Radiation characterization for space missions

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1st year activity report

31/10/2024

GRAN SASSO SCIENCE INSTITUTE
SCHOOL OF ADVANCED STUDIES
Scuola Universitaria Superiore

Overview

Radiation Hardness for the NUSES space mission:

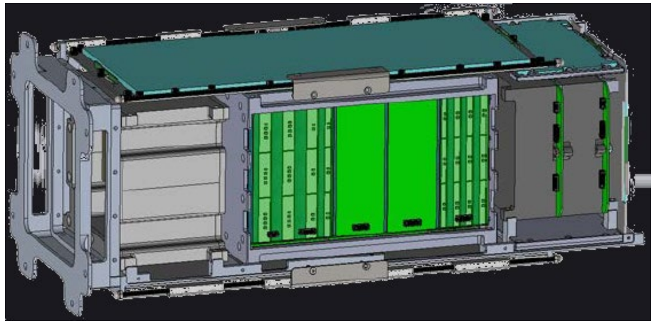
- The NUSES space mission
- Simulation of the radiation environment
- Preliminary test and simulations of the damage
- Next short-term and long-term project activities

Radiation Hardness comparison for HERD and WINK space missions:

- Simulation of the radiation environment

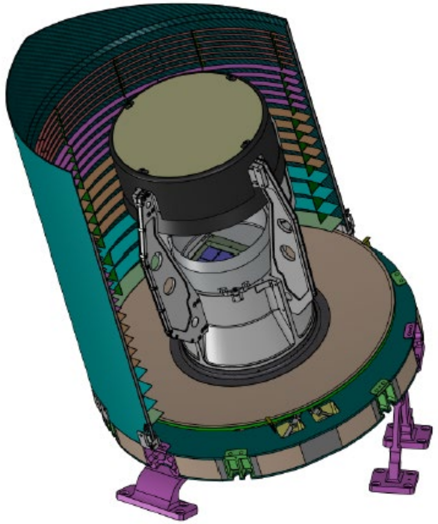
NUSES in a nutshell

Ziré



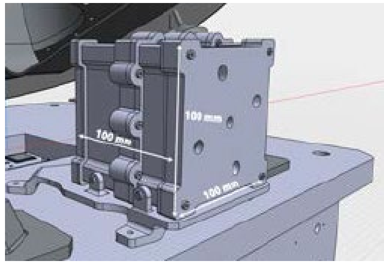
- To monitor the fluxes of low energy(< 300 MeV) **e,p, and low Z nuclei** of solar/galactic origin;
- To study the cosmic radiation variability (**Van Allen Belts**);
- To look for possible correlation with **seismic activity**;
- To study transient and steady **gamma sources**[0.1-30MeV];

Terzina



- To measure **UHE cosmic rays** and enable **neutrino astronomy** through space-based atmospheric Cherenkov light detection

Low Energy Module (LEM)

