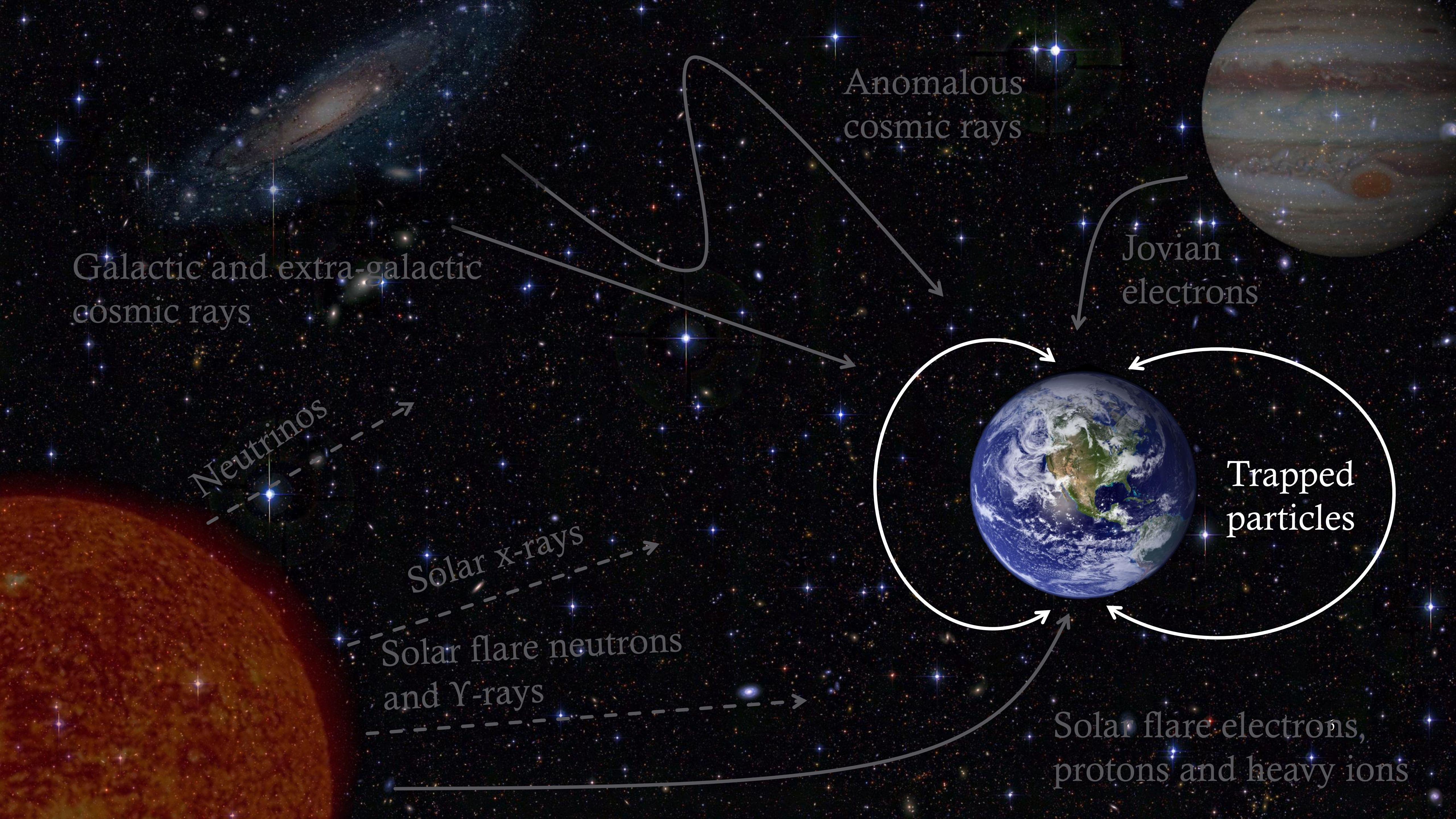

Anomalous
cosmic rays
Galactic and extra-galactic
cosmic rays



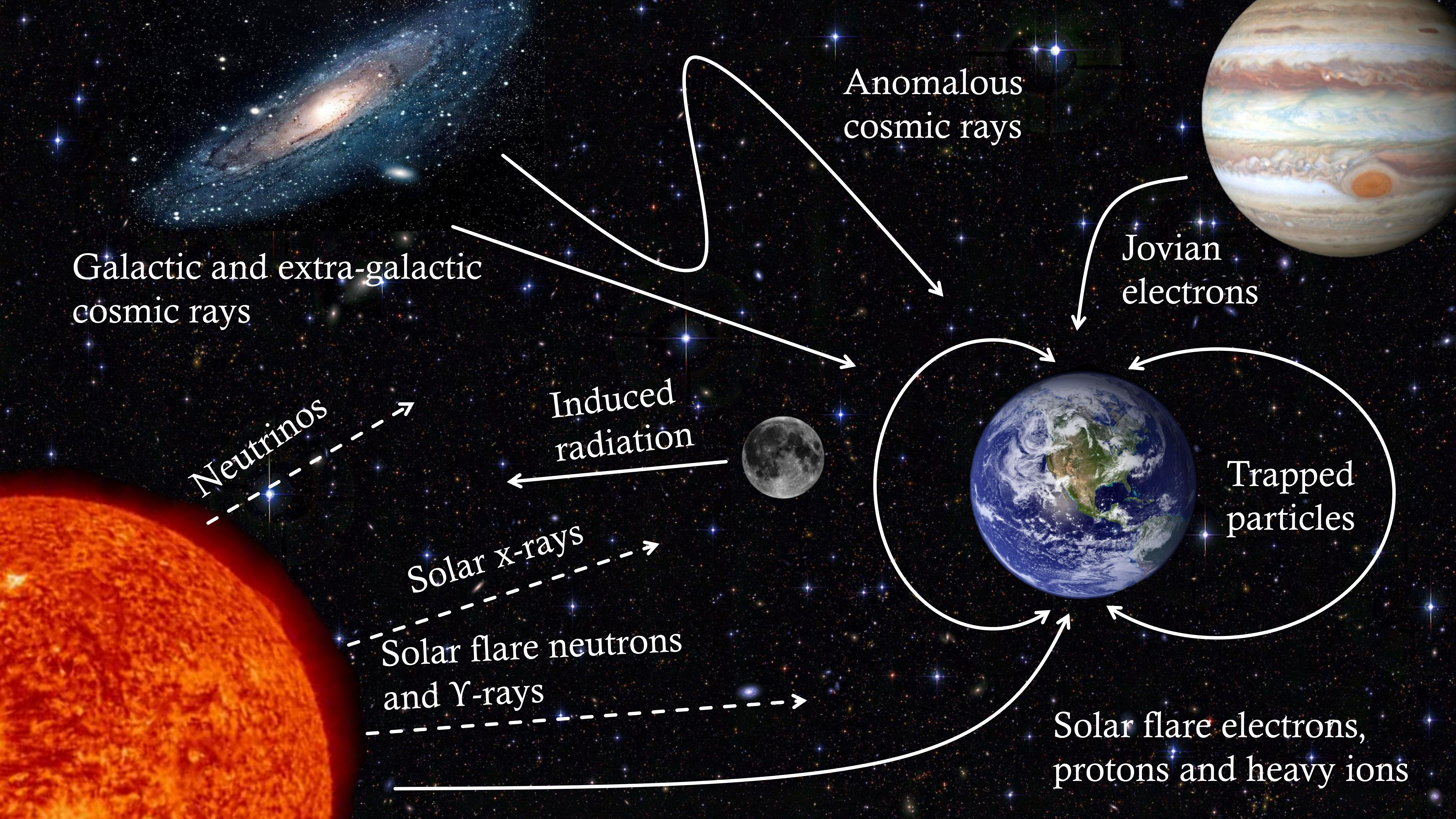
Anomalous
cosmic rays
Galactic and extra-galactic
cosmic rays
Neutrinos
Solar x-rays
Solar flare neutrons
and γ-rays
Solar flare electrons,
protons and heavy ions



Anomalous cosmic rays
Jovian electrons
Galactic and extra-galactic cosmic rays
Neutrinos
Solar x-rays
Solar flare neutrons and γ-rays
Solar flare electrons, protons and heavy ions



Anomalous cosmic rays
Jovian electrons
Galactic and extra-galactic cosmic rays
Neutrinos
Trapped particles
Solar x-rays
Solar flare neutrons and γ-rays
Solar flare electrons, protons and heavy ions


Anomalous
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Neutrinos
Induced
radiation
Trapped
particles
Solar x-rays
Solar flare neutrons
and Υ-rays
Solar flare electrons,
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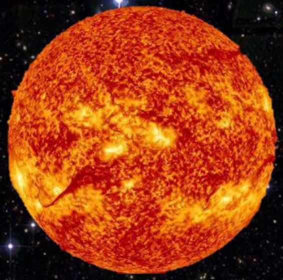
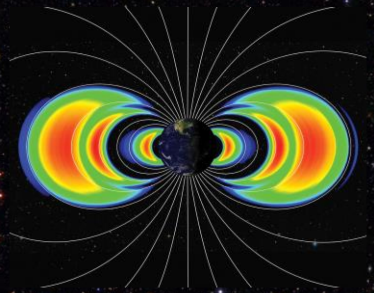
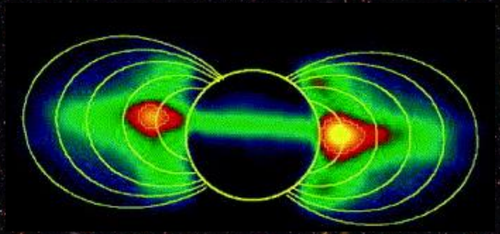
A bit of history

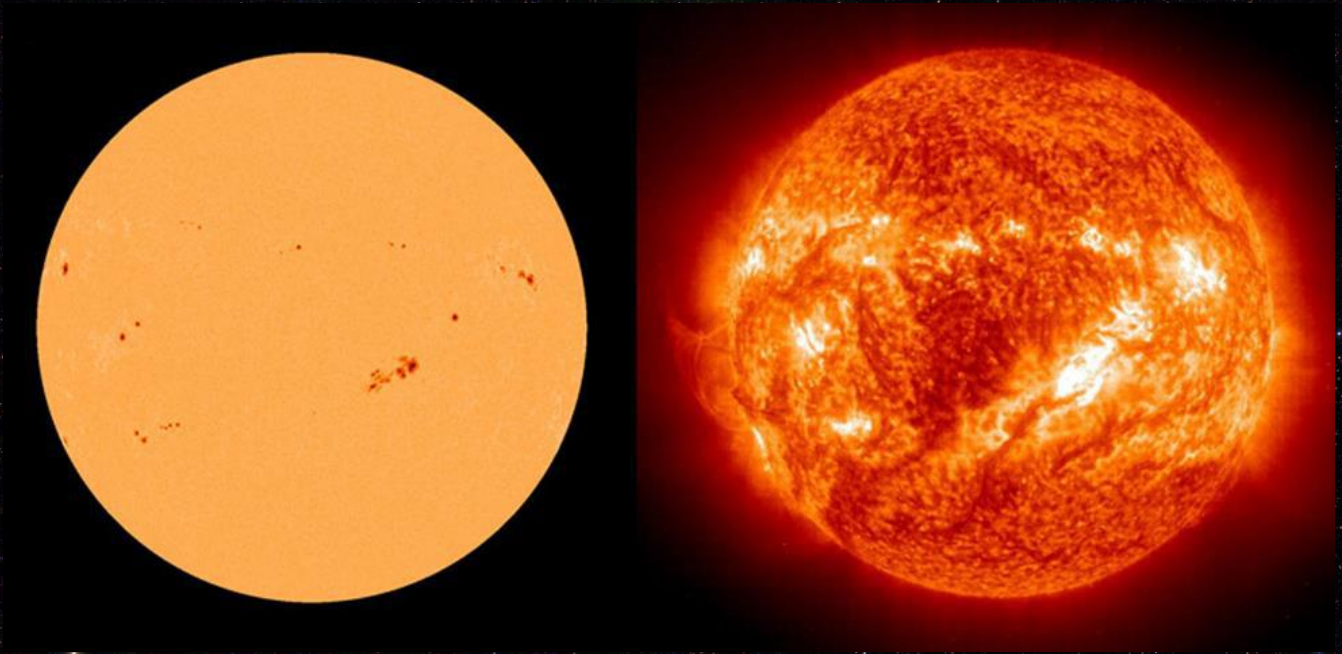


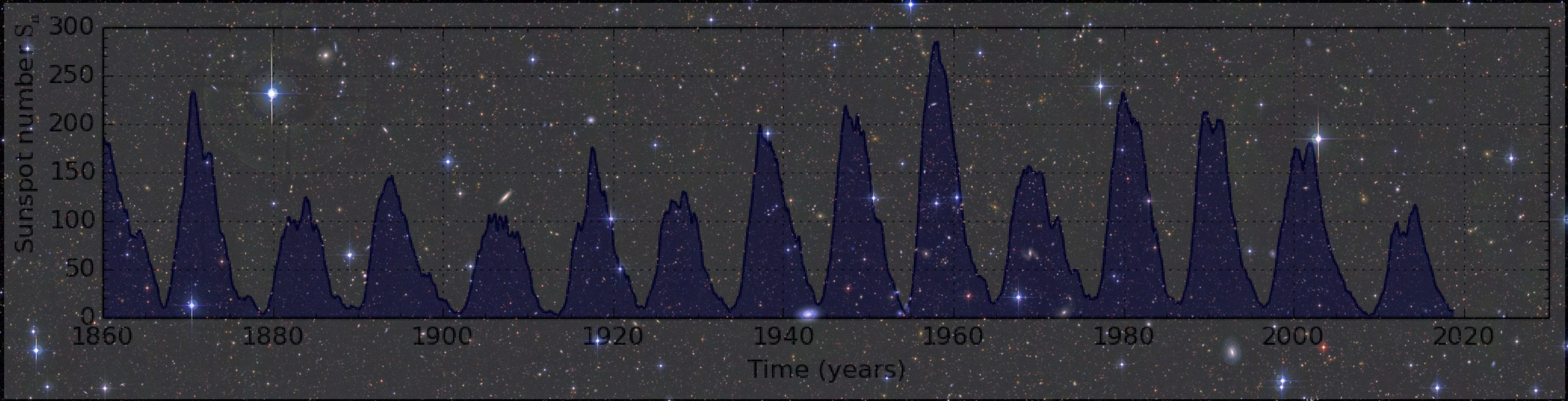
- 01 — 1912 — Discovery of Galactic Cosmic Rays
- 02 — 1942 — Discovery of Solar Energetic Particles
- 03 — 1947 — Transistor invented
- 04 — 1958 — Van Allen Belts discovered
- 05 — 1960 — Synchrotron radiation on Jupiter detected
- 06 — 1964 — First NSREC





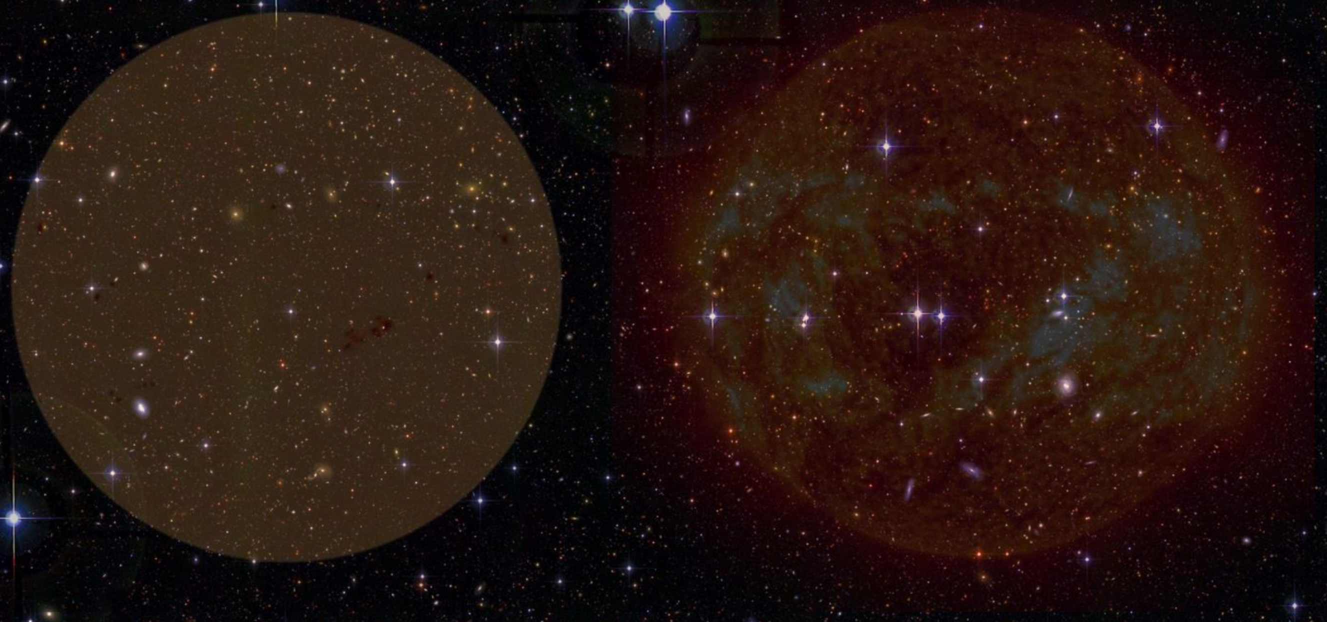
Solar Cycle

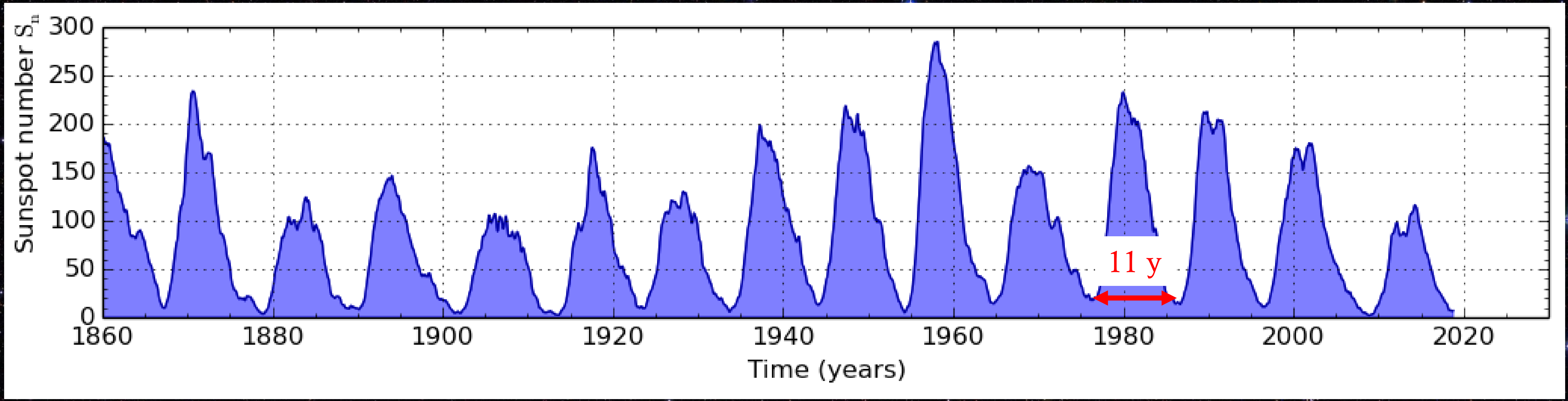




Sunspot number S_n
300
250
200
150
100
50
0
1860
1880
1900
1920
1940
1960
1980
2000
2020
Time (years)

Solar Cycle




Sunspot number S_n
300
250
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1860
1880
1900
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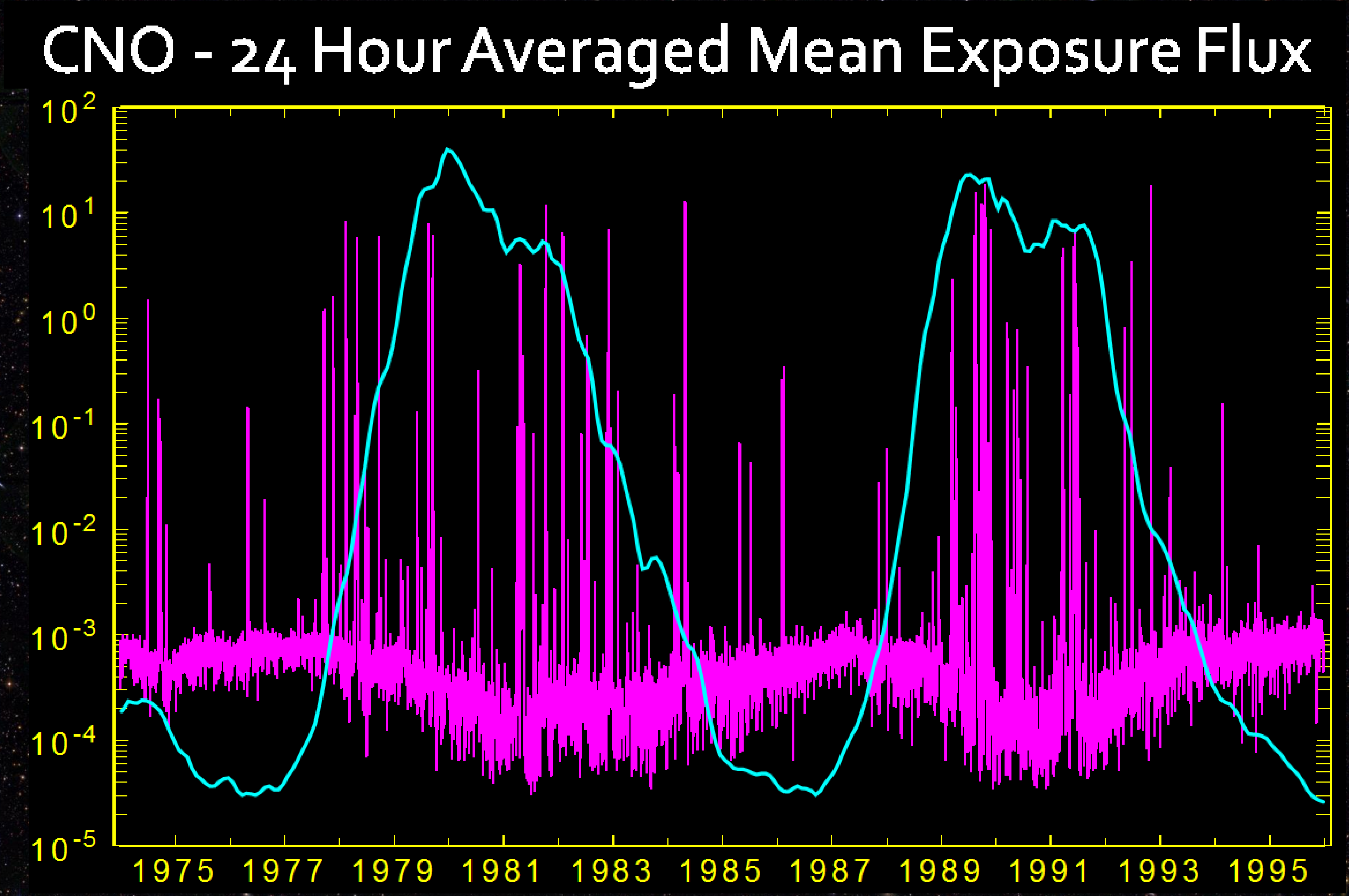
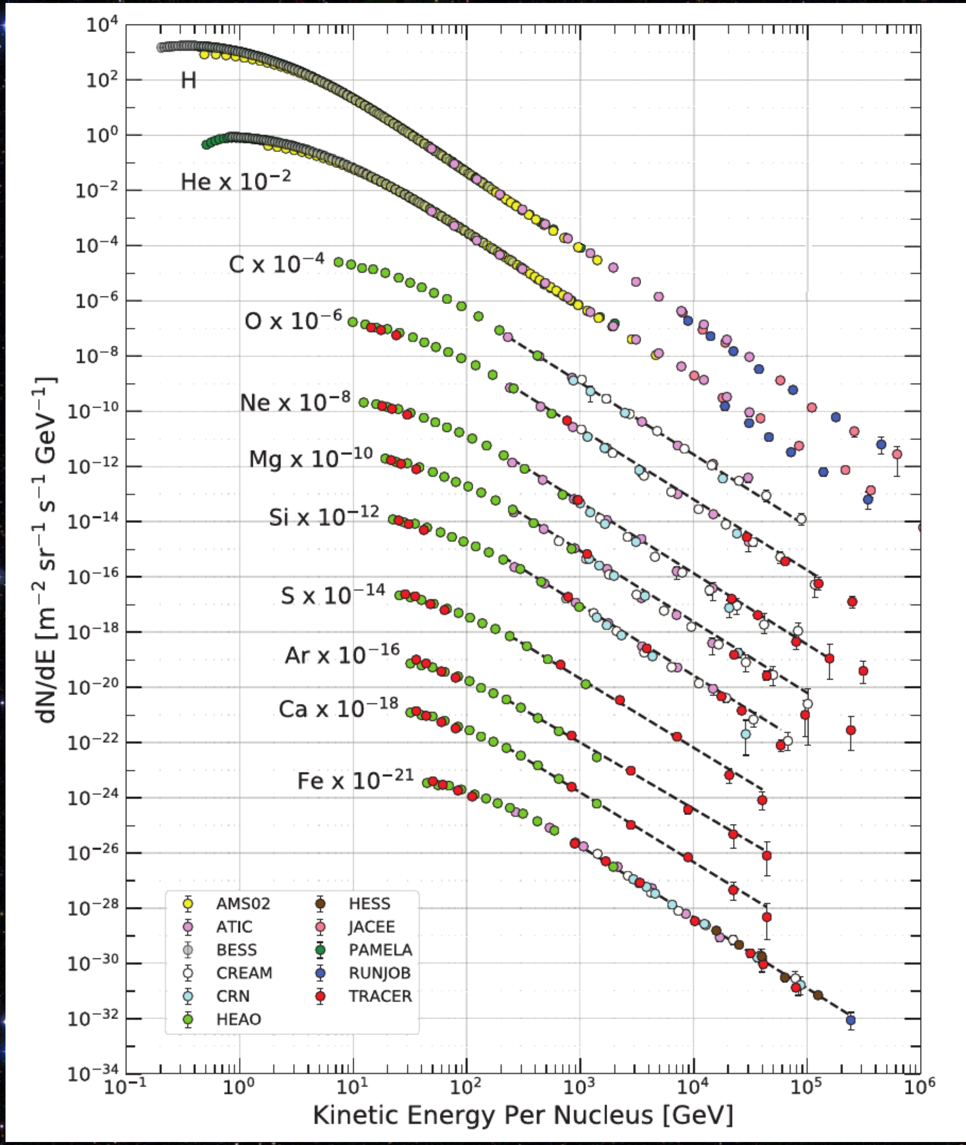
1940
1960
1980
2000
2020
Time (years)
11 y