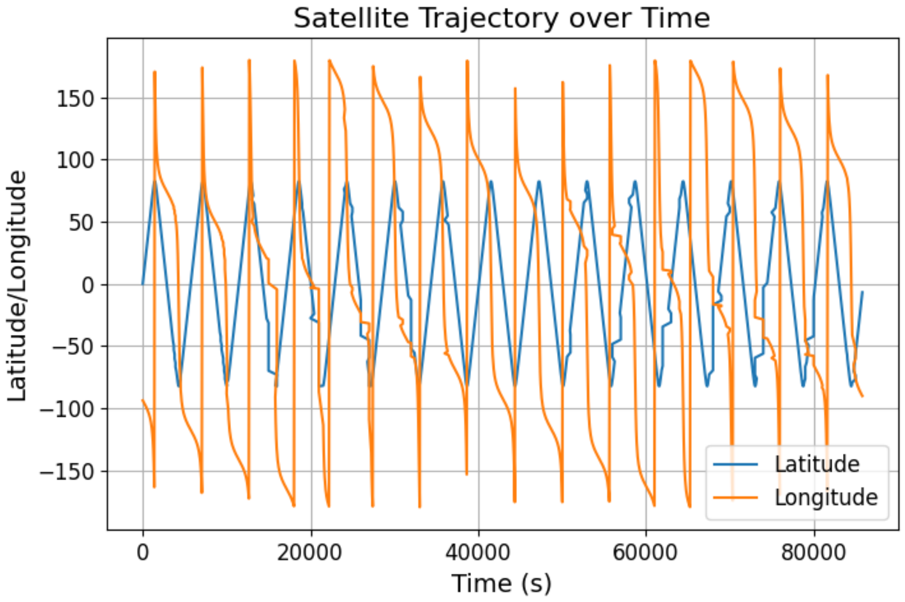


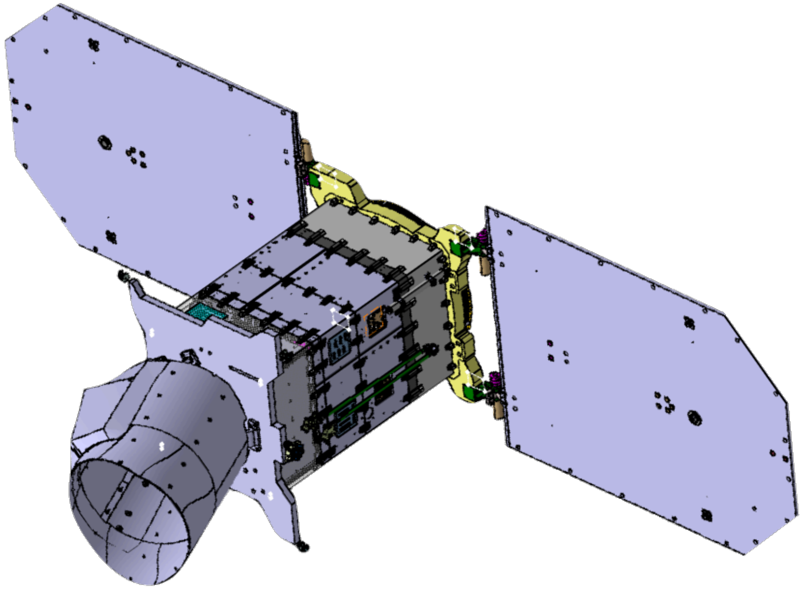
- to detect low-energy fluxes of **e** in the 0.1–7-MeV range and **p** in the 3–50 MeV range

The NUSES orbit

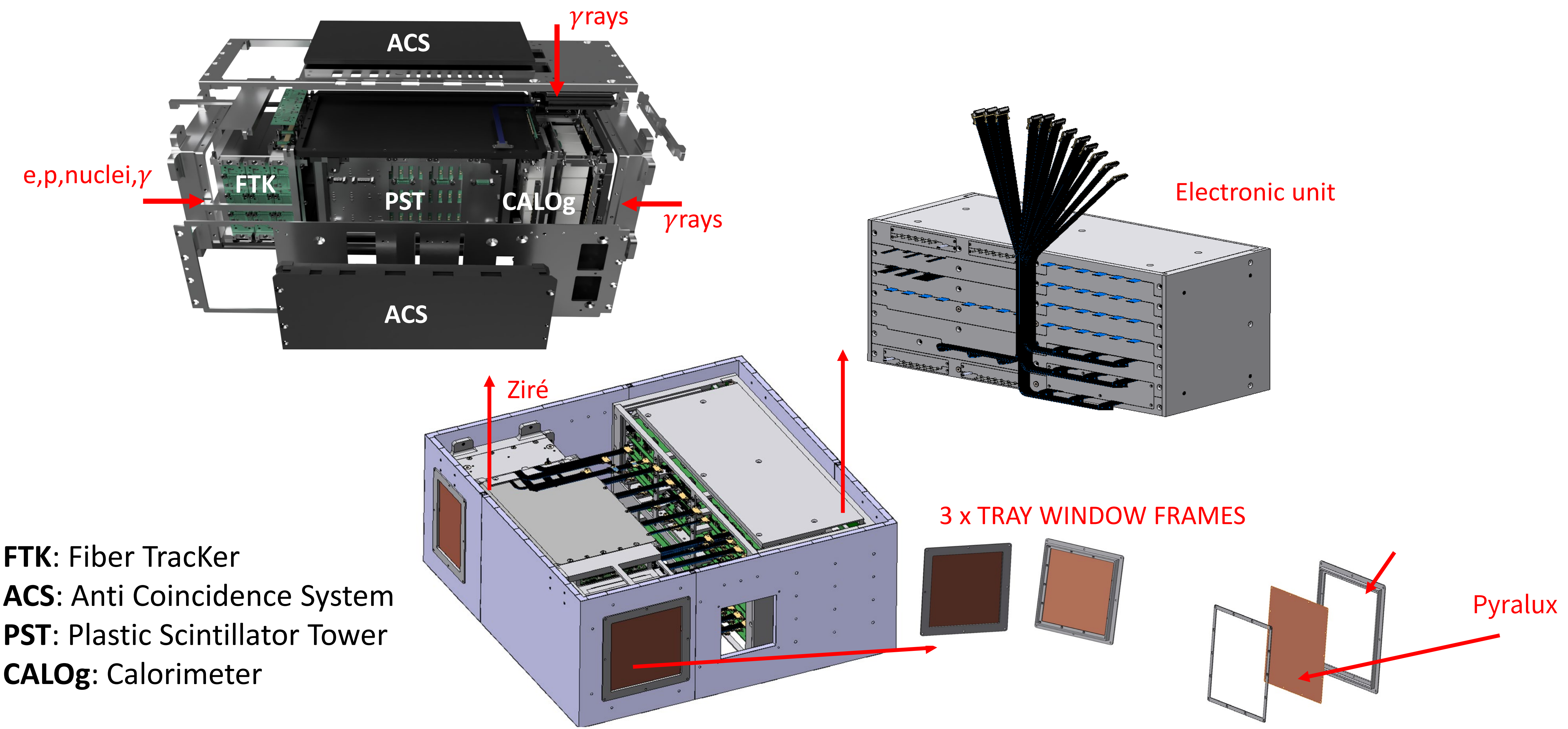
Mission Lifetime	3.3 y
Mean Altitude	535 km, LEO
Semi-major axis	6913 km
Eccentricity	0
Inclination	97.6 deg, SunSync
LTAN	16:46
Pointing	< 0.1 deg

- Low Earth Orbit at high inclination, Sun-Sync orbit on the day-night border;
- The orbit has been tailored around the requirement for the optimal detection of the Cherenkov light;
- “Ballistic” mission (no propulsion for orbital elevation corrections);
- Expected launch window 2026





Ziré mechanical overview



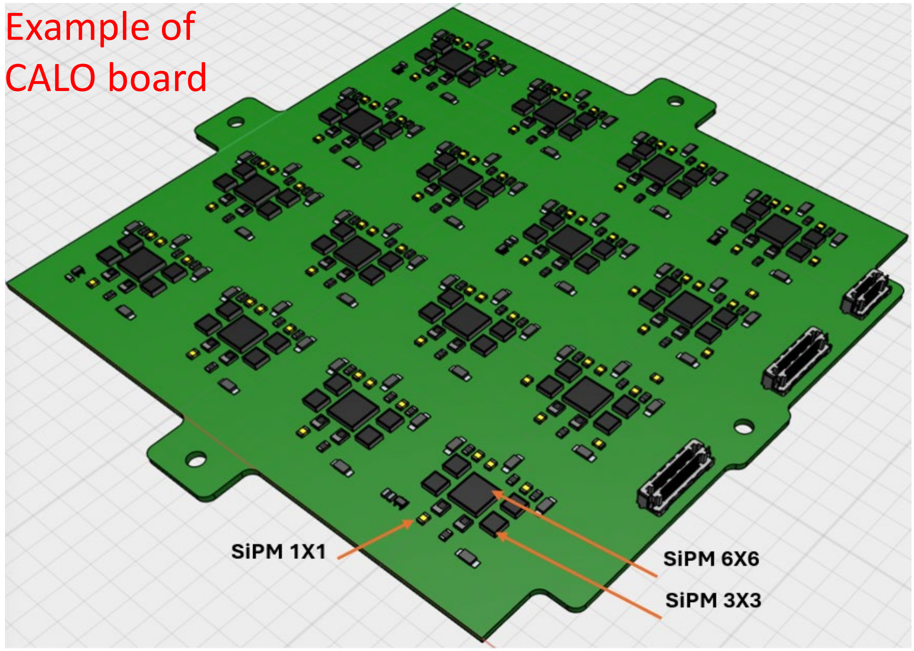
FTK: Fiber TracKer
ACS: Anti Coincidence System
PST: Plastic Scintillator Tower
CALOg: Calorimeter