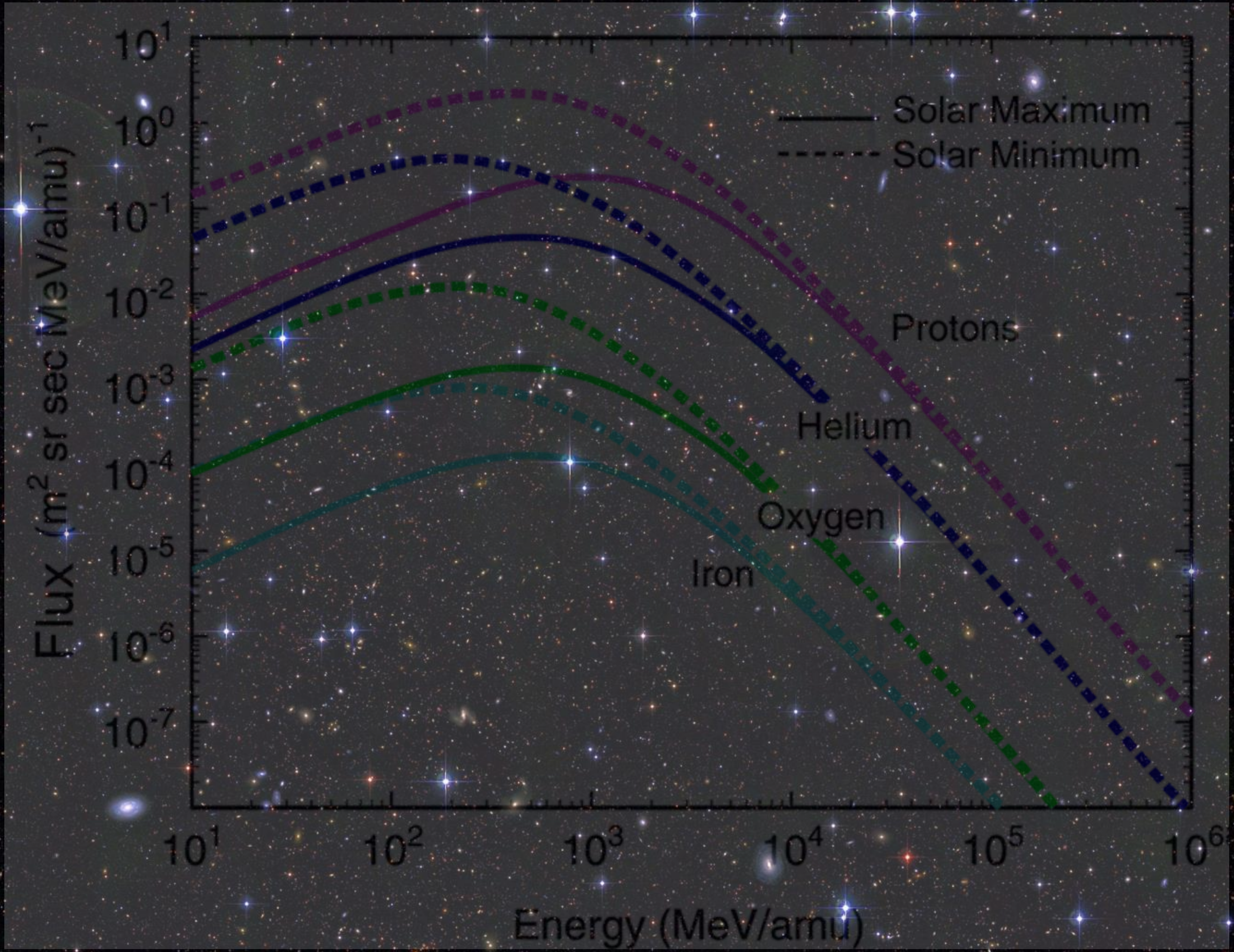
Solar Energetic Particles



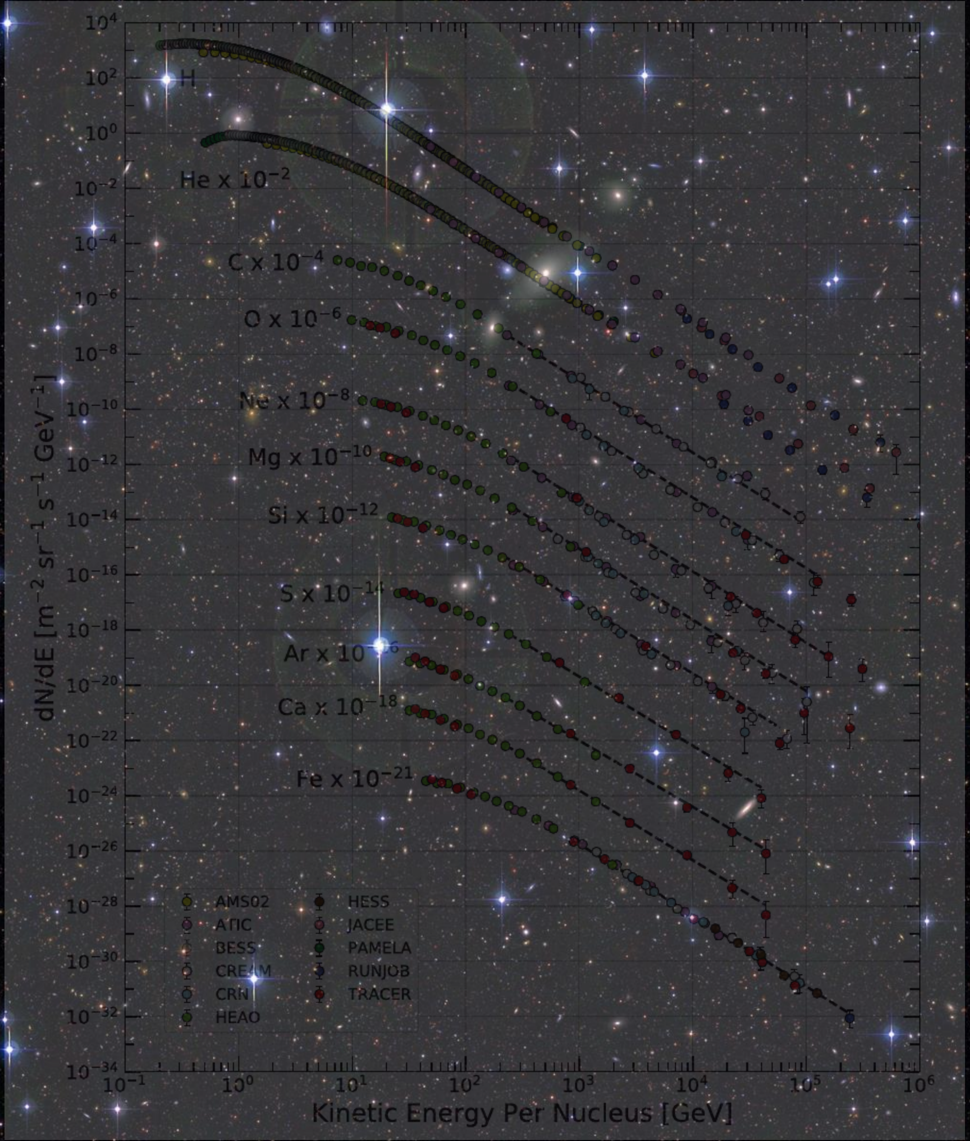
Galactic Cosmic Rays



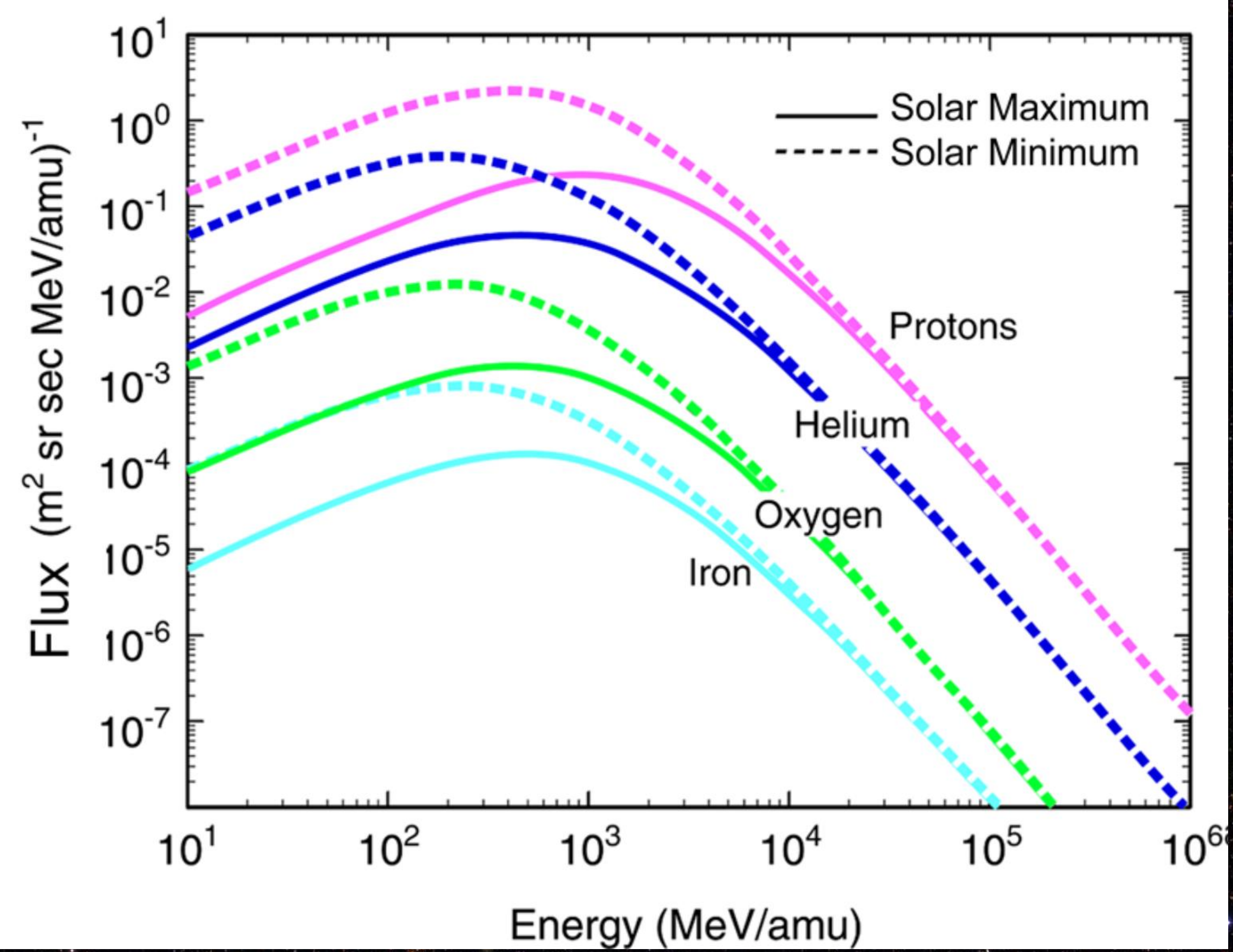
$$Rigidity = \frac{pc}{Ze}$$



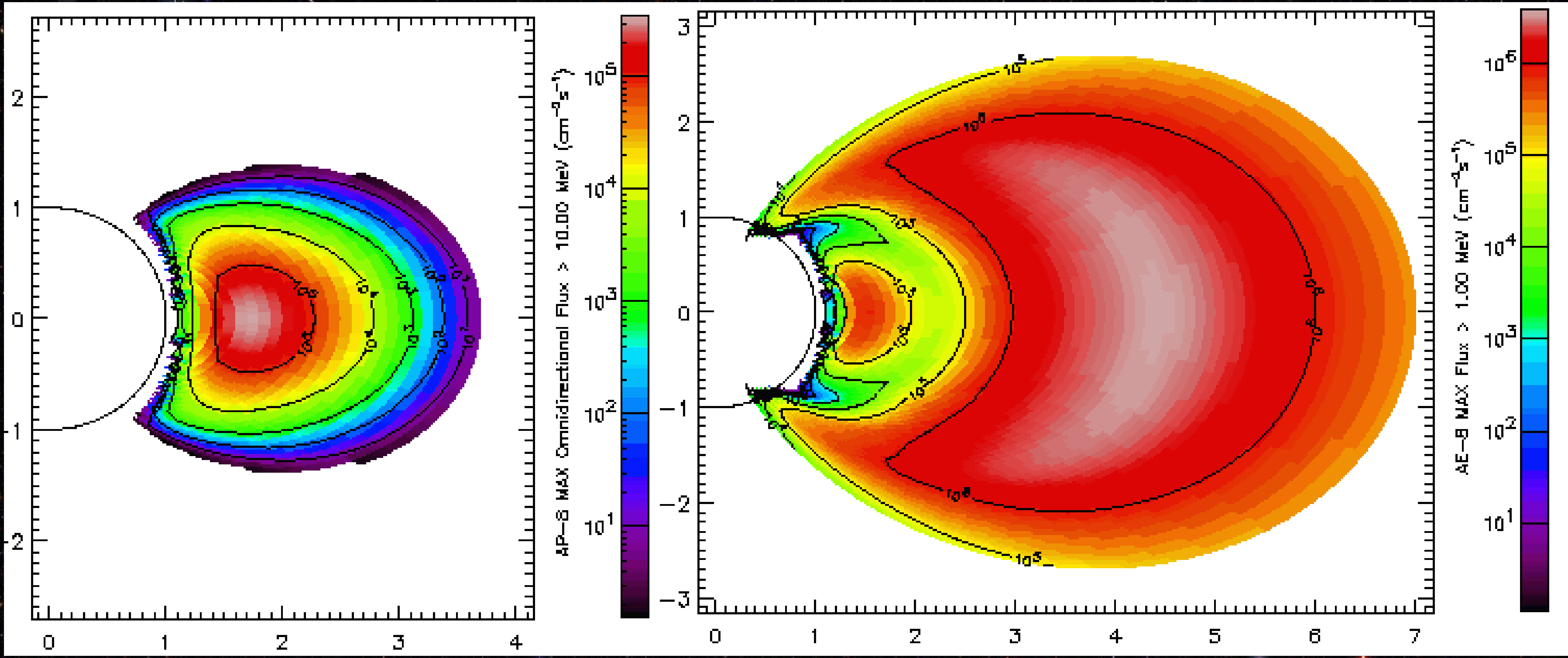
Galactic Cosmic Rays



$$Rigidity = \frac{pc}{Ze}$$

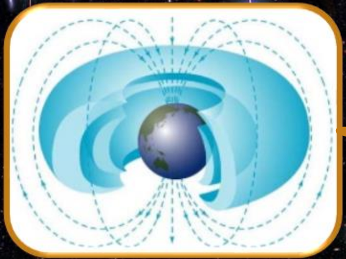


Trapped belts



Space Radiation Environment

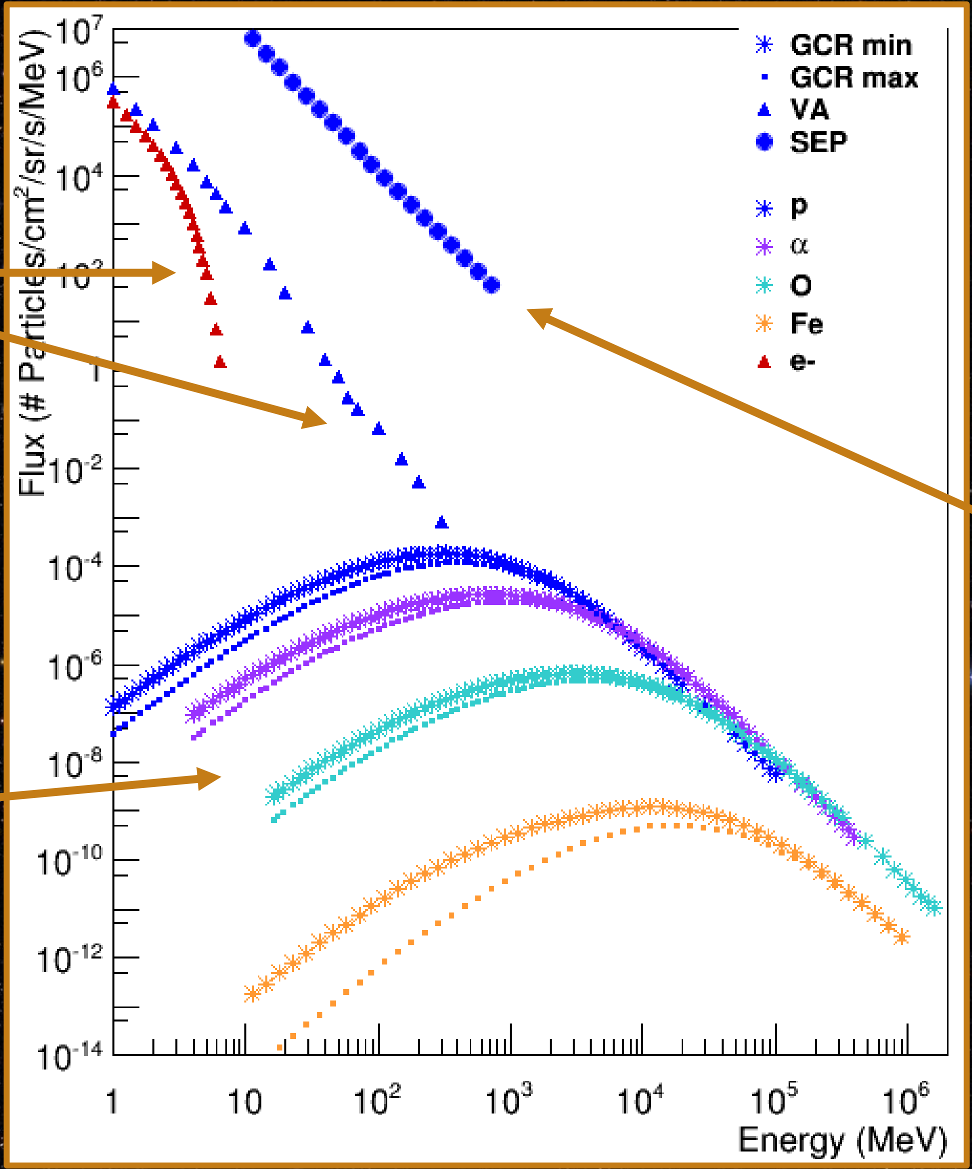
Van Allen Radiation Belts



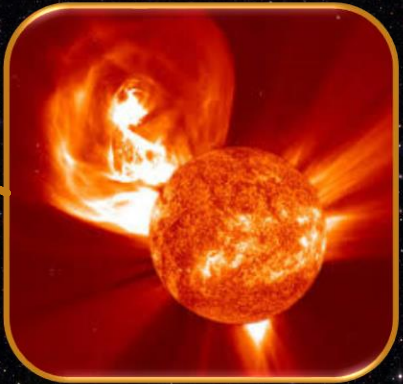
Protons and **electrons**
AP-8 and **AE-8** models

Galactic Cosmic Radiation (GCR)

p,a, 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

Planetary Science

Solar Physics

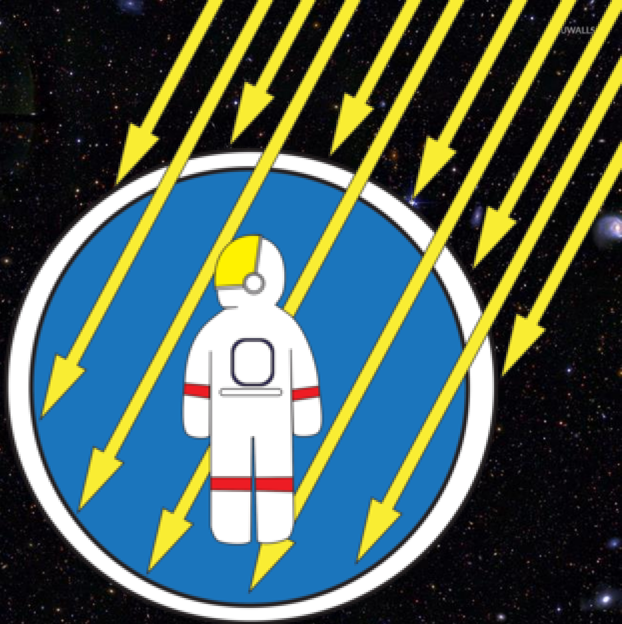
Astrophysics

Why does it matter?

Astronaut safety

Mission reliability

Radiation Effects



Cumulative

Premature aging

Cataracts

Increased cancer risk

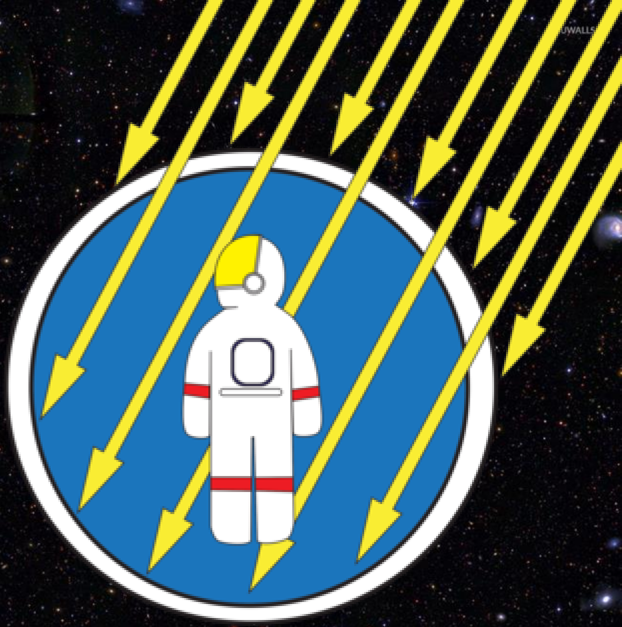
Acute

Impaired eye-sight

Psychological distress

Radiation sickness

Radiation Effects



~ 2.4 mSv annual dose from natural sources on Earth

20 mSv annual limit for radiation workers on Earth

Career Exposure Limits for NASA Astronauts by Age and Gender*				
Age (years)	25	35	45	55
Male	1.50 Sv	2.50 Sv	3.25 Sv	4.00 Sv
Female	1.00 Sv	1.75 Sv	2.50 Sv	3.00 Sv

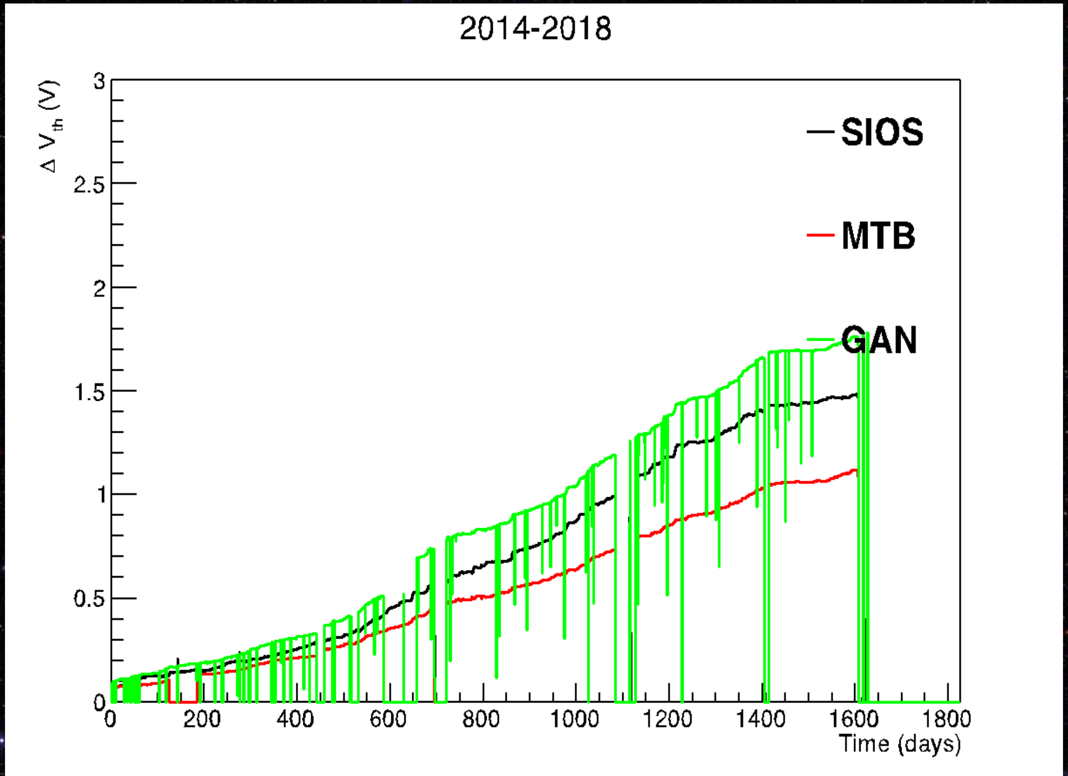
Mission Type	Radiation Dose
Space Shuttle Mission 41-C (8-day mission orbiting the Earth at 460 km)	5.59 mSv
Apollo 14 (9-day mission to the Moon)	11.4 mSv
Skylab 4 (87-day mission orbiting the Earth at 473 km)	178 mSv
ISS Mission (up to 6 months orbiting Earth at 353 km)	160 mSv
Estimated Mars mission (3 years)	1,200 mSv

Radiation Effects

Cumulative

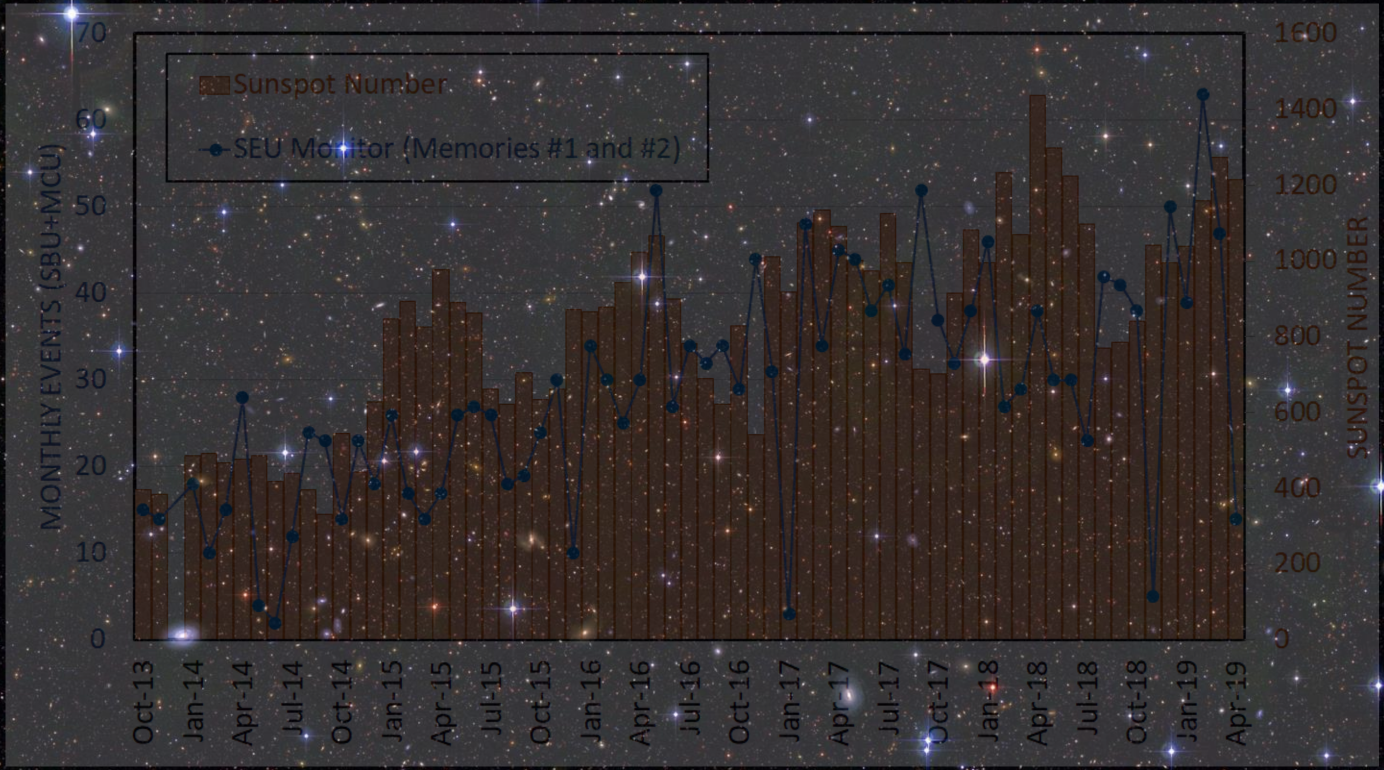
Total Ionizing Dose – TID

Displacement Damage Dose – DDD



Acute

Single Event Effects – SEE



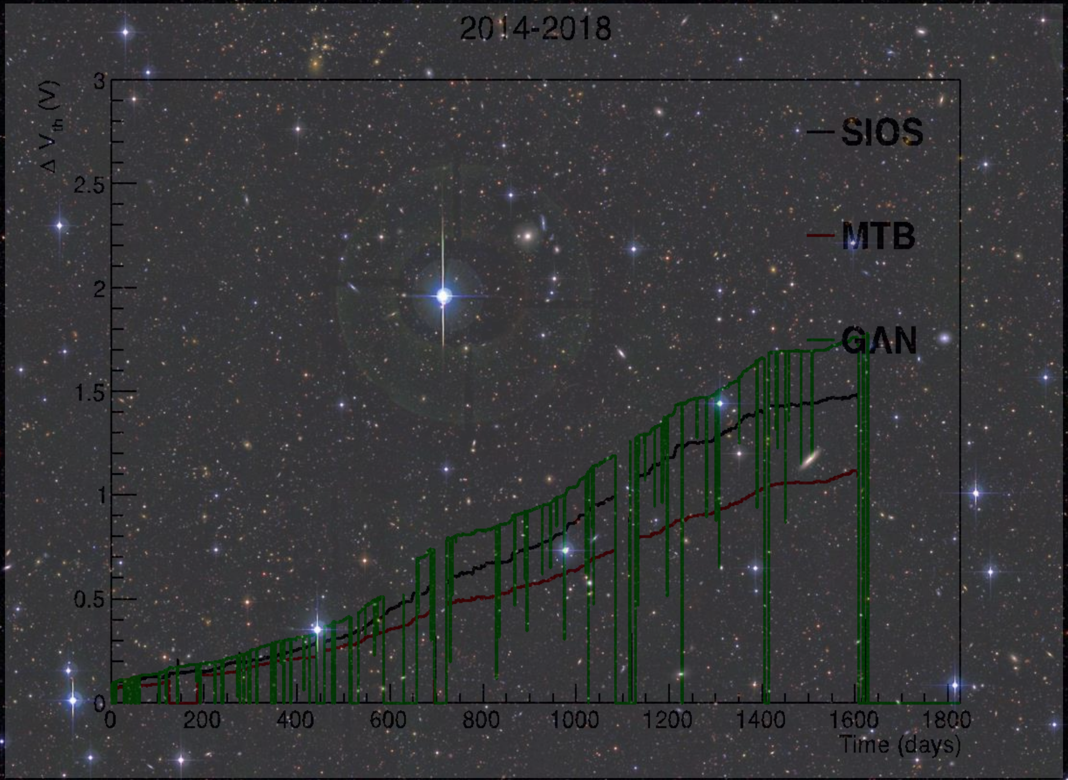
DOI: 10.1109/TNS.2019.2900398

Radiation Effects

Cumulative

Total Ionizing Dose – TID

Displacement Damage Dose – DDD



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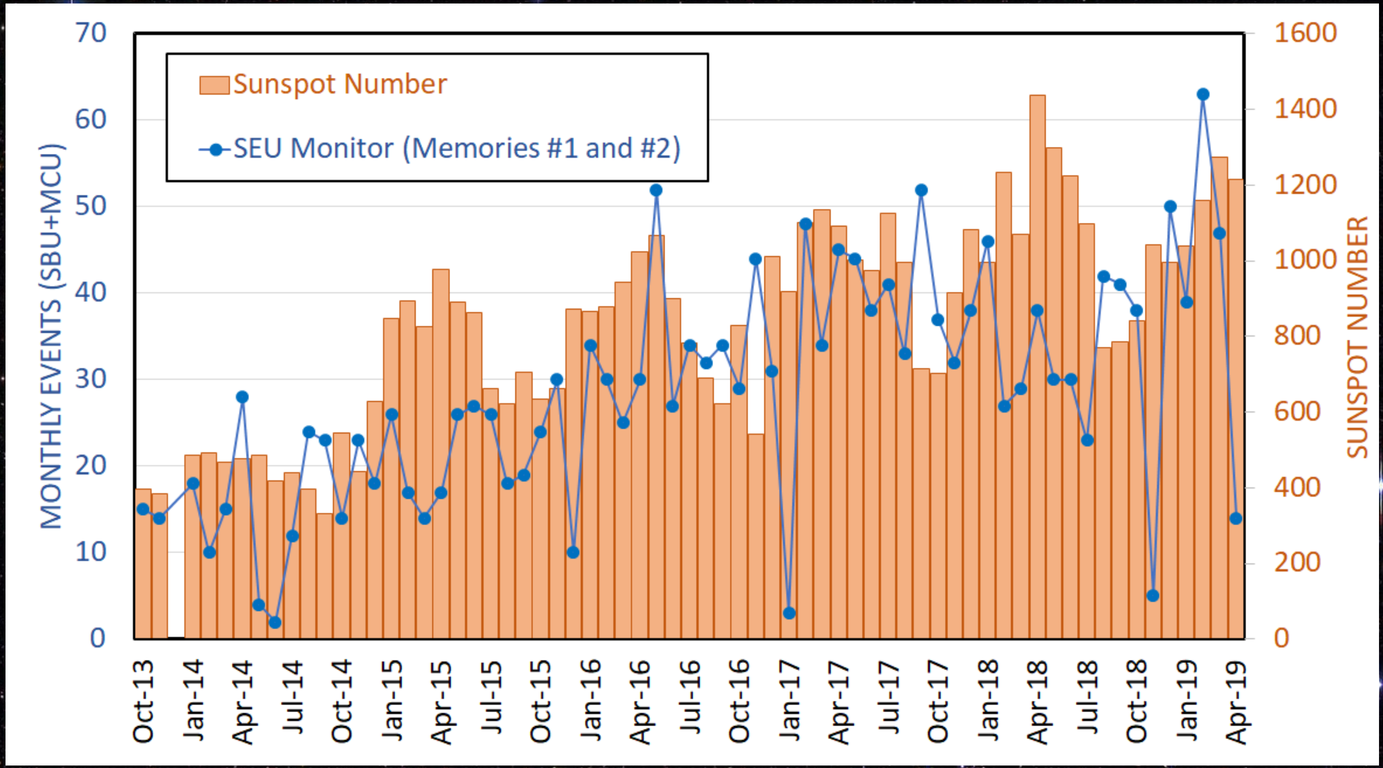

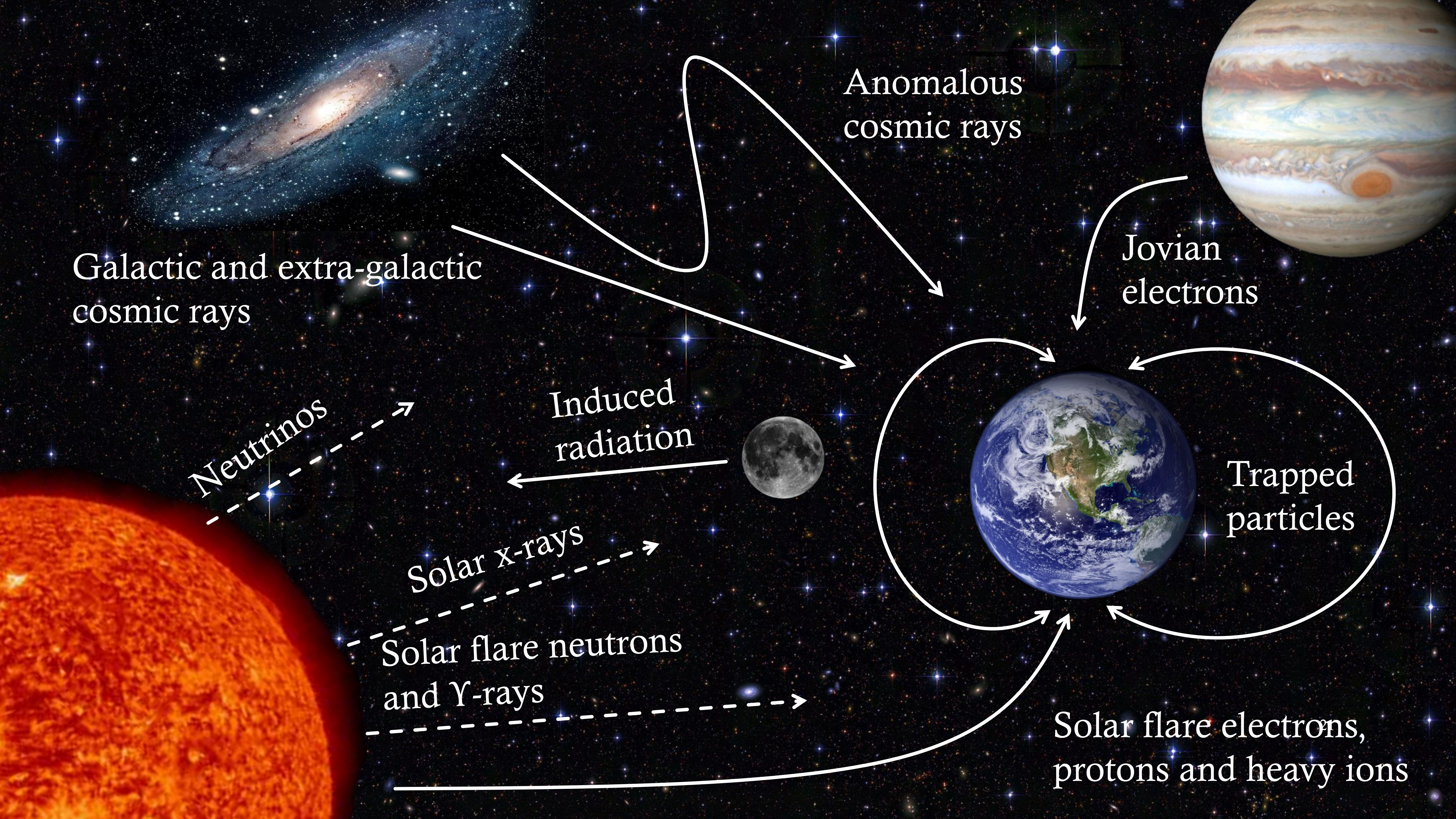
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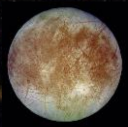
The JUICE Mission