Technological Challenges

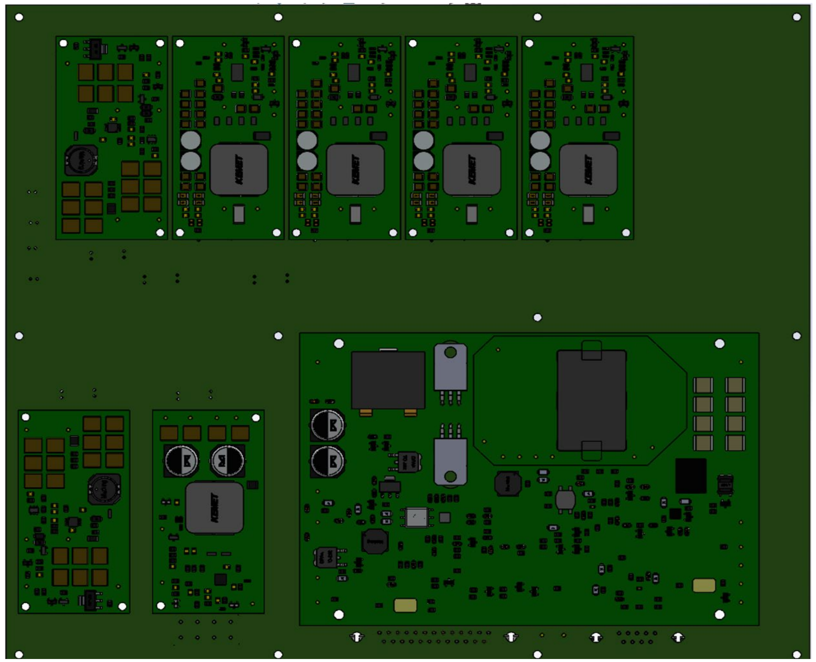
The crucial objectives of the mission are also to develop new observational techniques, to test **Silicon Photo Multiplier (SiPM)** and **related electronics/DAQ** for space missions.

Critical tests are those related to radiation damage, in particular:

- Total Ionizing Dose
- Single Event Effect
- Total non-Ionizing Dose



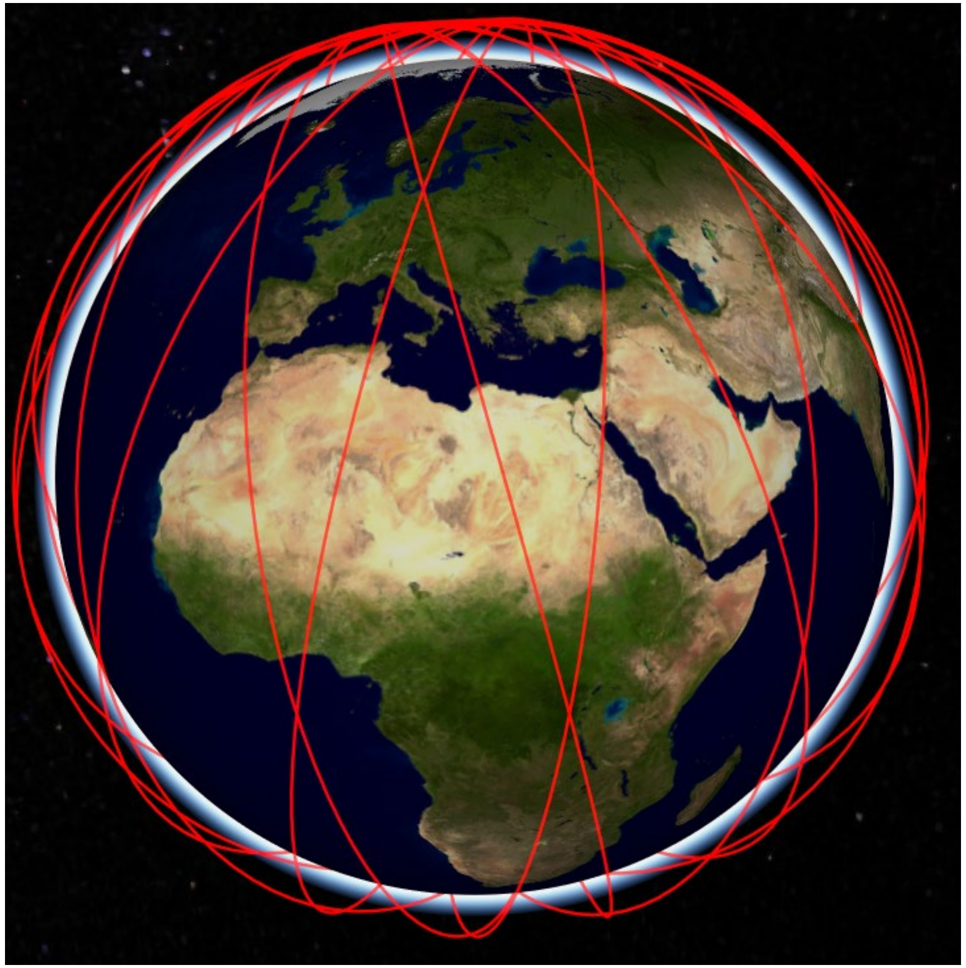
Massive use of SiPMs (Silicon PhotoMultipliers, FBK) and MPPC (Multi-Pixel Photon Counters, Hamamatsu Photonics) in Space. Total surface covered by SiPMs = 11420 mm^2



Electronics mostly based on the use of COTS

Definition of the radiation environment

NUSES polar orbit (~16orbits/day)



SPENVIS The Space Environment Information System

- Trapped Particles in VanAllen bands
- Solar Particle Events(SPE)