Cosmic Vision (2015-2025)
L-class Mission

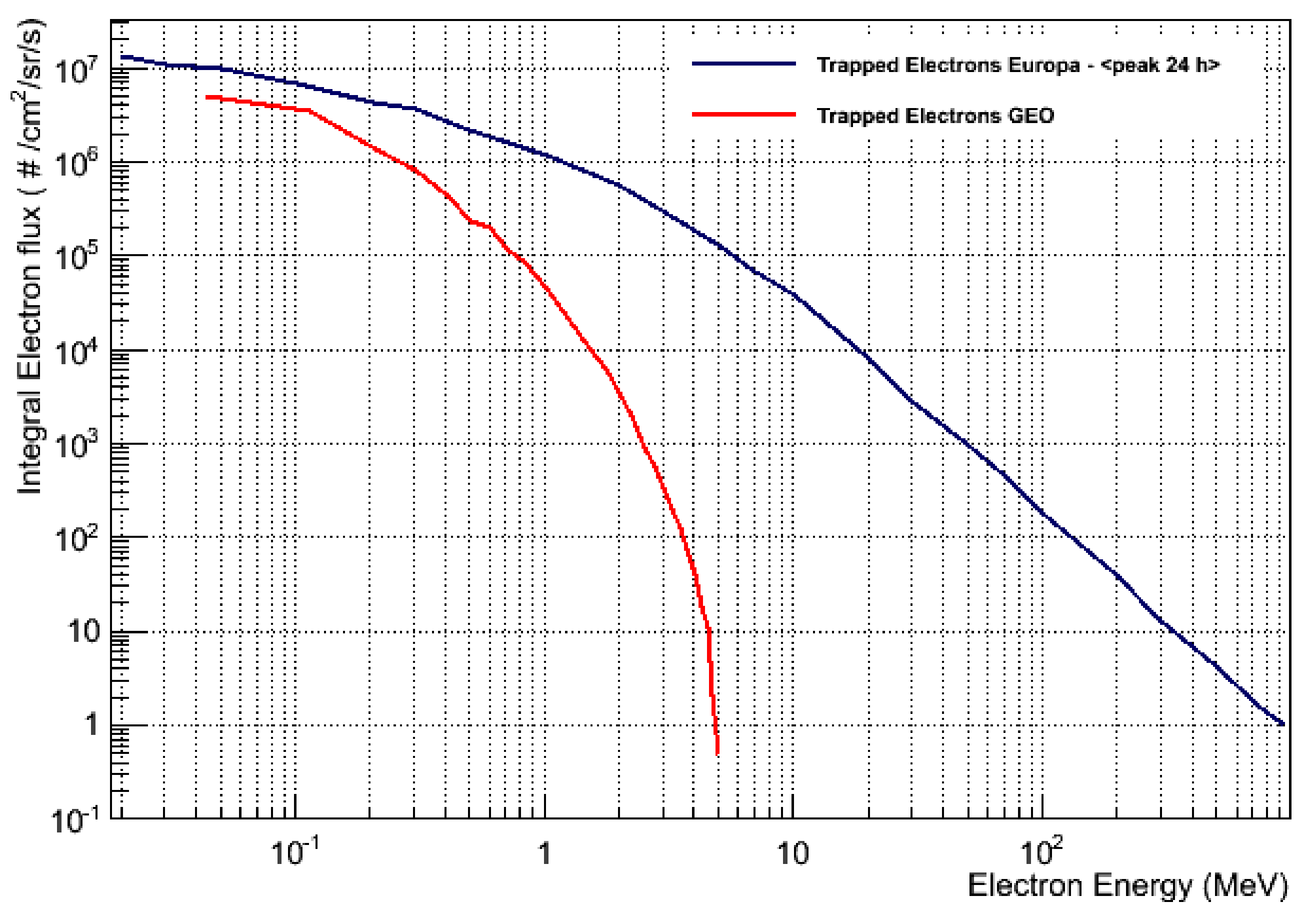
Arrival
2030

Launch
2022

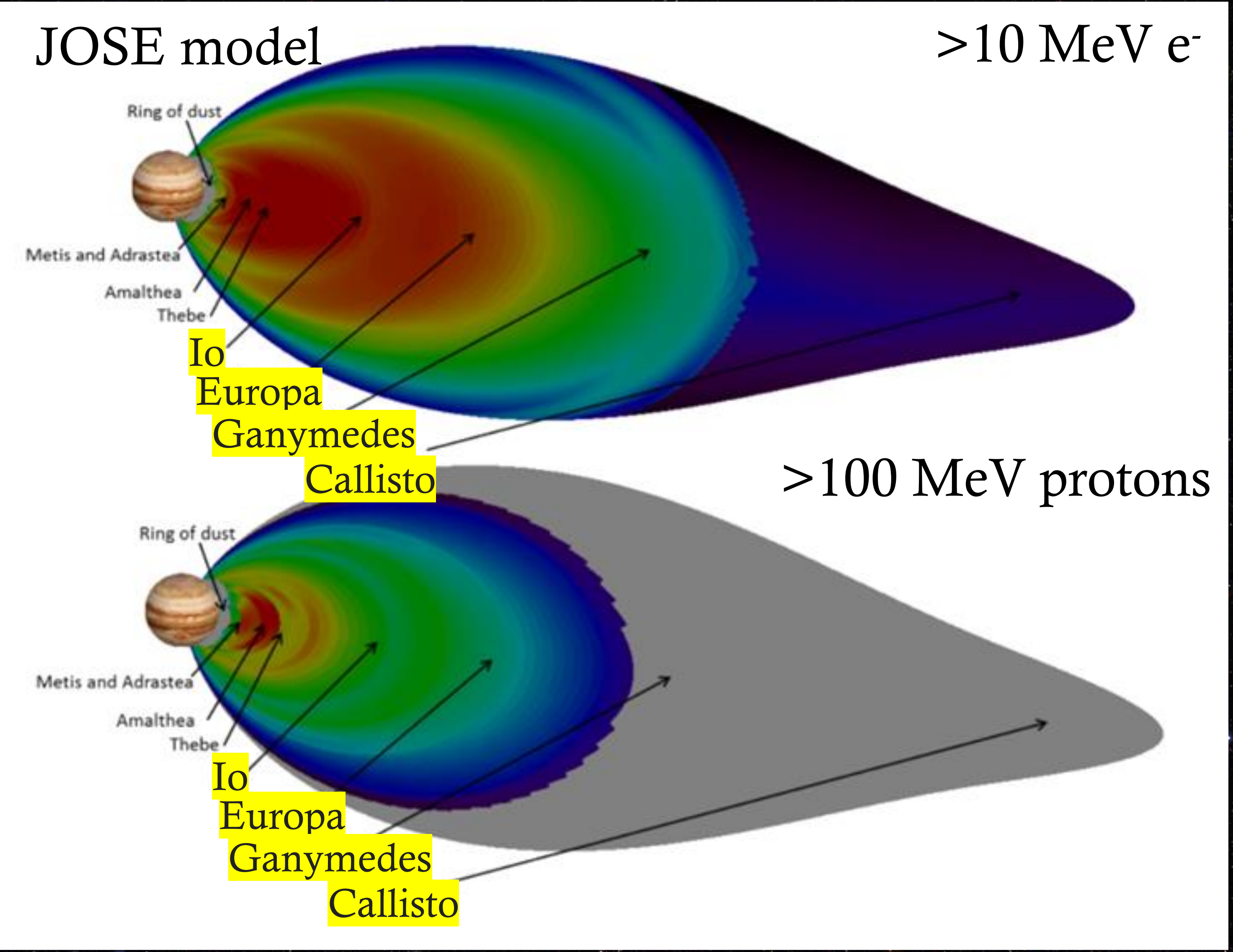


End
2033

Radiation Environment

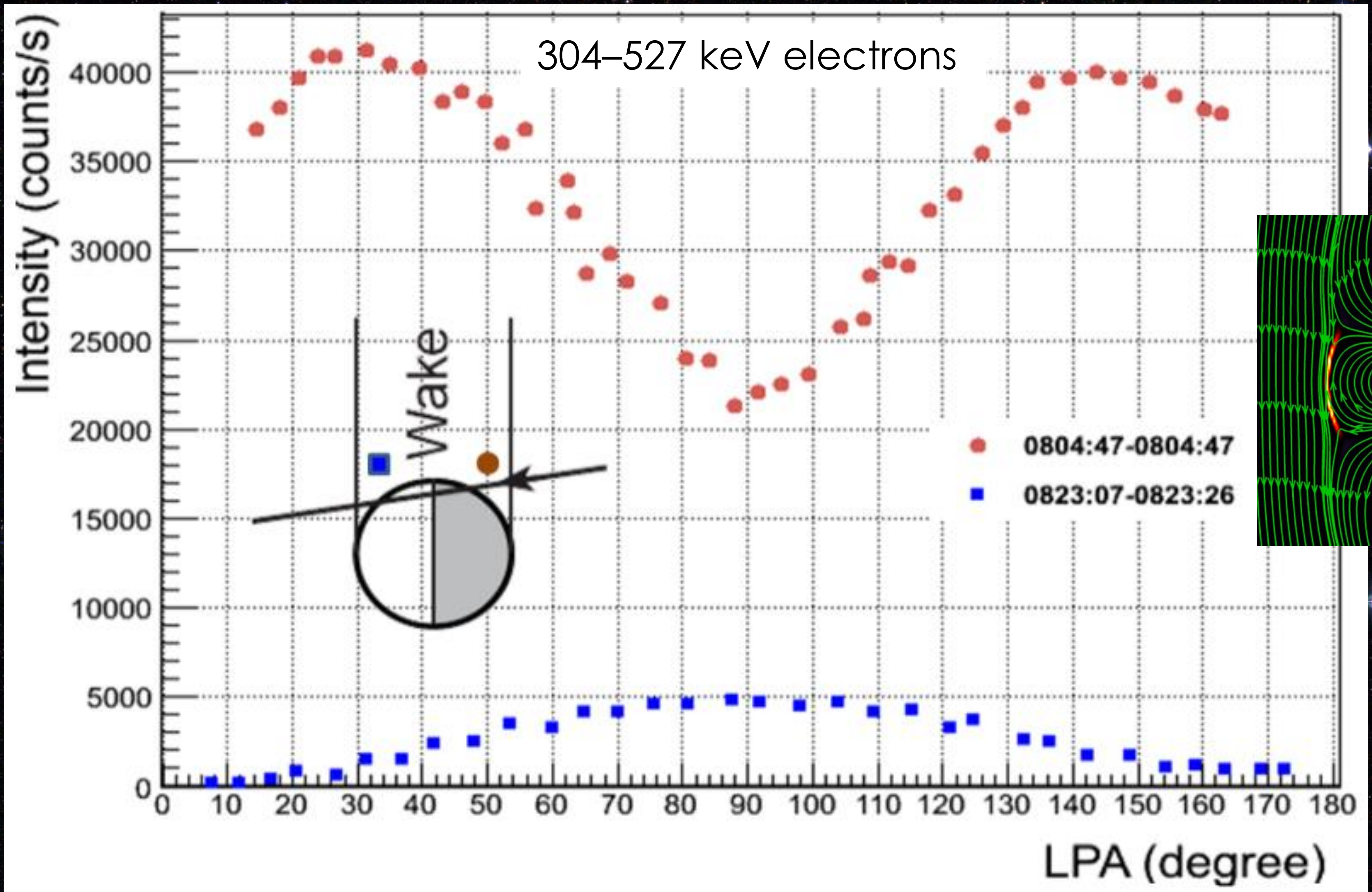


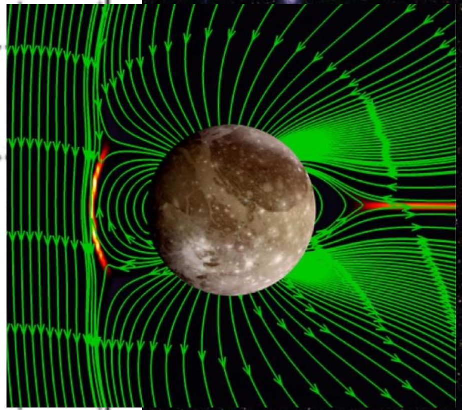
Radiation Environment



Credit: S. Bourdarie @ 2014 NSREC course

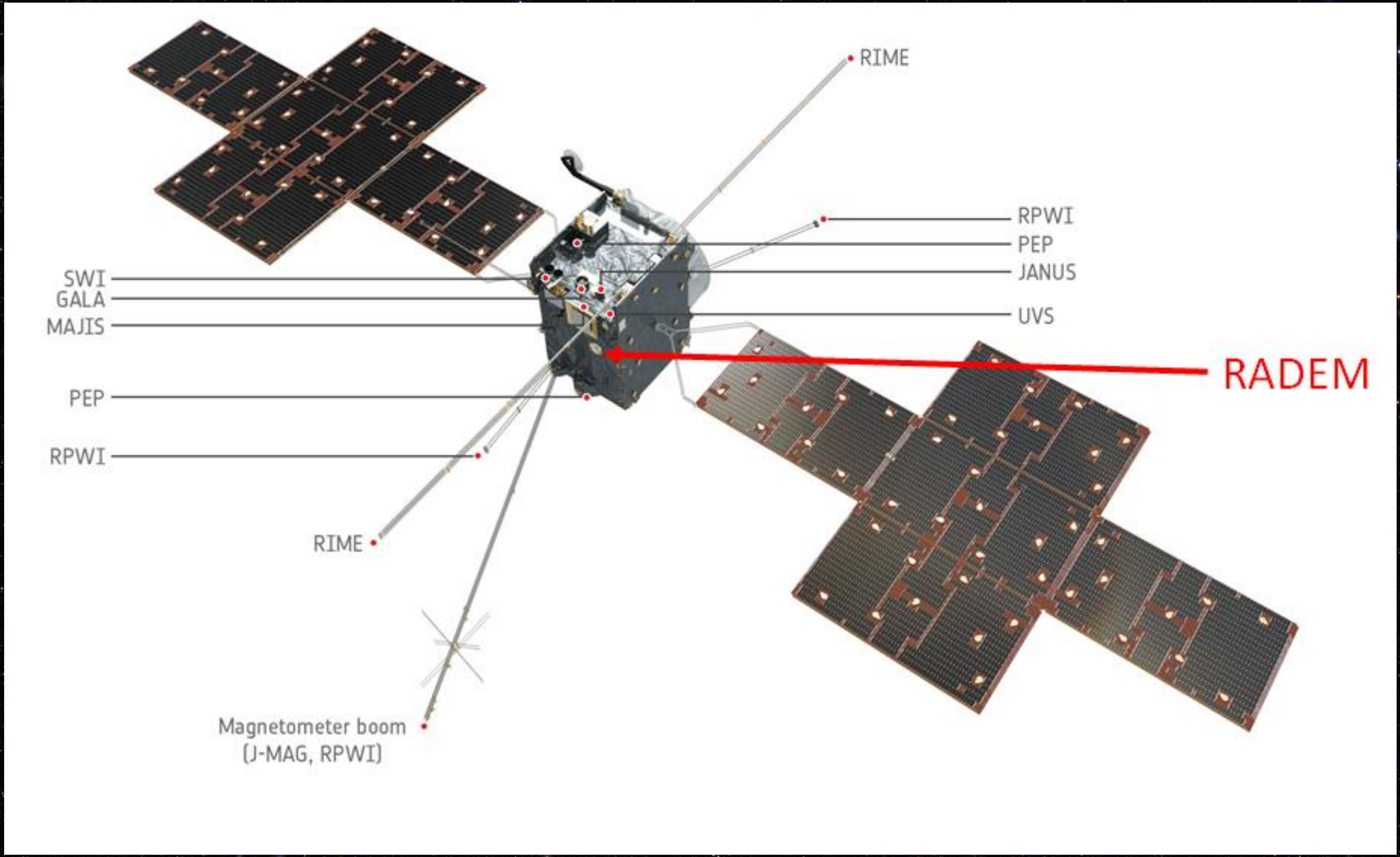
Radiation Environment





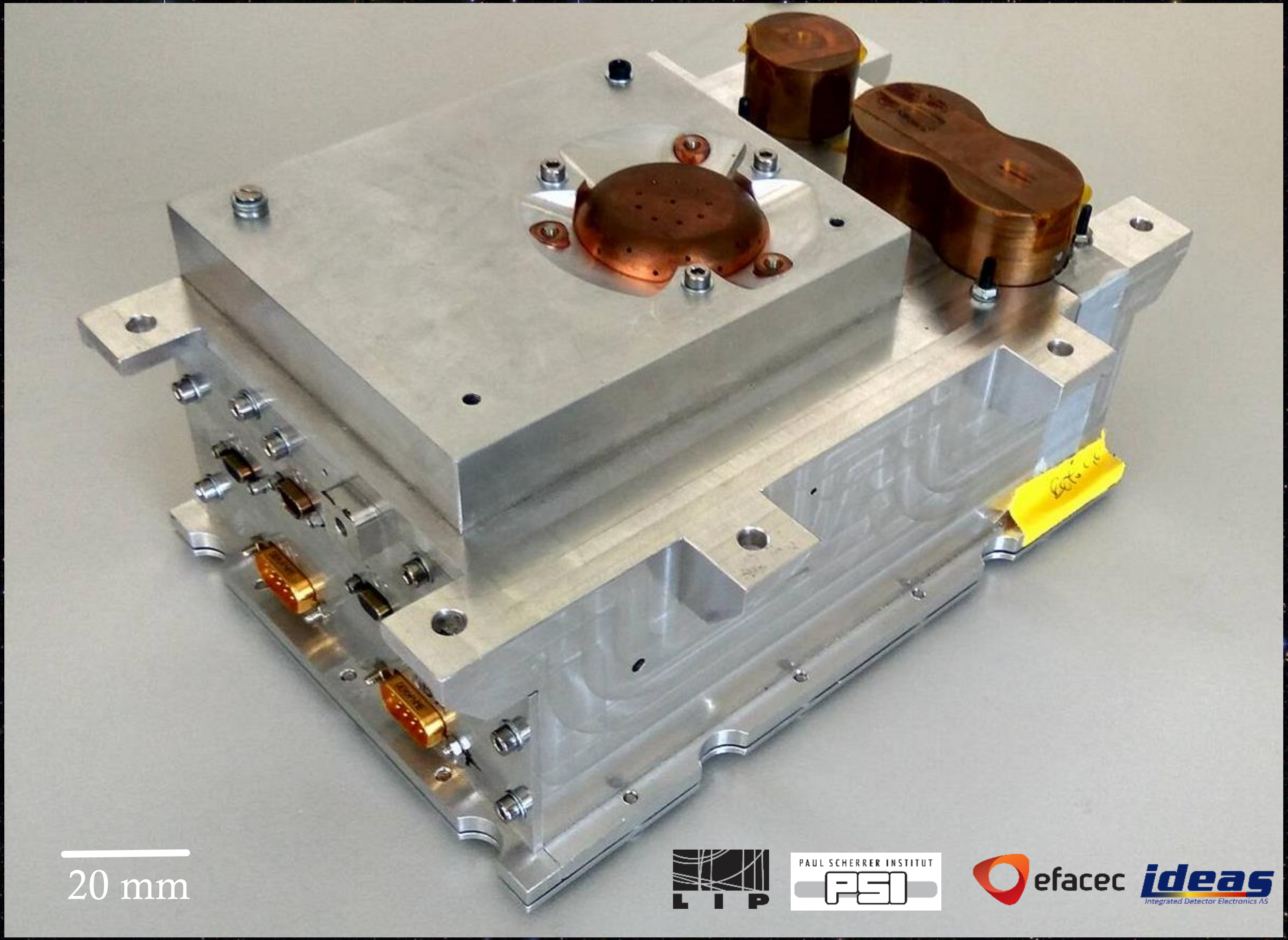
DATA: EPD measurements
Galileo G29 encounter with Ganymede in December 2000

Scientific Instruments



RADEM

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



Electrons 0.3-40 MeV

Protons 5-250 MeV

Heavy Ions (its complicated)

Peak Fluxes to 10^9 p/cm^2/s

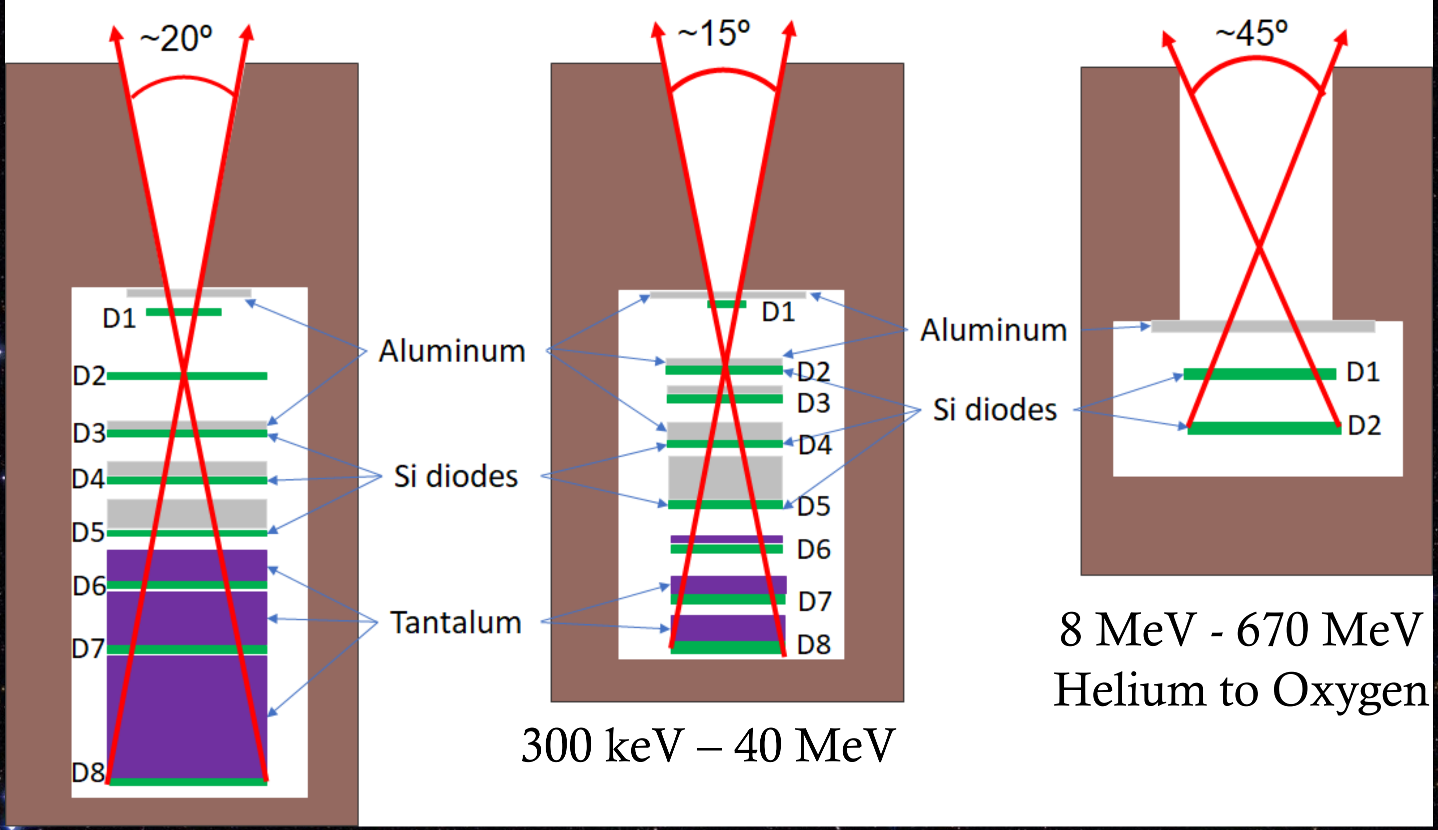
Dose assessment

RADEM – Detector Overview

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

New concept fully developed at LIP

Proton Detector (PDH) | Electron Detector (EDH) | Heavy Ion Detector (HIDH)

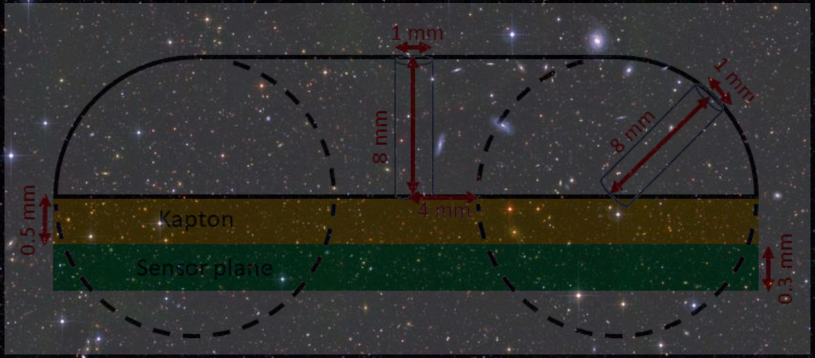


5 MeV– 250 MeV

300 keV – 40 MeV

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

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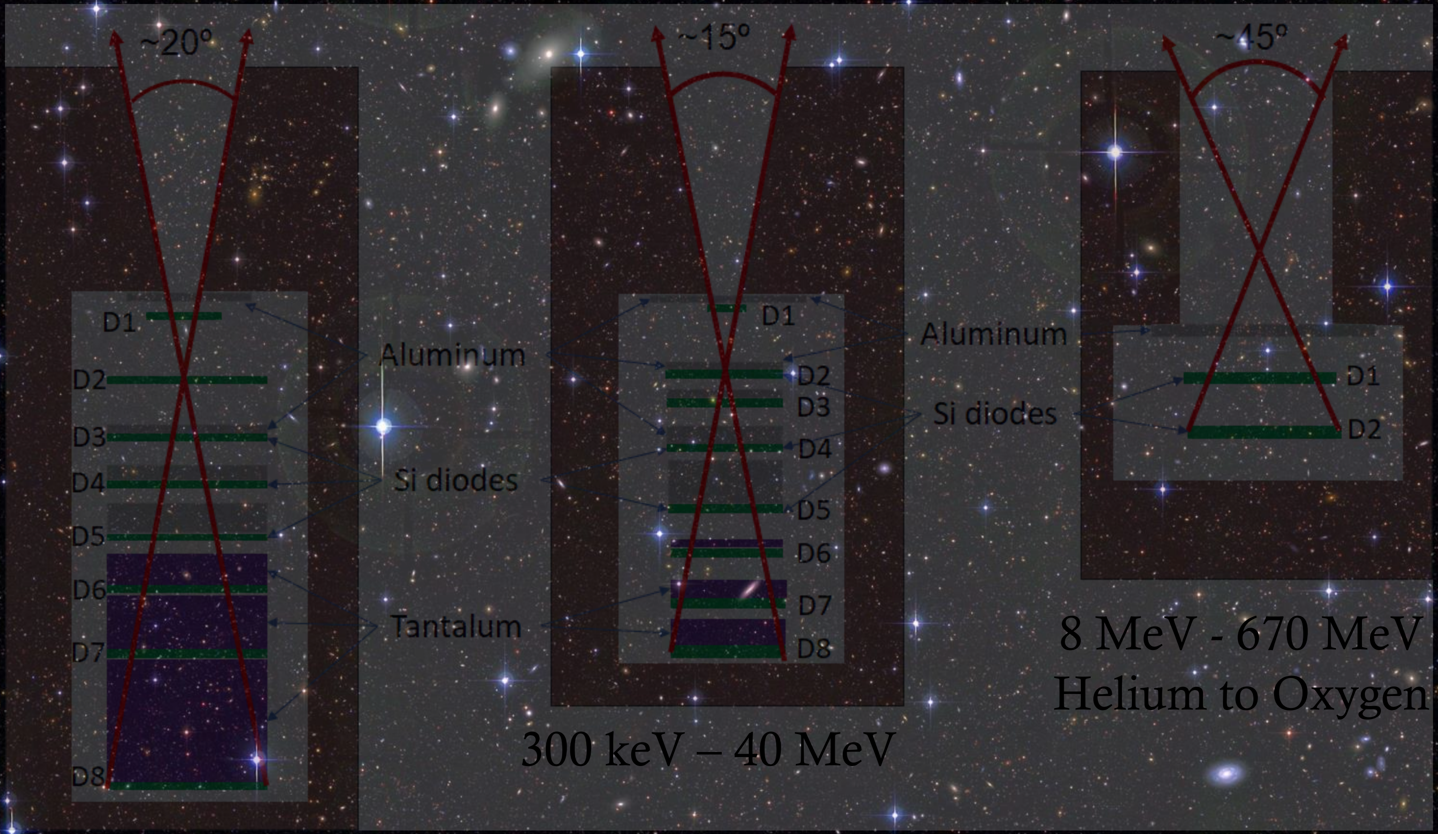

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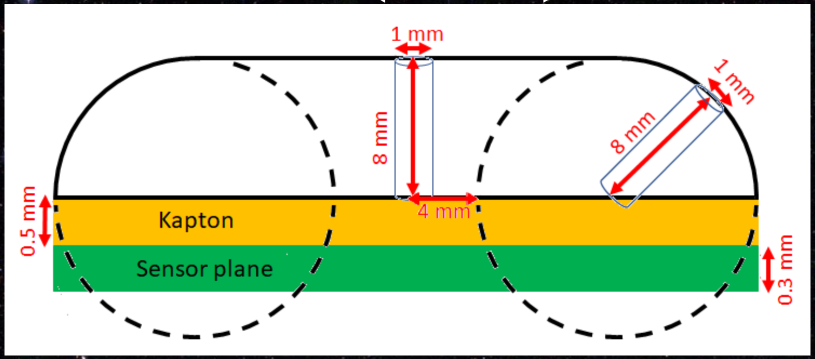

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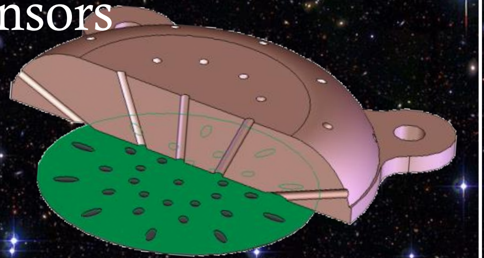
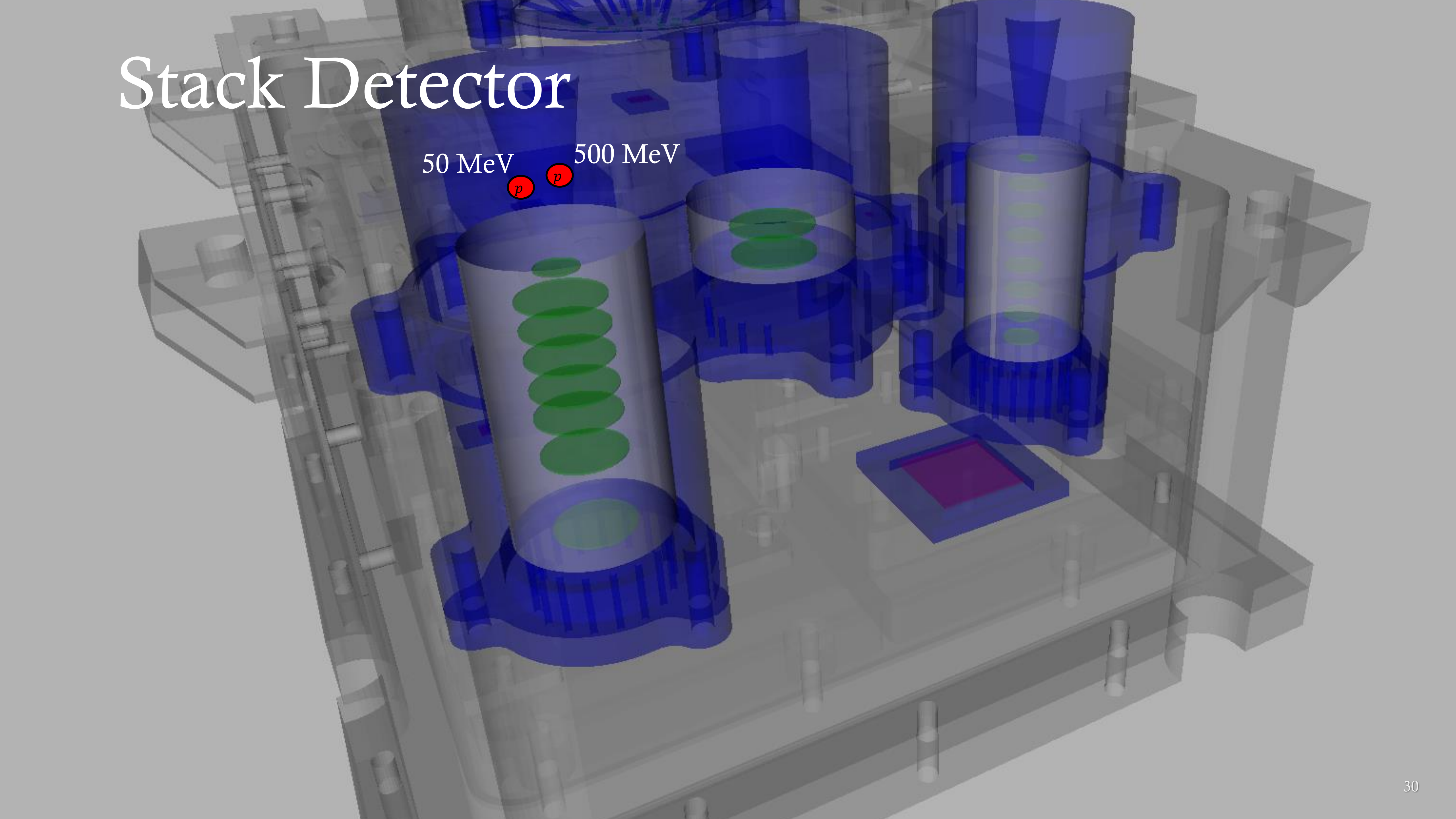
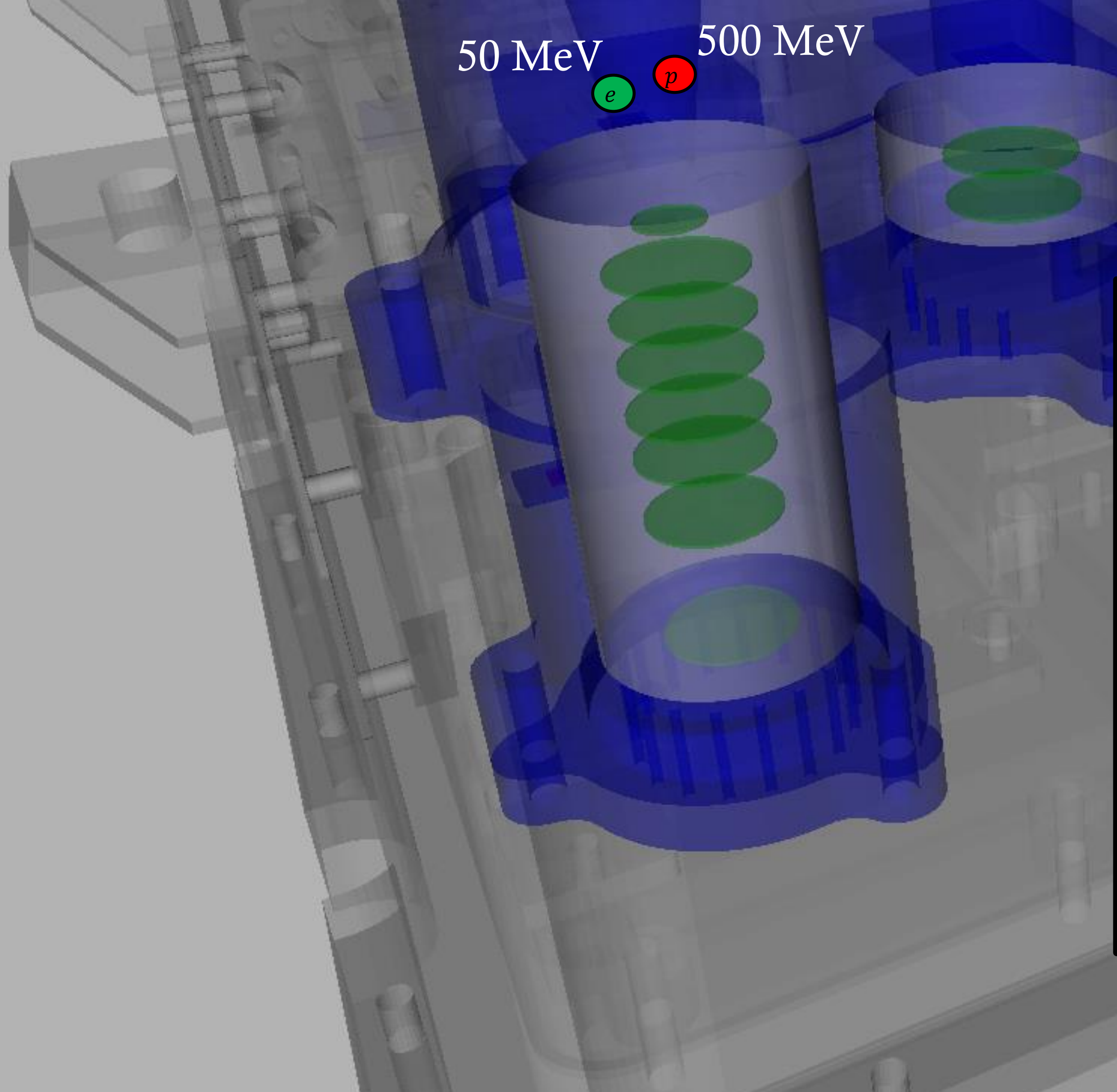
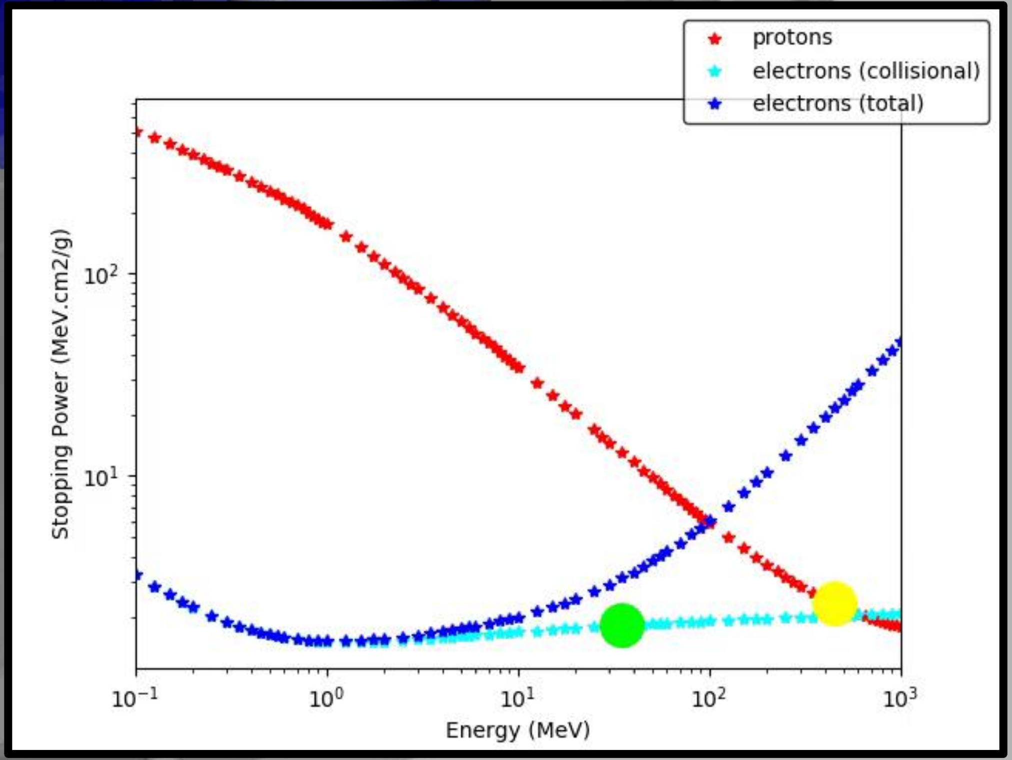


Stack Detector



Stack Detector





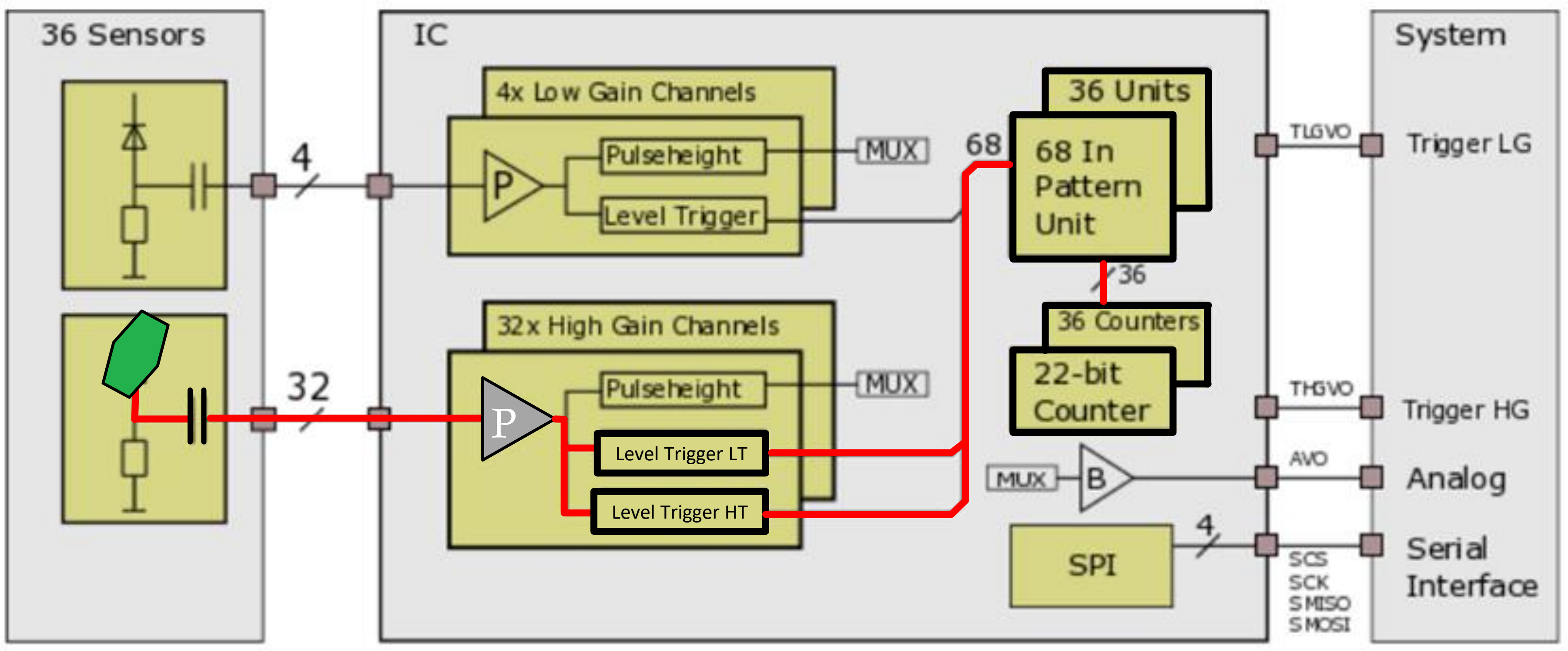
Readout

- ❑ 3x ASIC VATA 466 – developed specifically for RADEM
  - PDH+HIDH
  - EDH
  - DDH

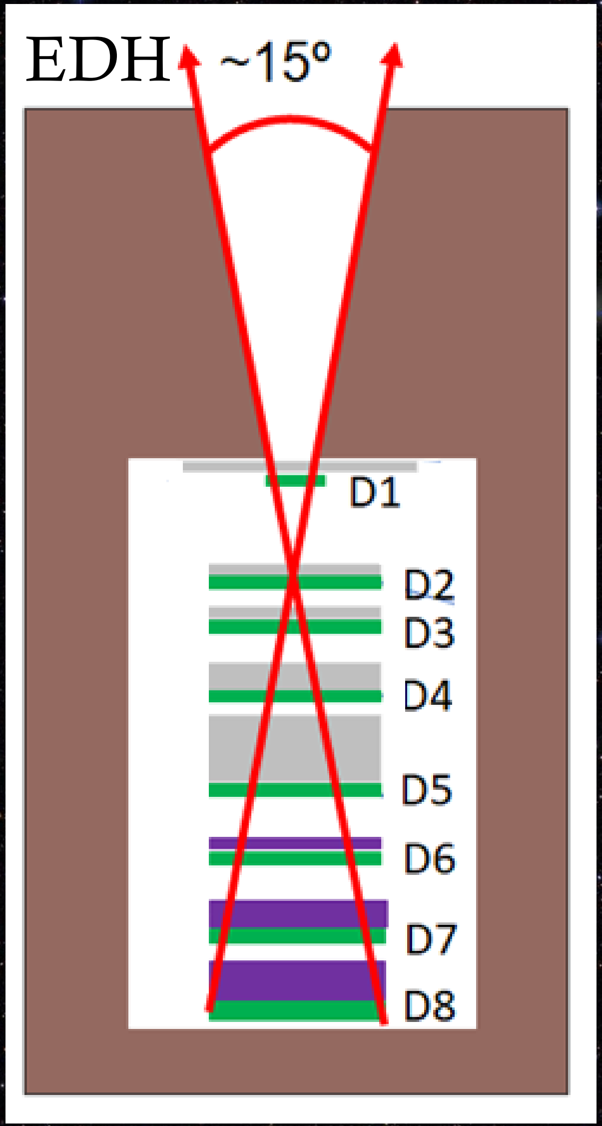
1 MHz max count rate

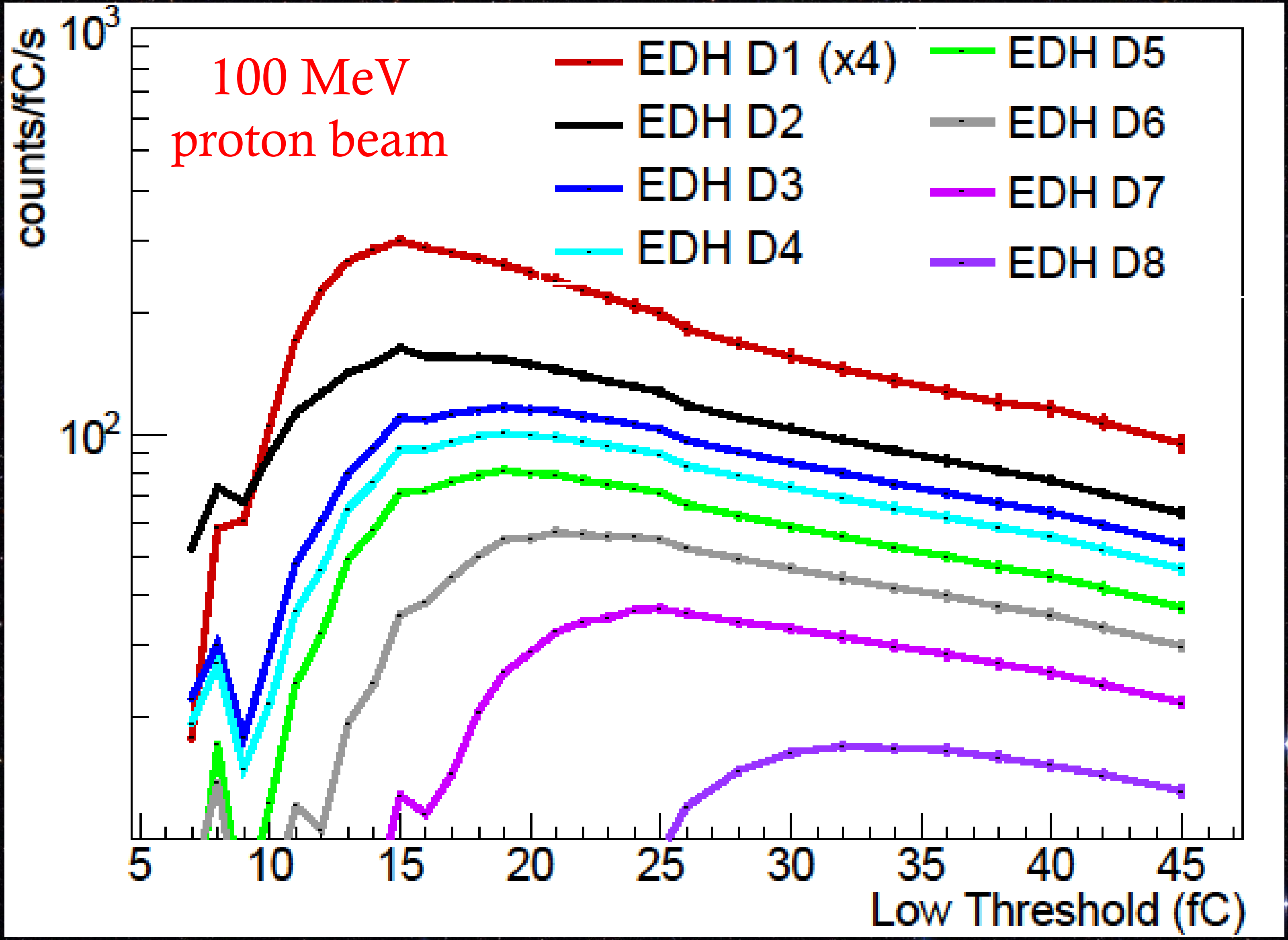
❑ Programable Low and High Thresholds

❑ Coincidence Logic



Beam tests





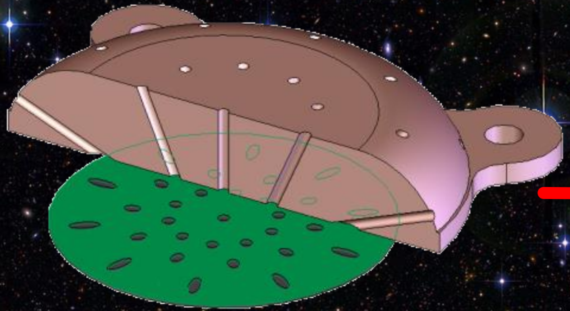
(M. Pinto et al., DOI: https://doi.org/10.1016/j.nima.2019.162795)