European standard for the radiation environment

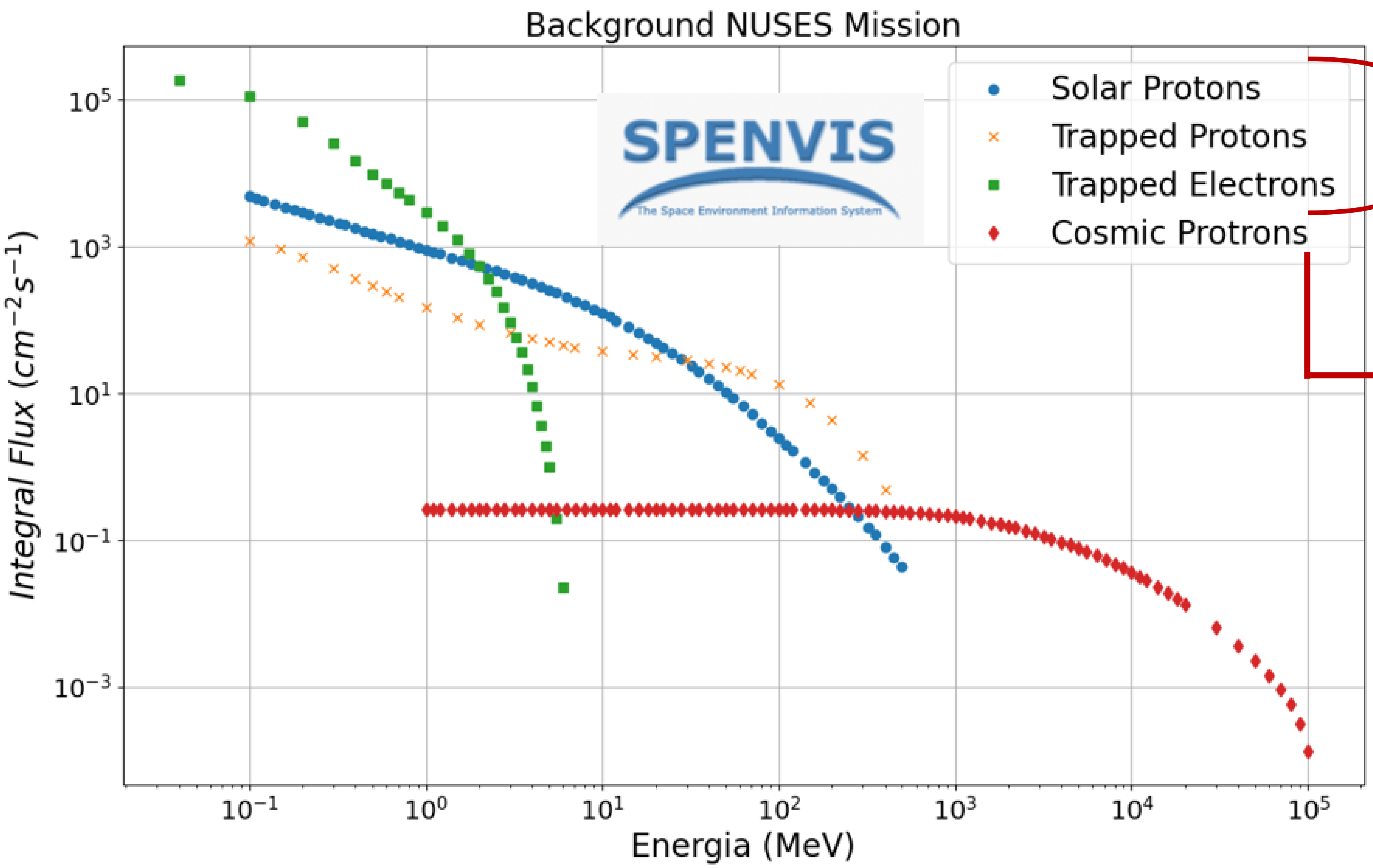
Environment specification standards:

- **Trapped radiation belt fluxes**: ECSS-E-ST-10-04C Rev.1-0760055, 15 June 2020
- **Proton fluence spectra from Solar Particle Events:** ECSS-E-ST-10-04C Rev.1-0760069, 15 June 2020
- **Solar Particle Peak Flux models:** ECSS-E-ST-10-04C Rev.1-0760073, 15 June 2020
- **Cosmic Ray flux models:** ECSS-E-ST-10-04C Rev.1-0760075, 15 June 2020

Radiation damage specification standars:

- **TID hardness assurance:** ECSS-Q-ST-60-15C, 1 October 2012
- **TNID hardness assurance:** ECSS-Q-ST-60-15C, 1 October 2012