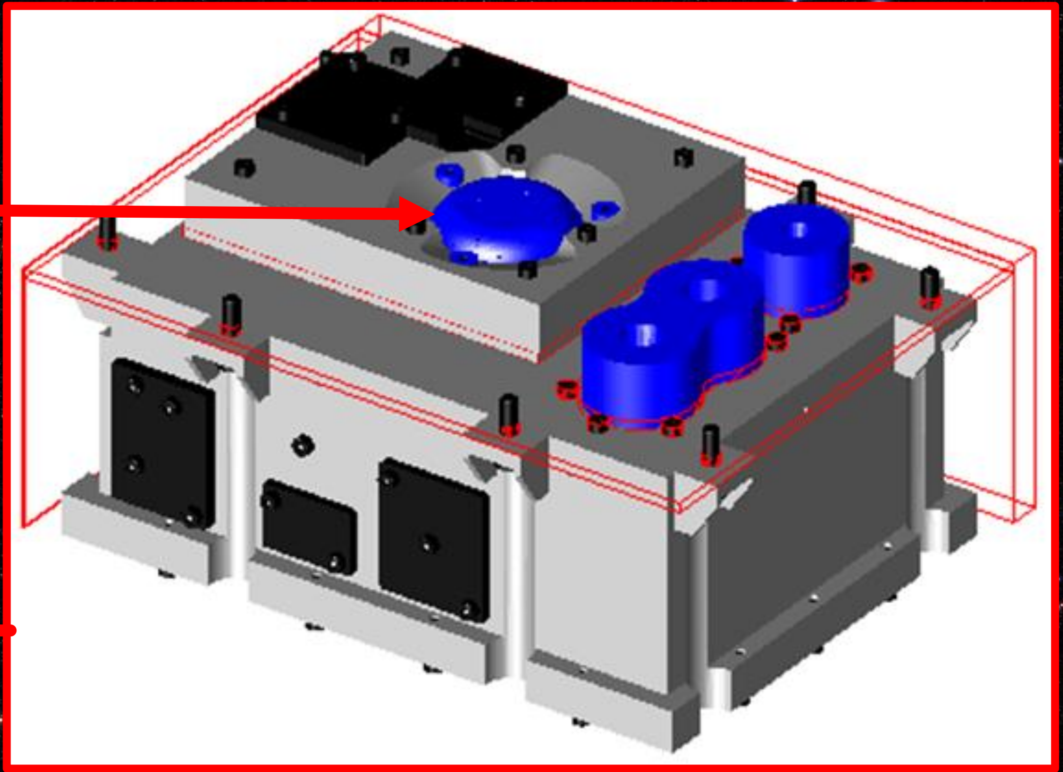
Developing Directionality Detector

Design studied with Geant4

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

3 background sensors

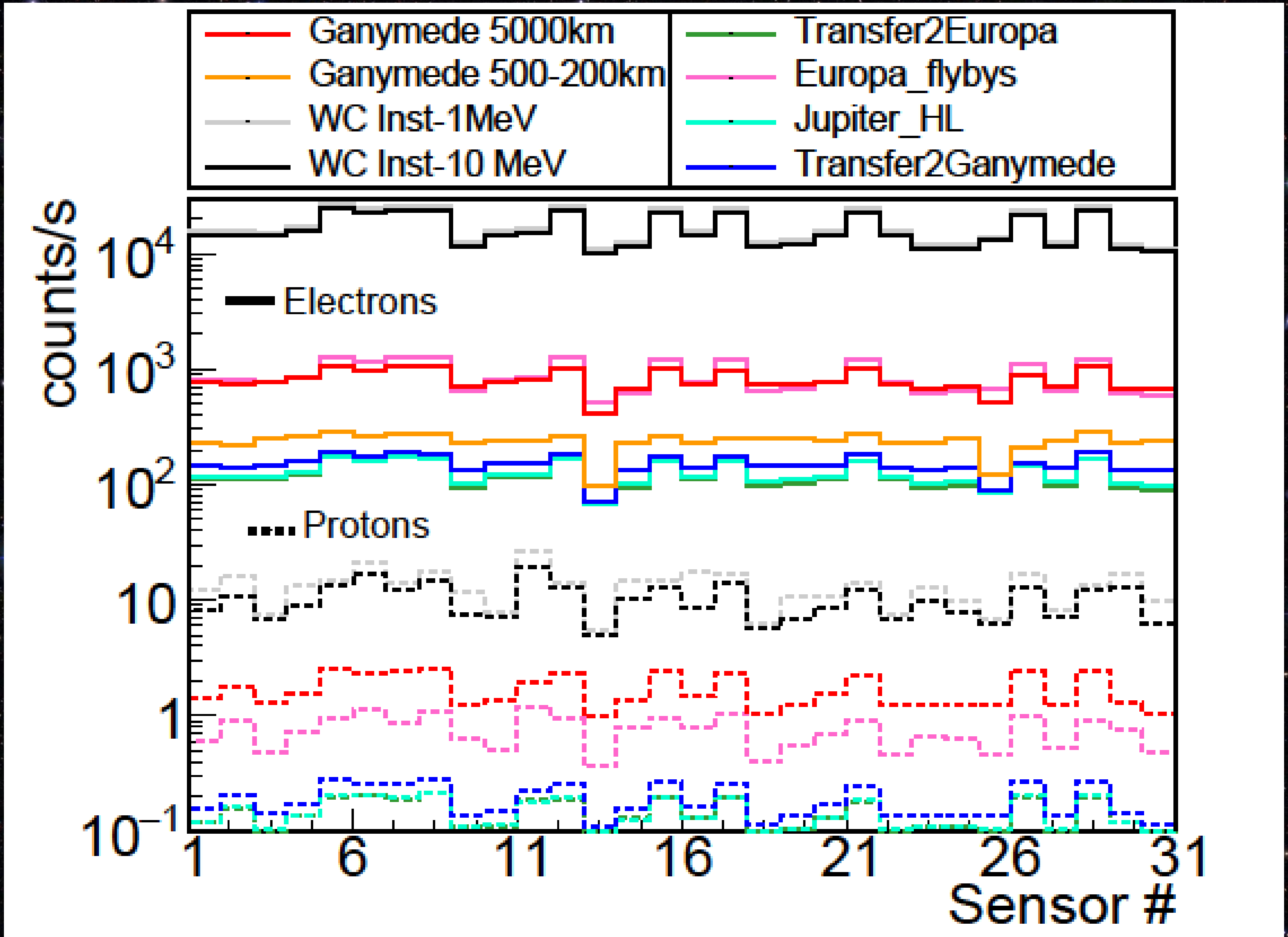




>700 solids
GUIMesh tool developed

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

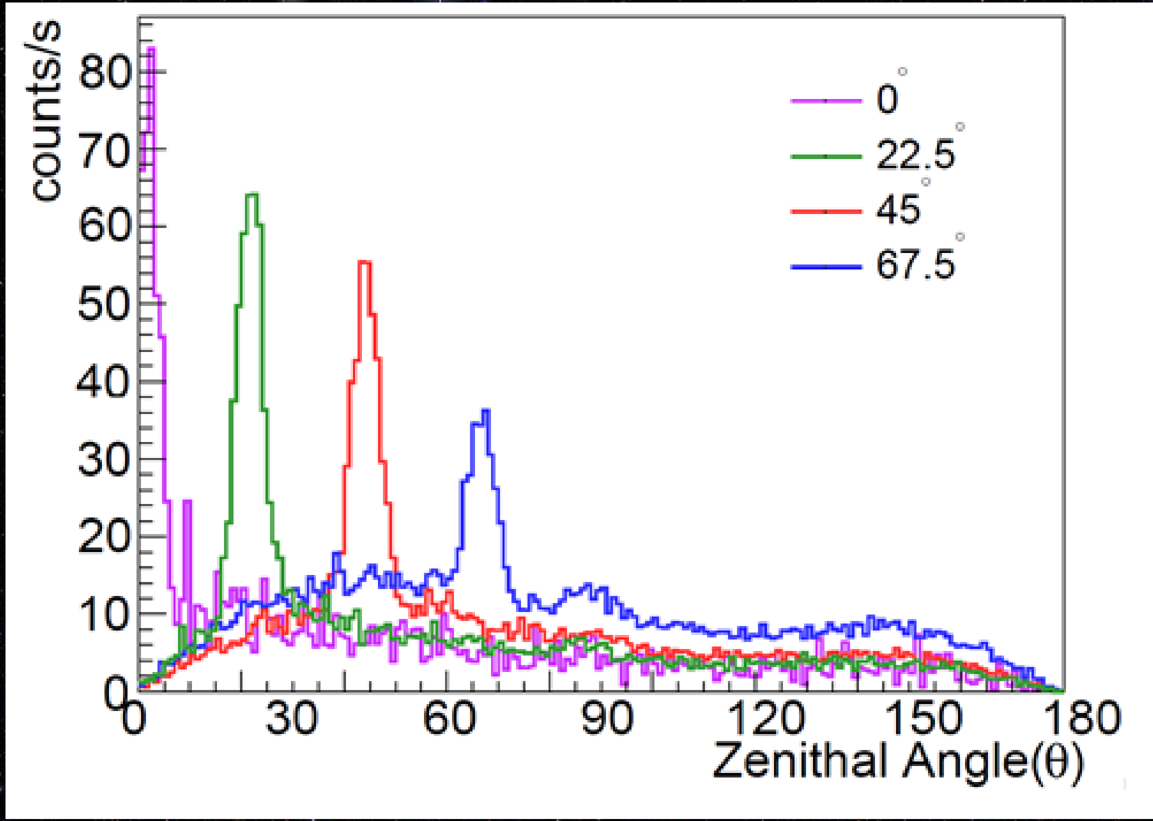
DDH – Count rate



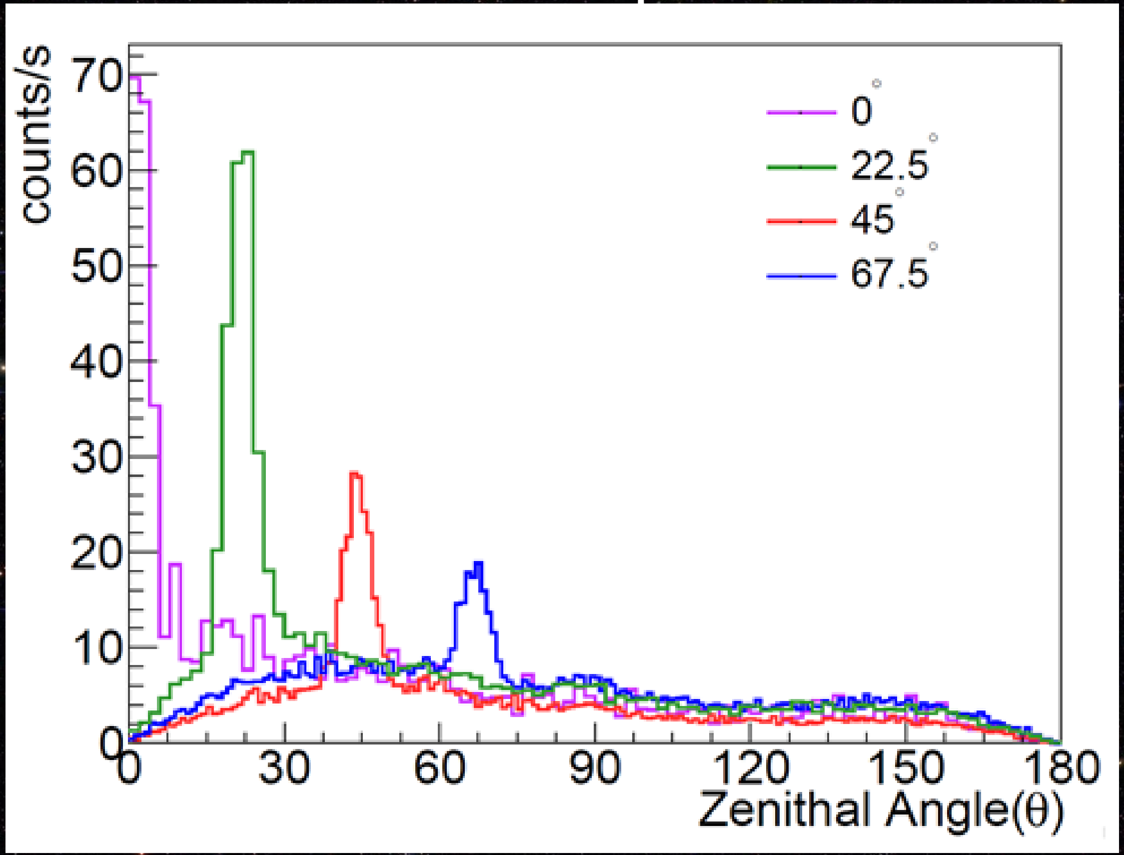
(M. Pinto et al, DOI: 10.1109/TNS.2019.2900398)

DDH – Baseline Directional Response

Ganymede



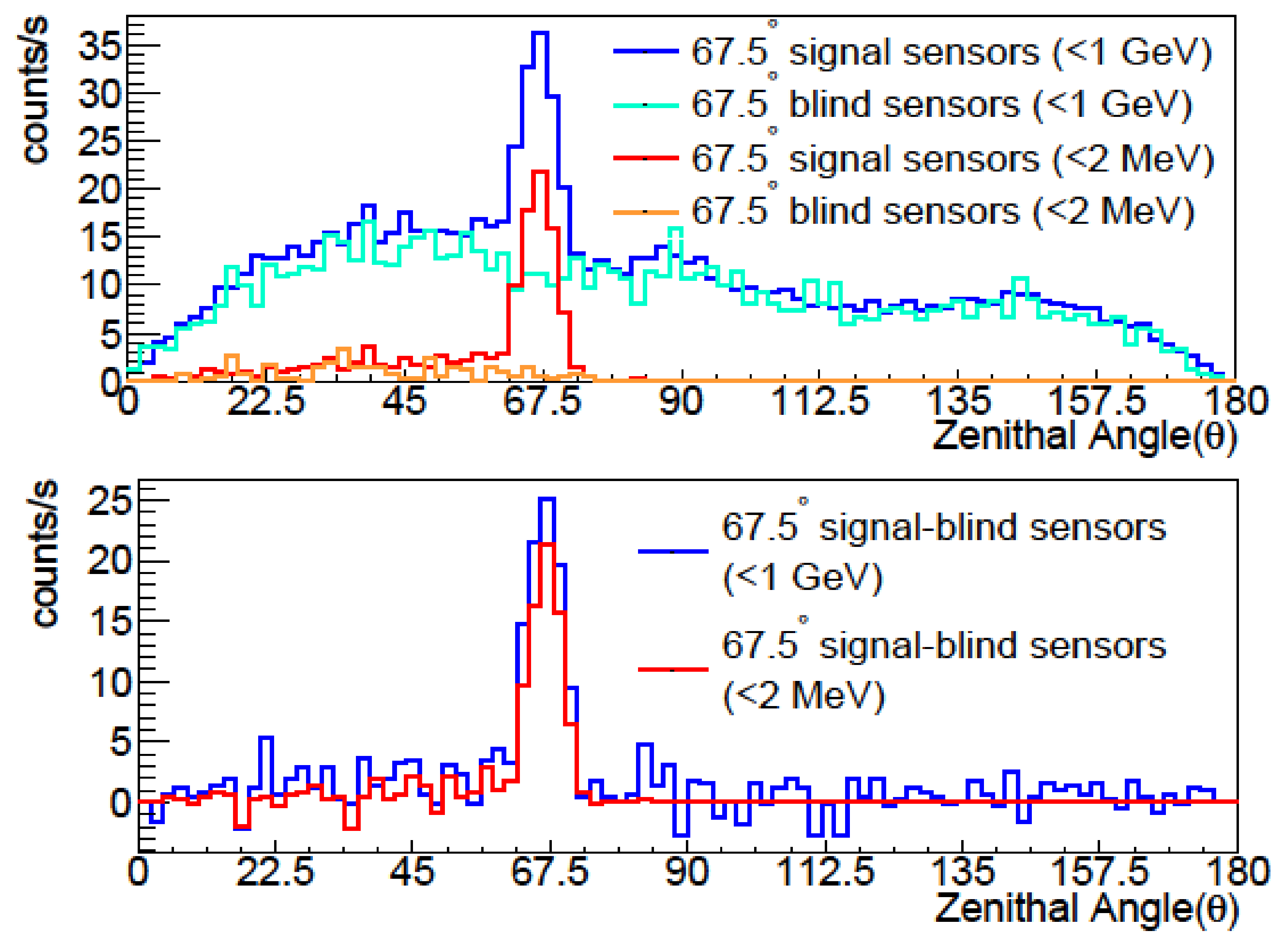
Europa



Directional Response depends on electron spectrum → EDH

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

DDH – Background



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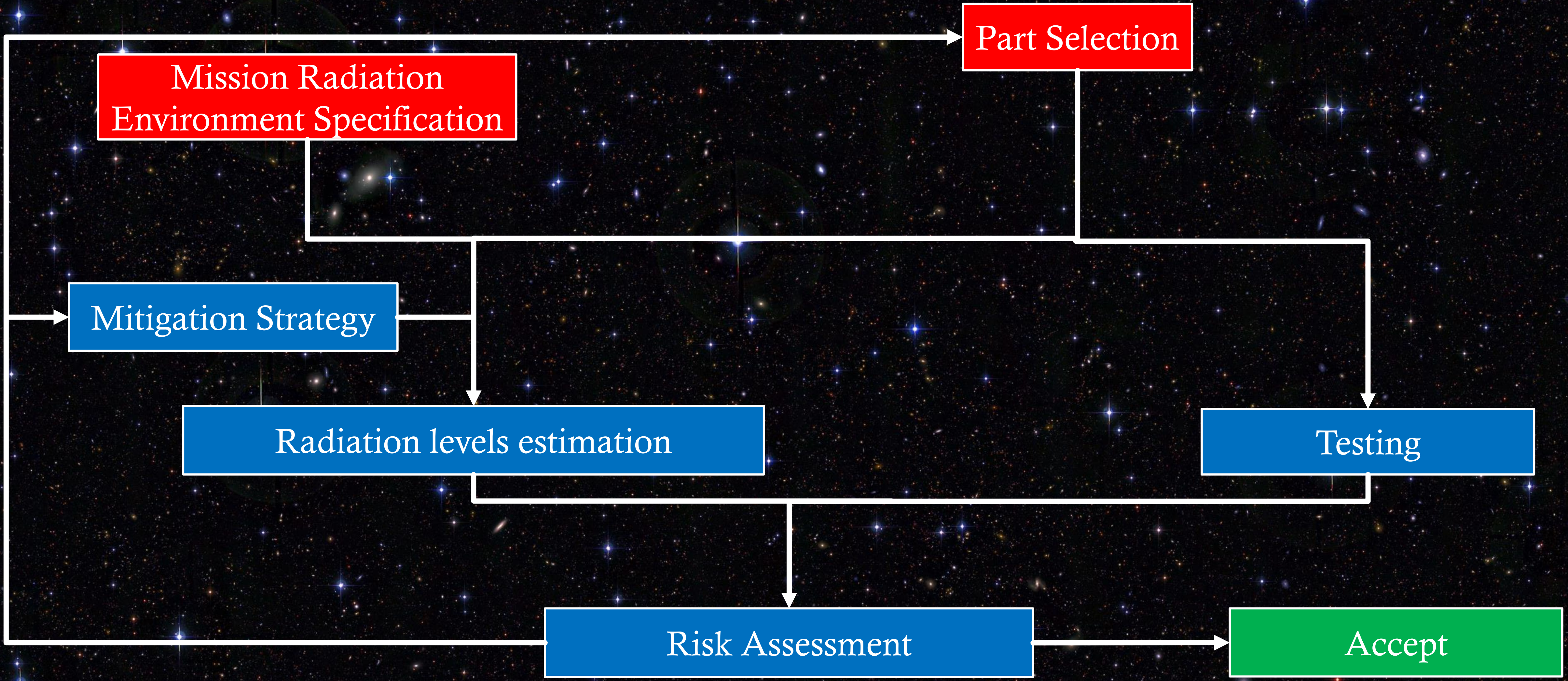
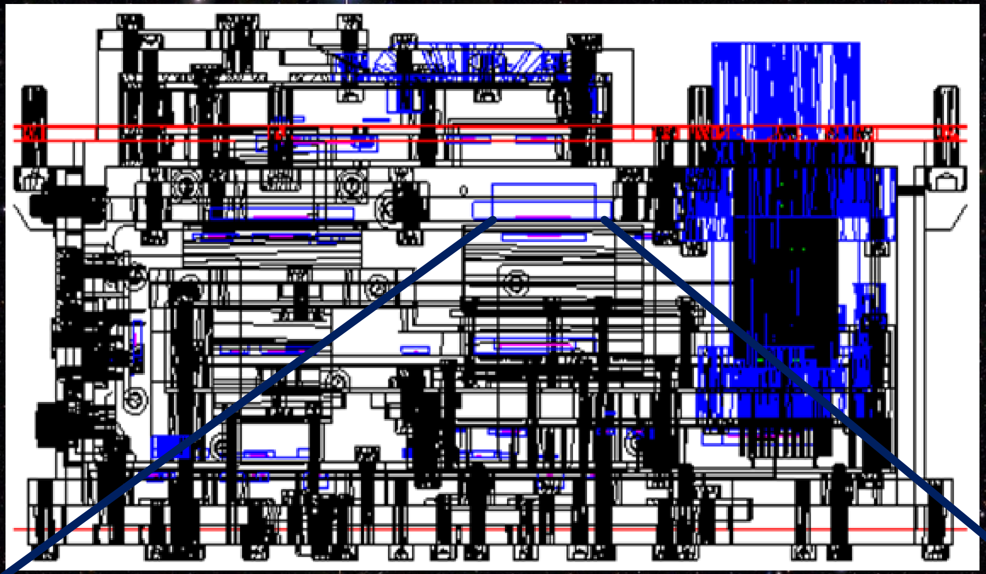
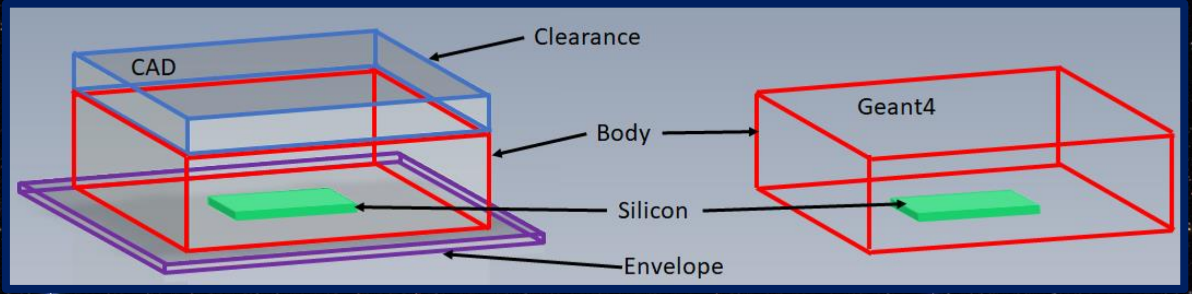
Radiation Hardness Assurance

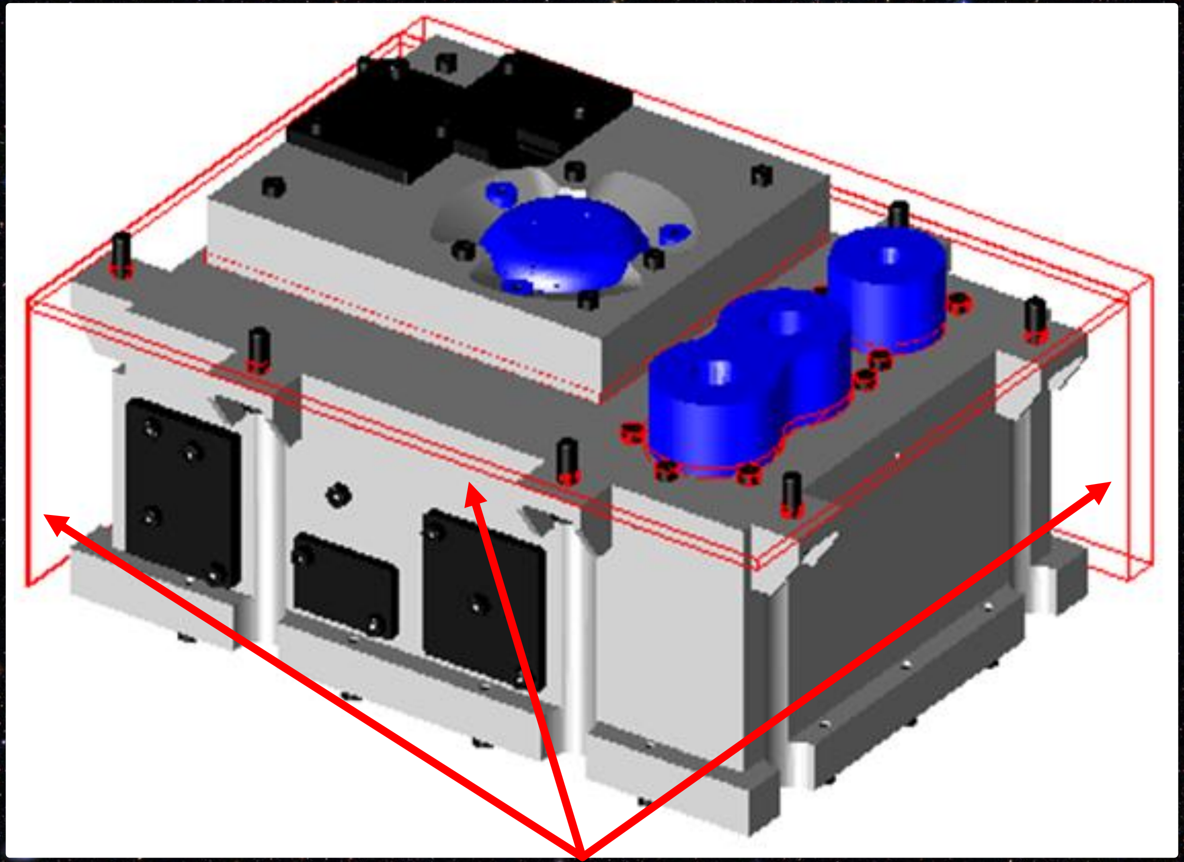


Radiation Level Estimation

Full geometry imported as tessellated solids via GDML with GUIMesh







Spacecraft described as Aluminum shielding equivalent

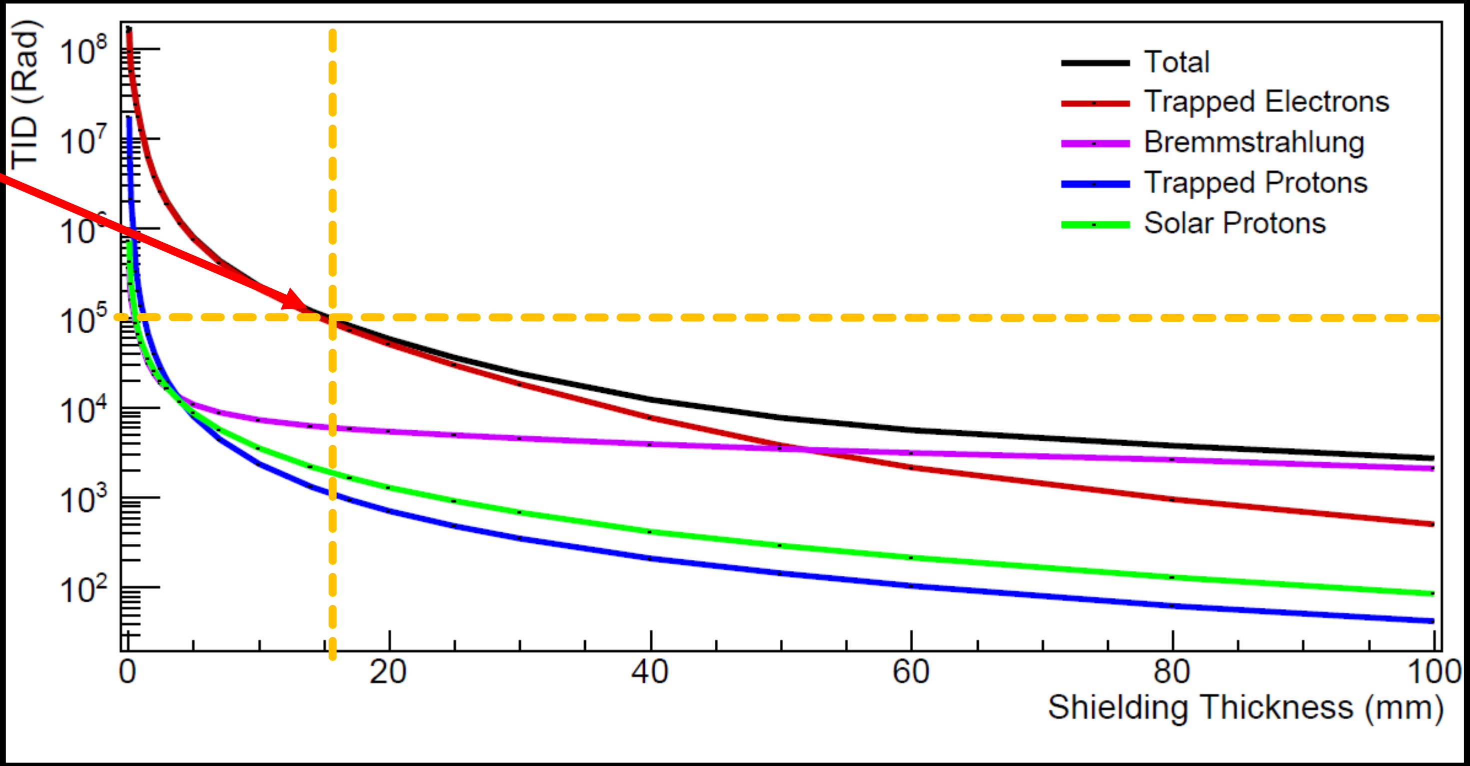
(M. Pinto and P. Gonçalves, DOI: https://doi.org/10.1016/j.cpc.2019.01.024)

Radiation Level Estimation

Mission Dose = 1.26 Mrad behind 1 mm Al. Shielding

129 sensitive components – Mostly from JUICE Preferred Parts List

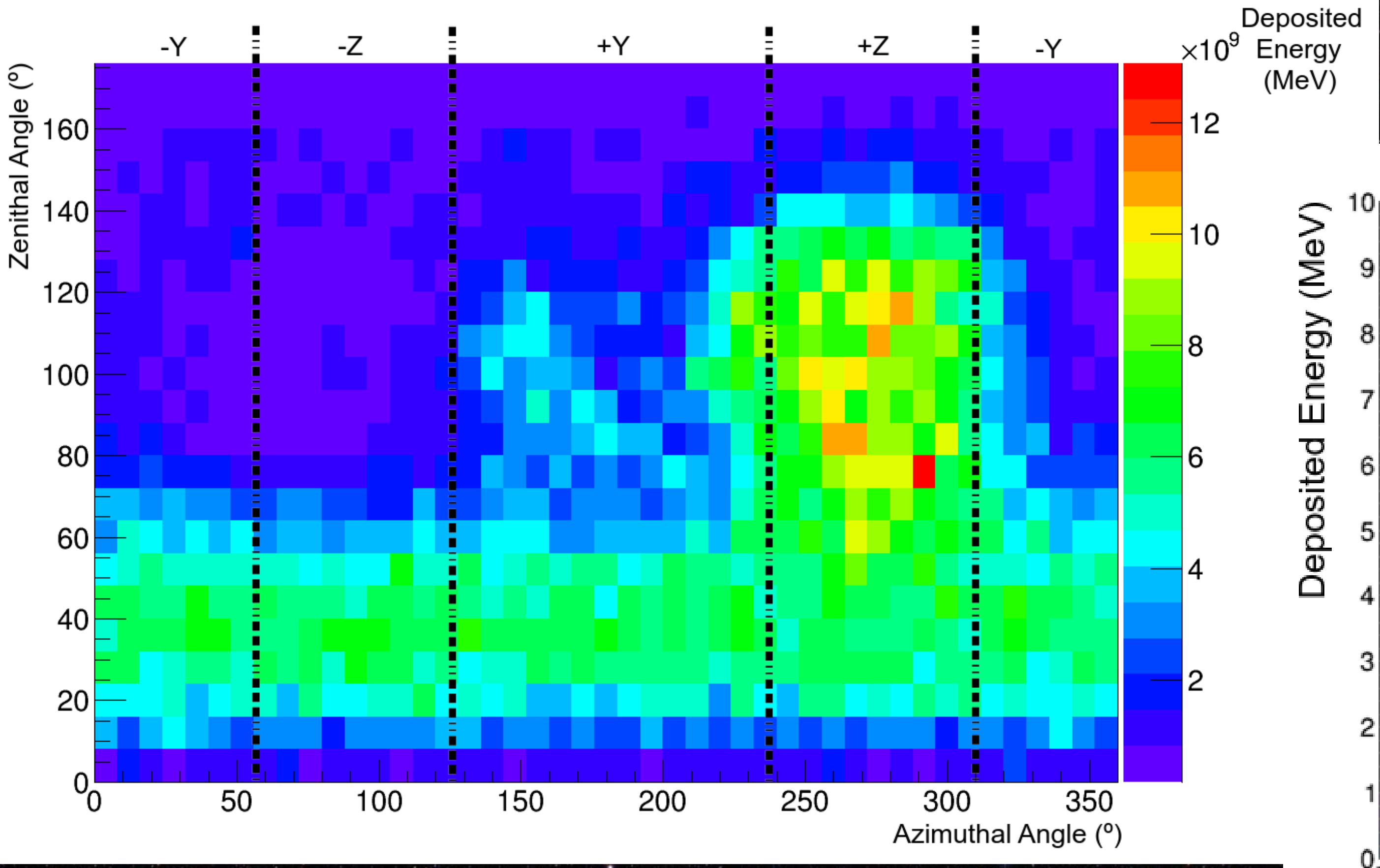
- ➢ Total Ionizing Dose
- ❖ 110 EEE components - 100-300 krad
- ❖ Silicon Trackers - 1 Mrad



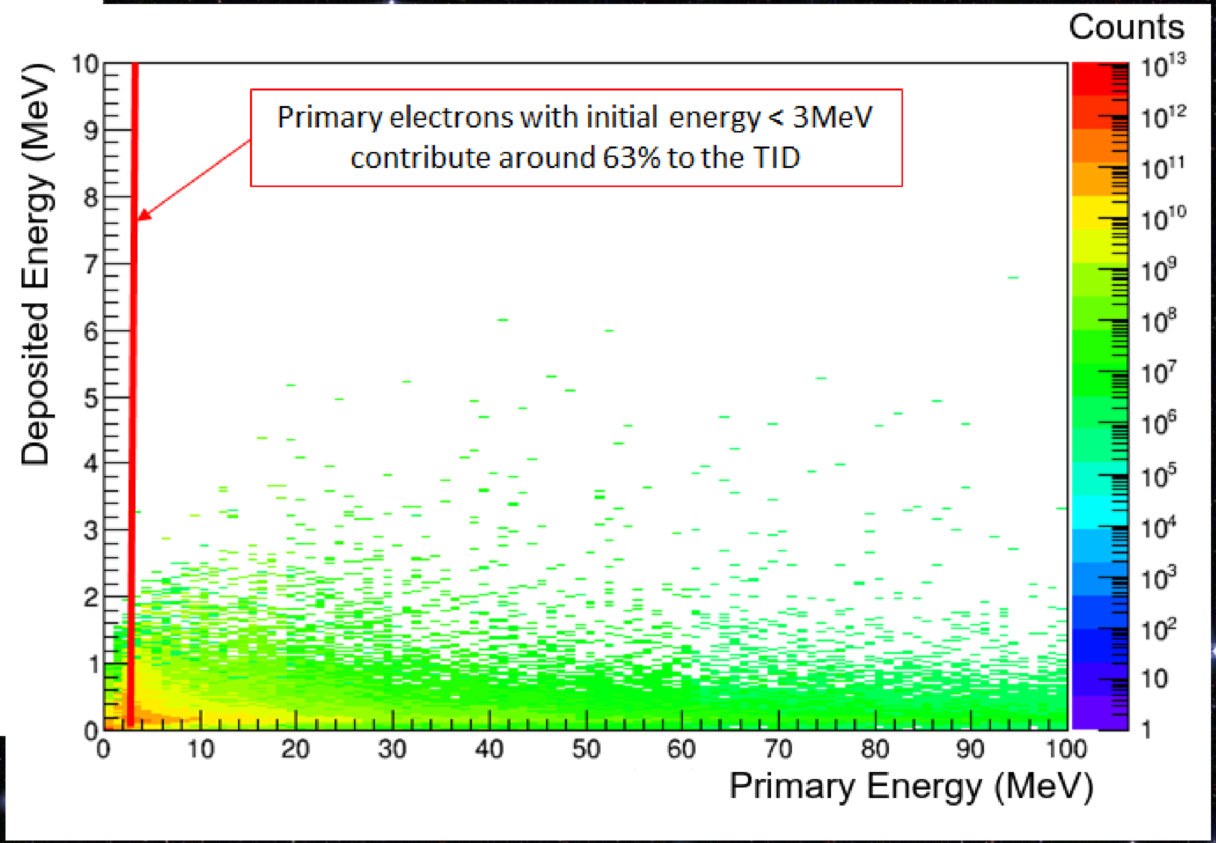
- ➢ Displacement Damage Dose
- ❖ >2E+011 50 MeV proton eq. fluence

- ➢ Single Event Effect sensitivity:
- ❖ ASIC
- ❖ Oscillator
- ❖ PROM
- ❖ SRAM

Radiation Level Estimation

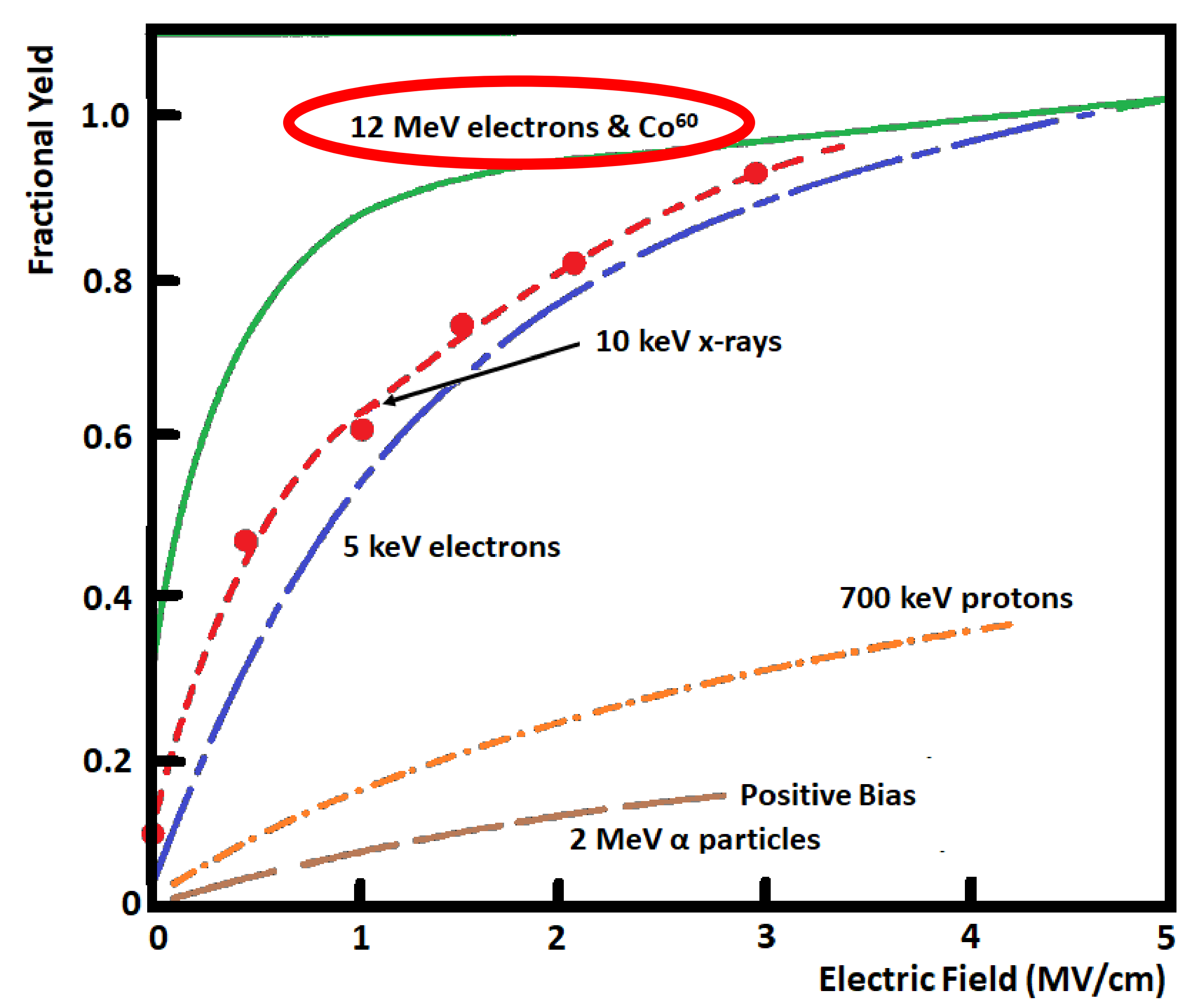


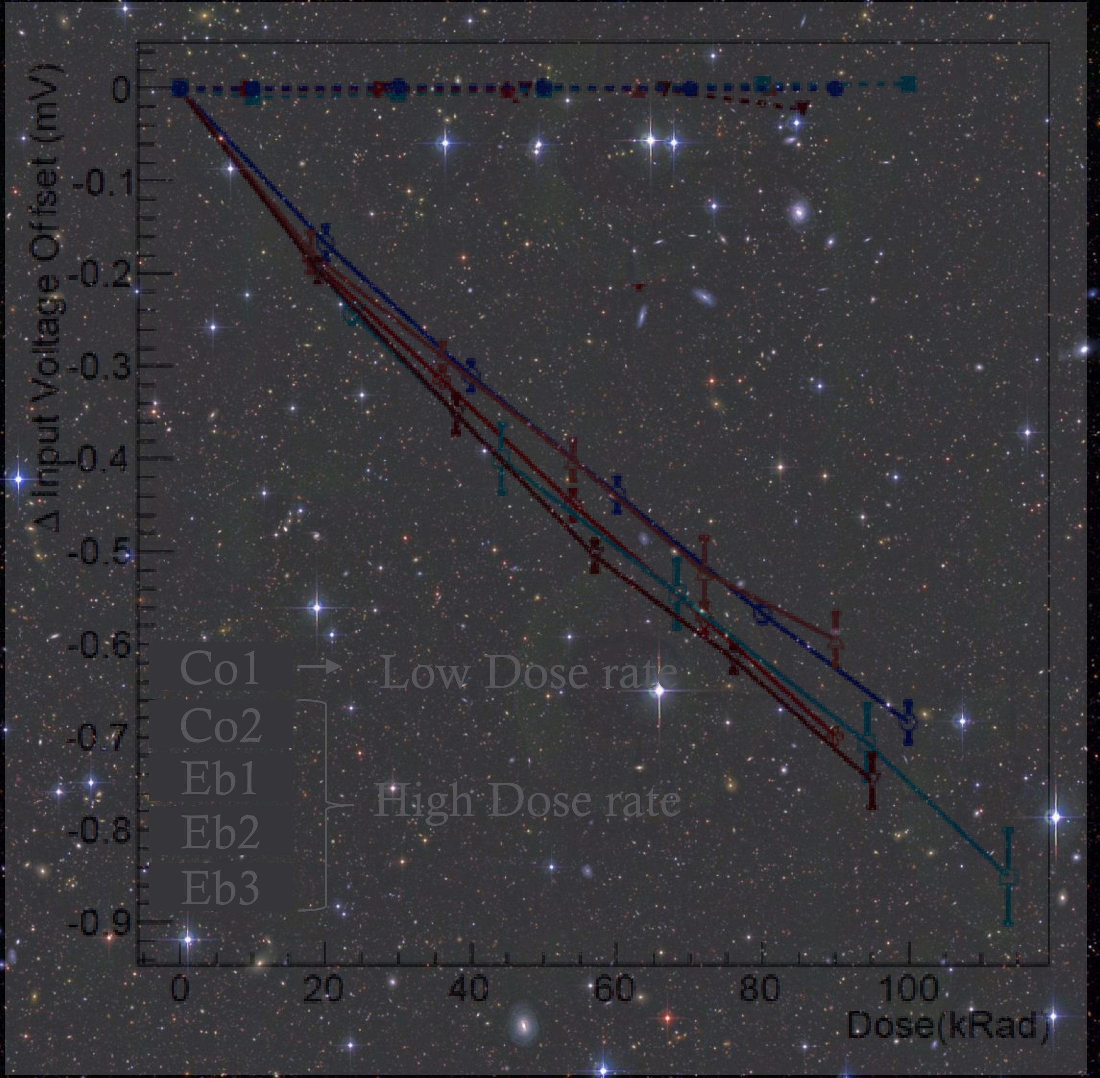
Dose distribution – ASIC P&HIDH



Testing

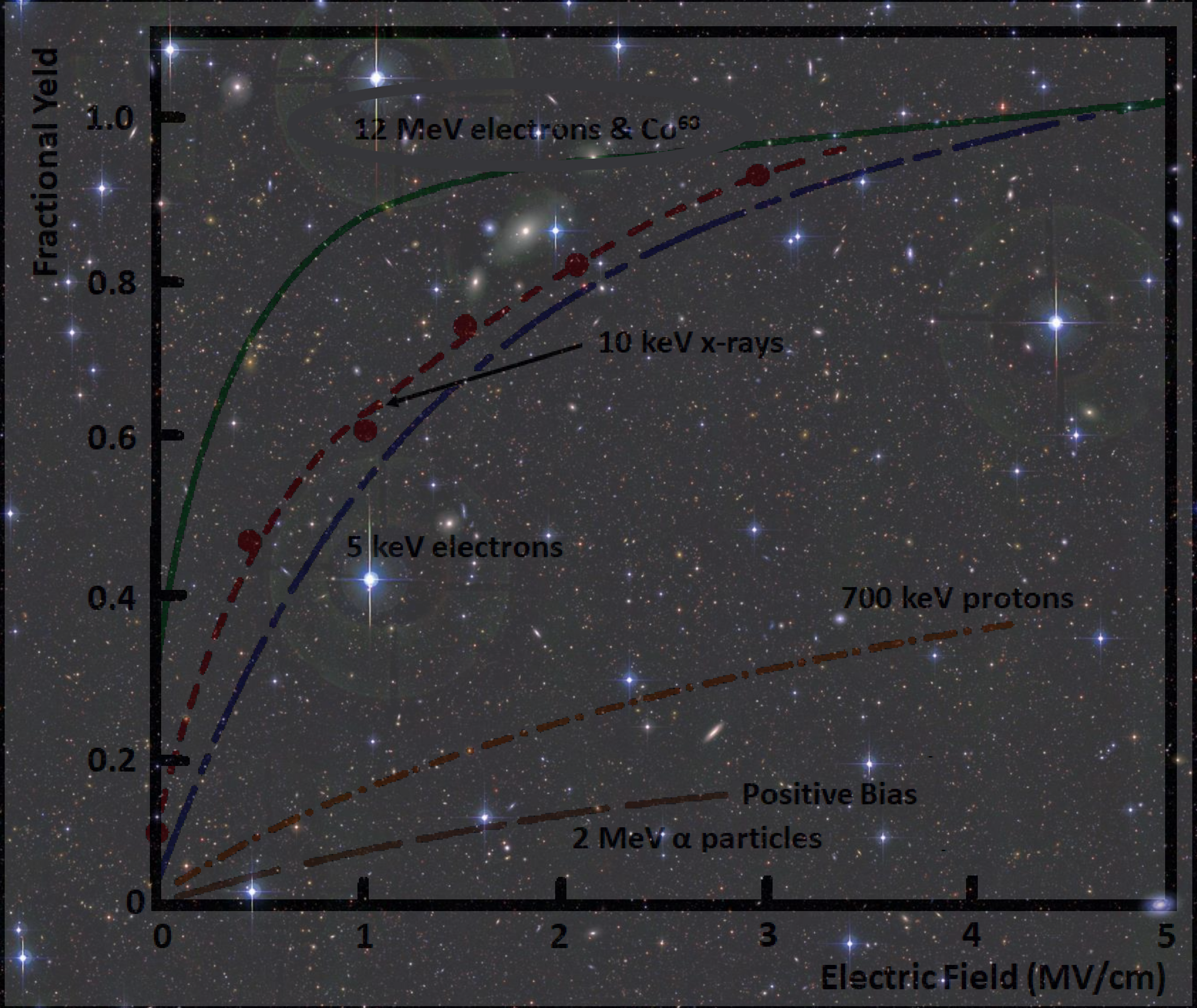
ESA Contract No: RFQ/3-13975/13/NL/PA

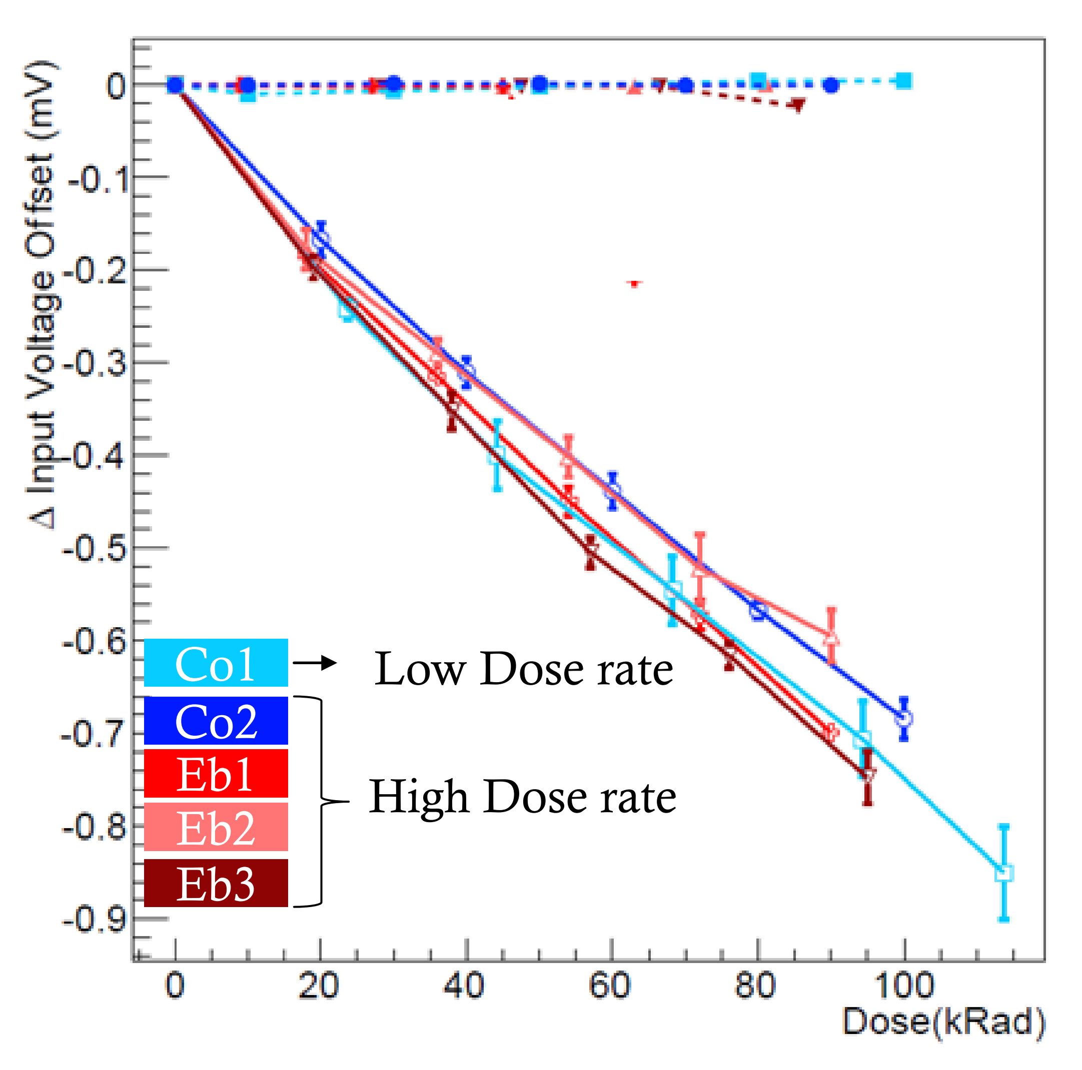




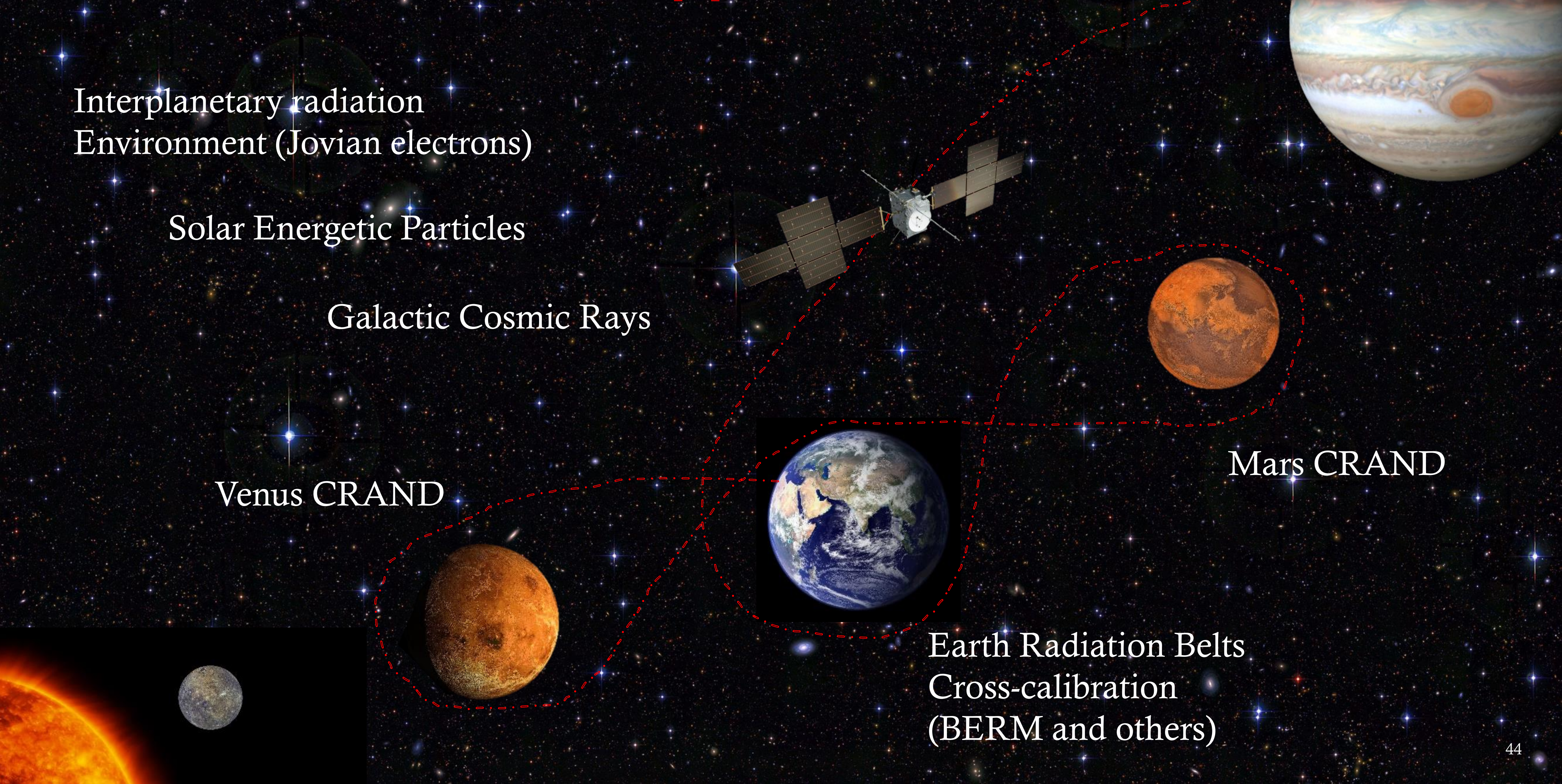
Testing

ESA Contract No: RFQ/3-13975/13/NL/PA



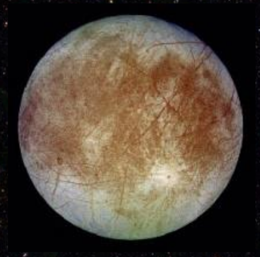


RADEM – Scientific Opportunities



RADEM – Scientific Opportunities

Jupiter CRAND as a source of protons

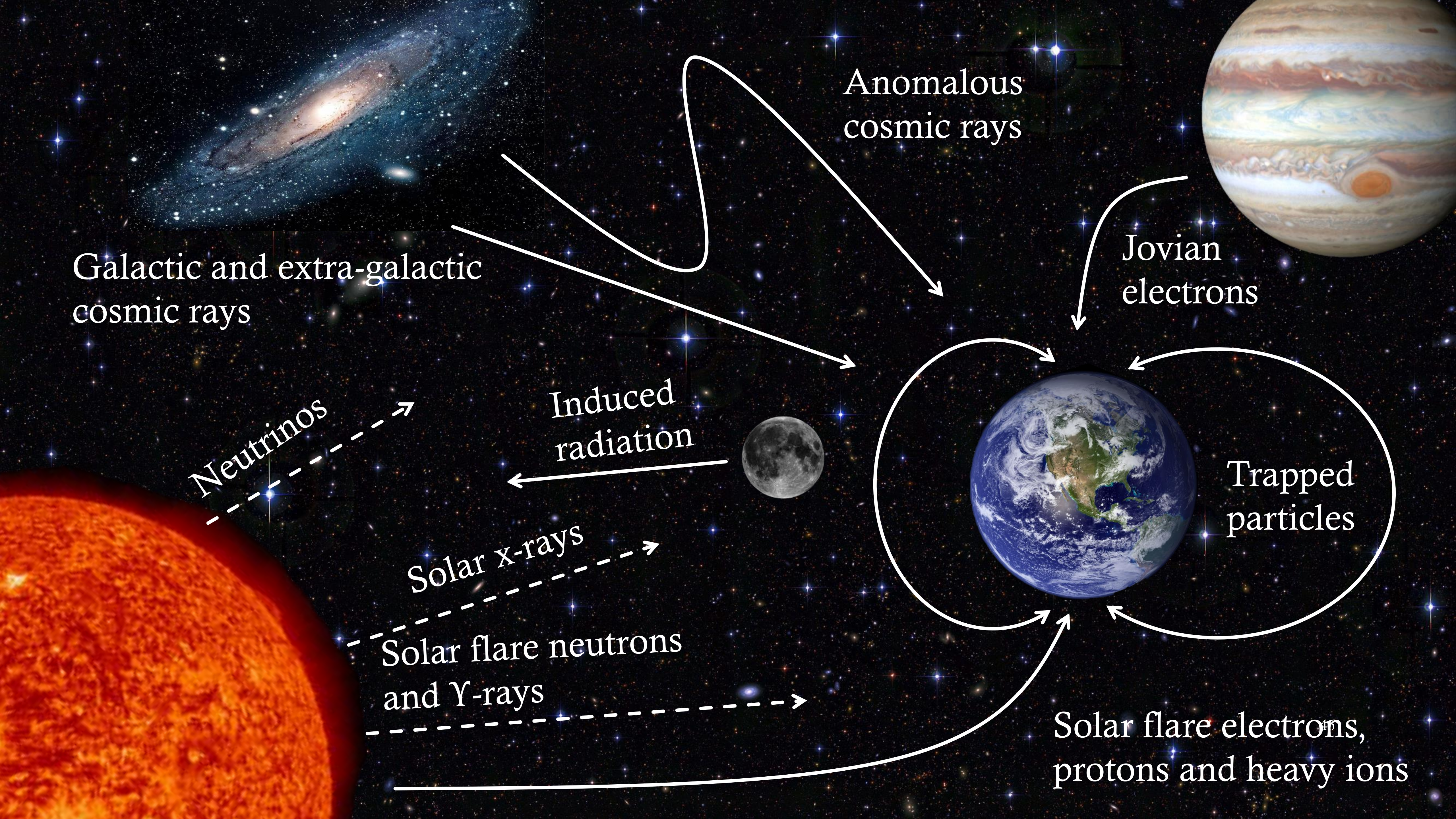


Jupiter-Moon interactions

Constrain Acceleration Mechanism

Improve Radiation models

Astrobiological implications of radiation

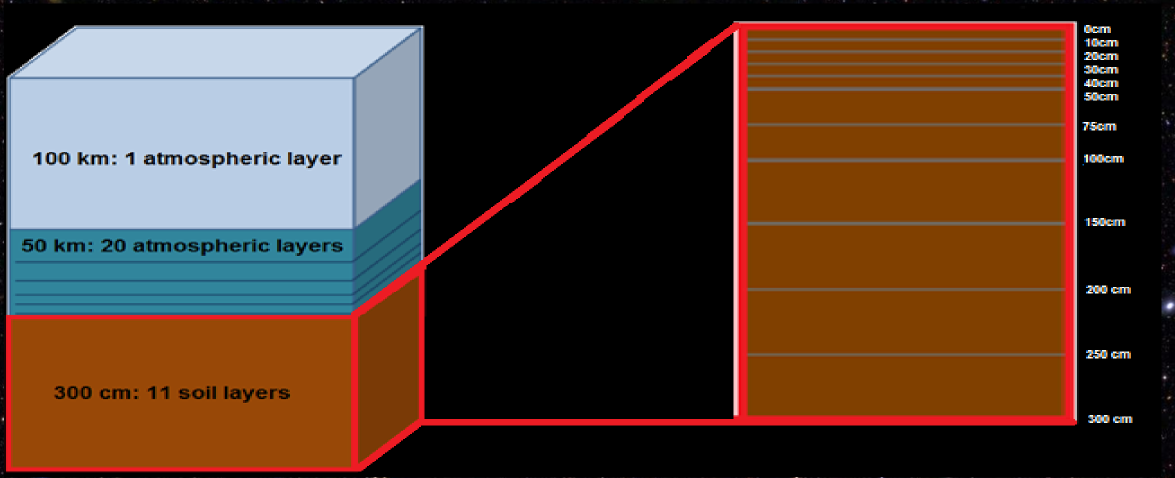

Anomalous cosmic rays
Galactic and extra-galactic cosmic rays
Jovian electrons
Neutrinos
Induced radiation
Trapped particles
Solar x-rays
Solar flare neutrons and Υ-rays
Solar flare electrons, protons and heavy ions

Mars Radiation Environment: dMEREM

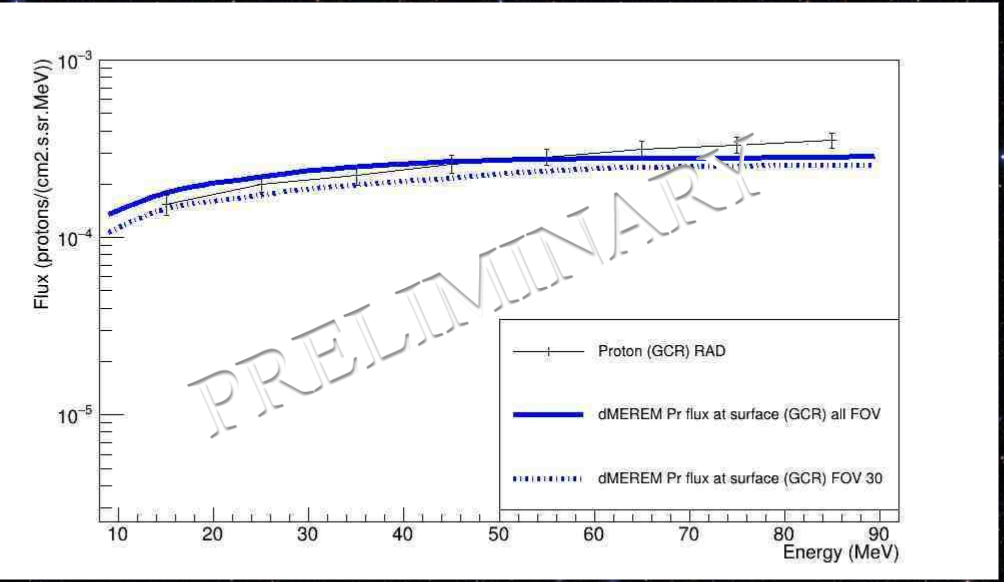
ESA contract 19770/06/NL/JD

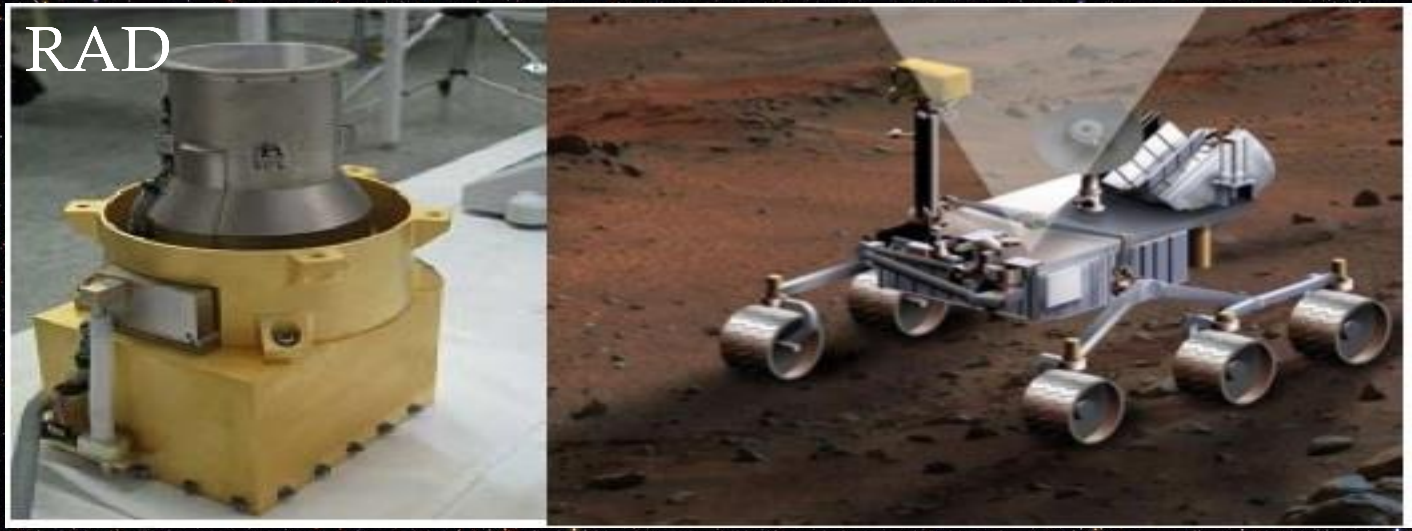
Modelling Mars radiation (Geant4)

- ❑ Local treatment (Physical properties)
- ❑ Validation



Risk assessment





Geostationary orbit - Alphasat

Technology Demonstration Payload 8 (TDP8)

ESA/ESTEC CONTRACT 3-14025/13/NL/AK

› MultiFunctional Spectrometer (MFS)

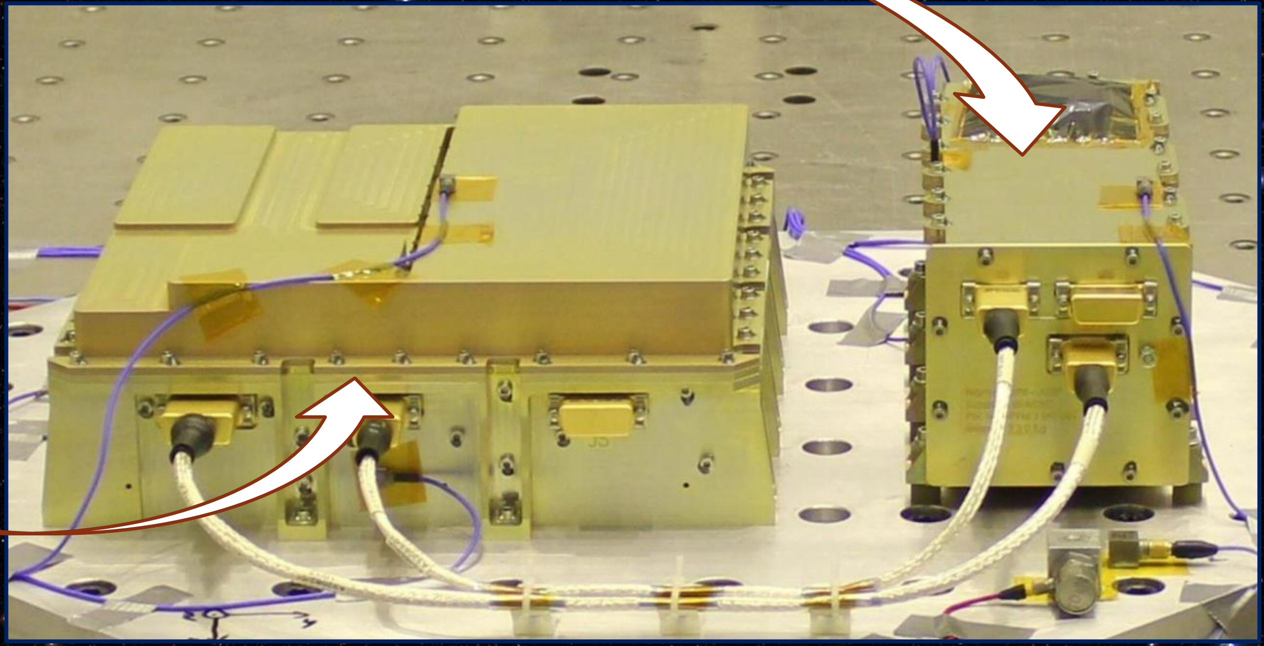
DOI: 10.1109/TNS.2018.2854161

DOI: 10.1109/TNS.2017.2714461

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

› Component Technology Test-Bed (CTTB)

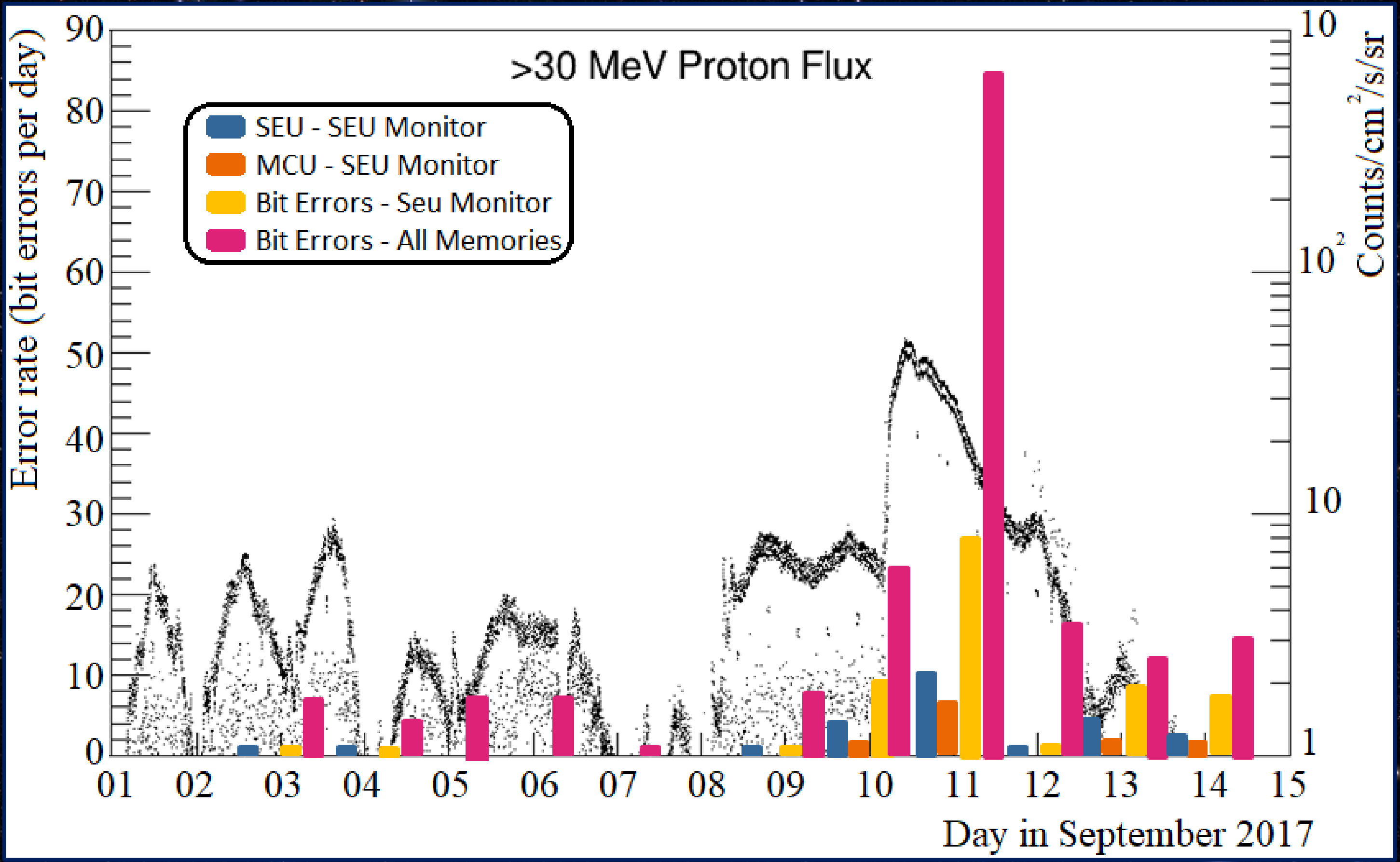
DOI: 10.1109/TNS.2020.3013035



3 experiments:

- GaN transistors (Aveiro)
- Optical Links (Valencia)
- Flash-NAND Memories

Geostationary orbit - Alphasat



Reconstruction Algorithms

Radiation Environment

Modelling

Benchmarking

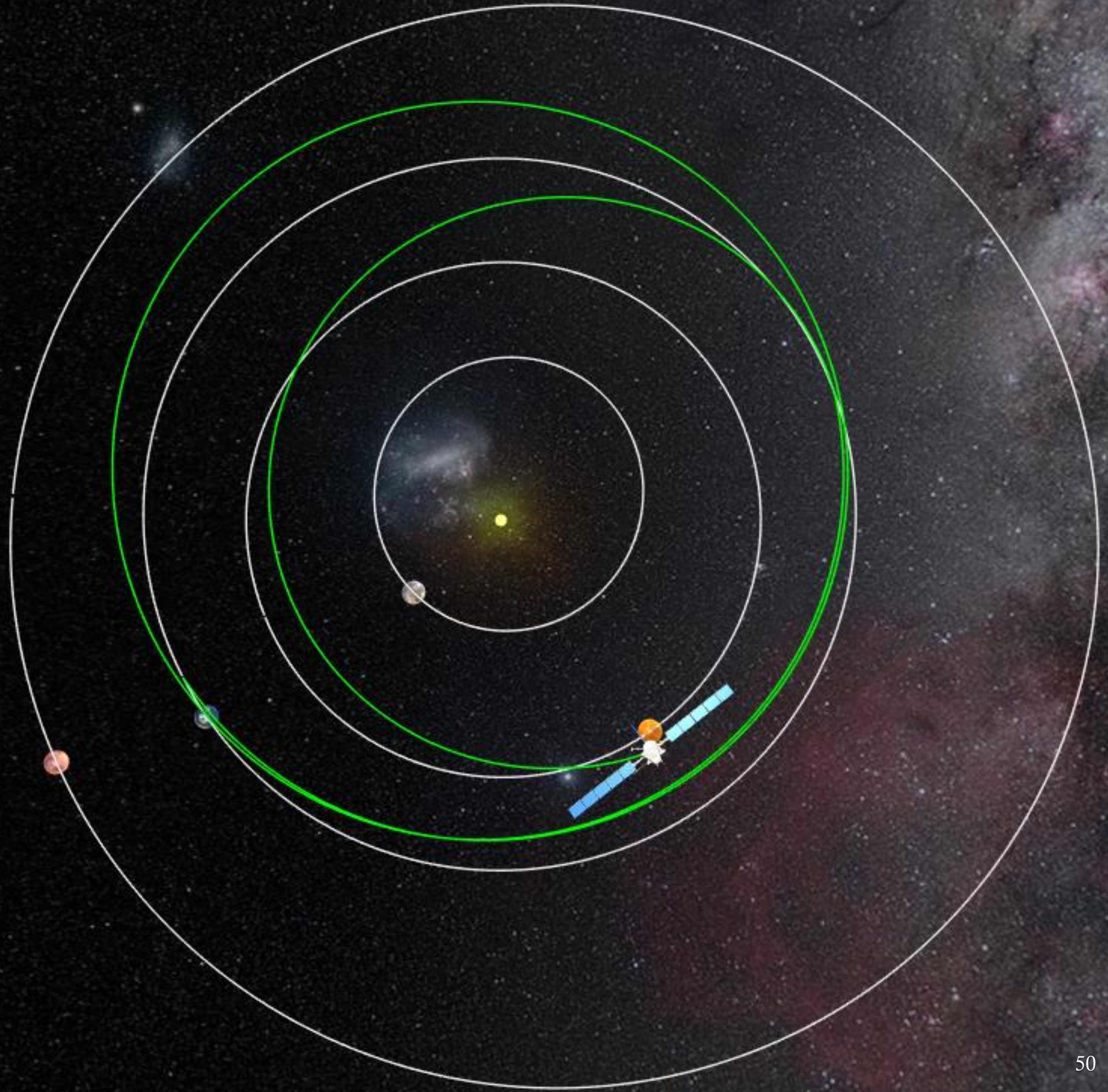
Radiation Effects

BepiColombo

Launched in 2018

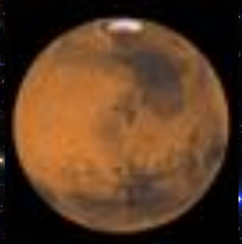
Two spacecrafts

BERM



Future work

RADEM Calibration and preparation of data analysis



dMEREM benchmarking

MFS Machine learning spectral deconvoluting

CTTB Radiation Effects Analysis

BERM Data Analysis