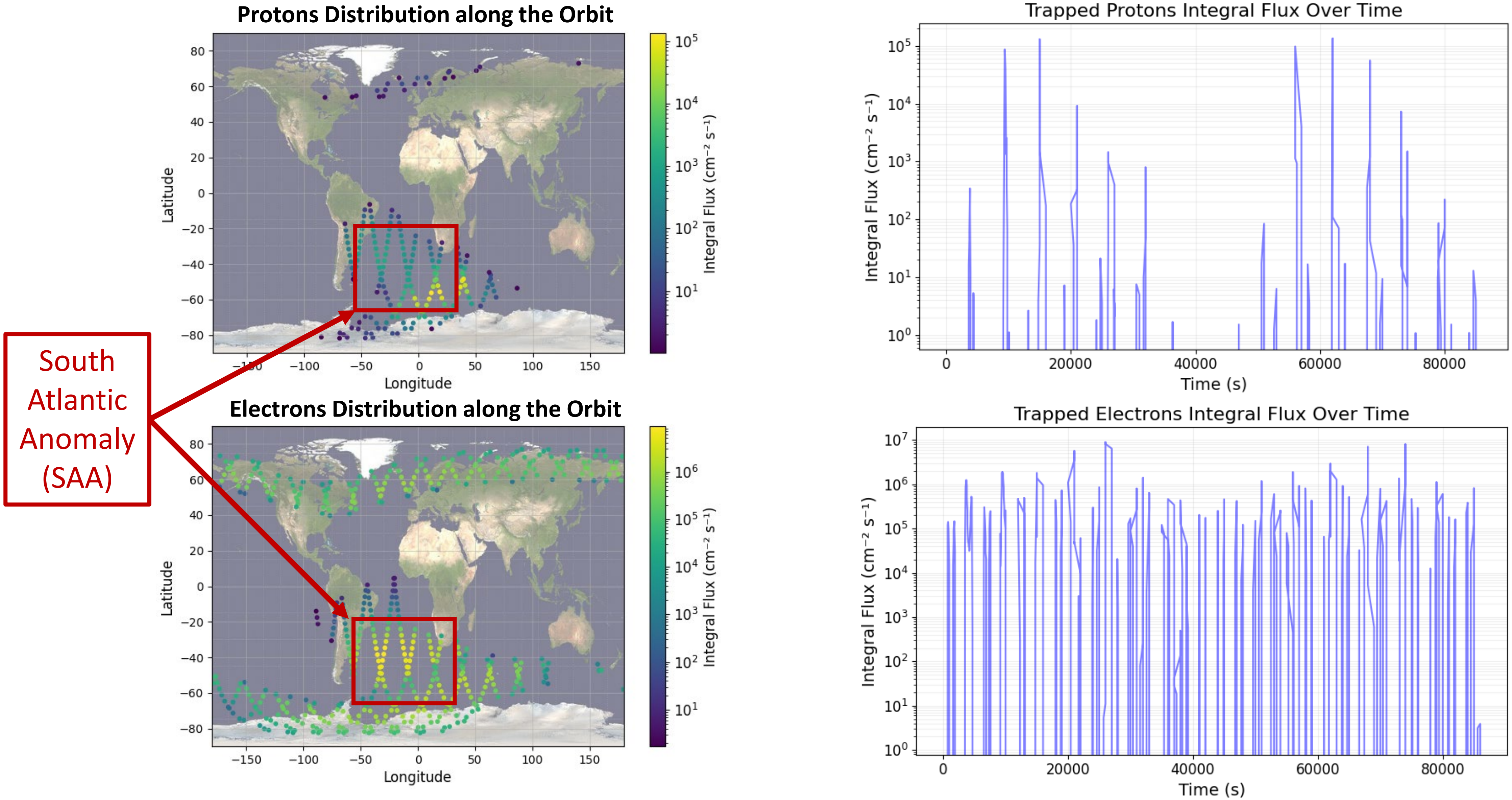
The NUSES background particles



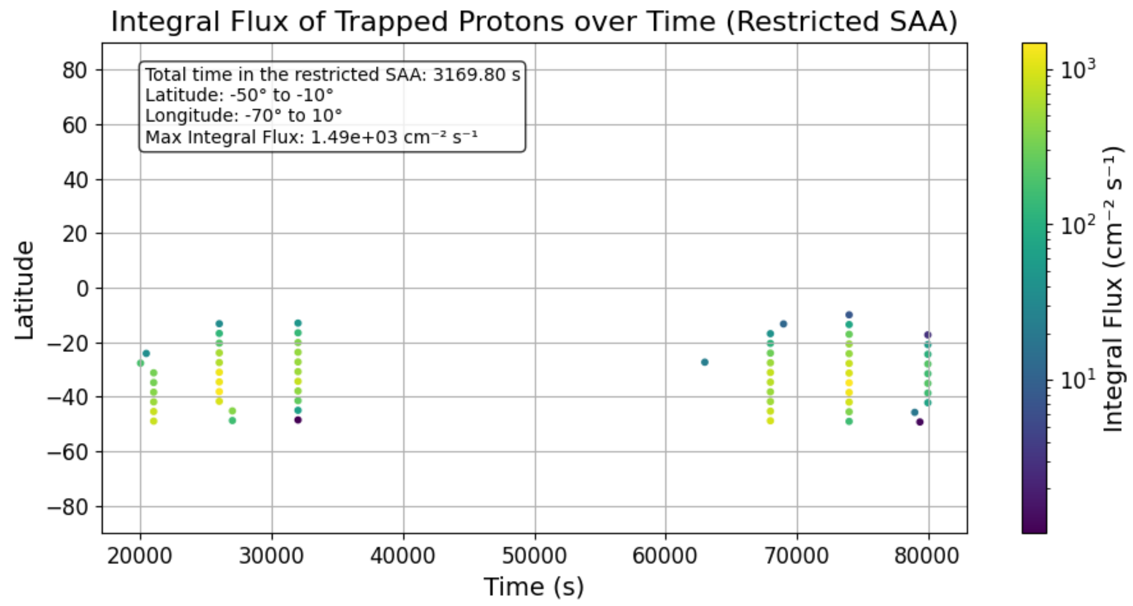
Values used to analyze cumulative radiation damage

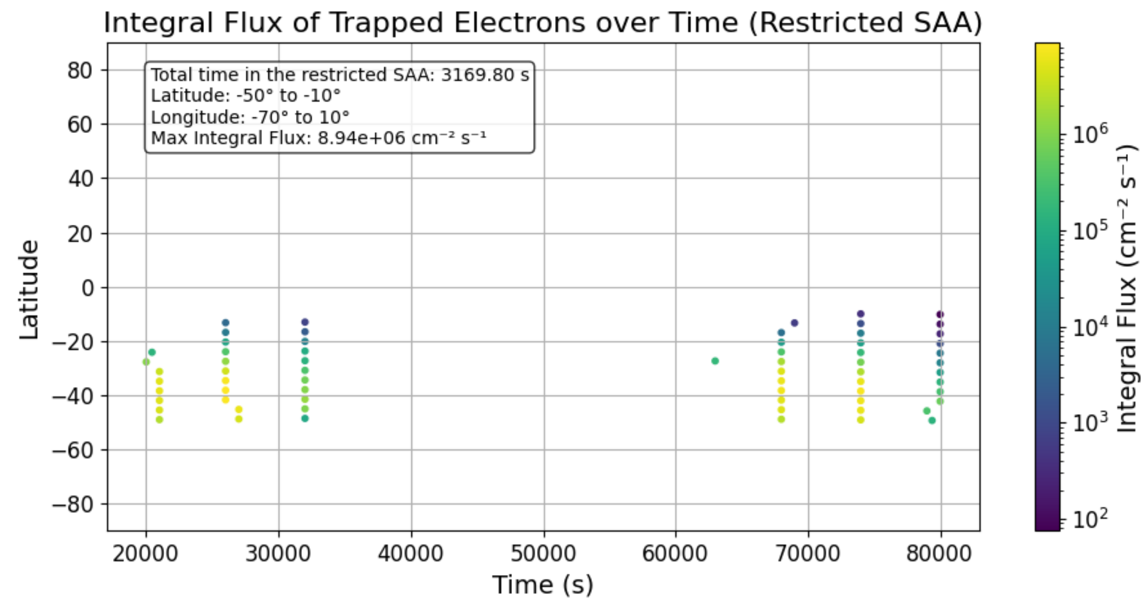
Values that will be used to analyze SEE damage. Values refer to the solar minimum of May 1996 (worst case)

Geographical distribution of trapped particles



South Atlantic Anomaly (SAA) time definition



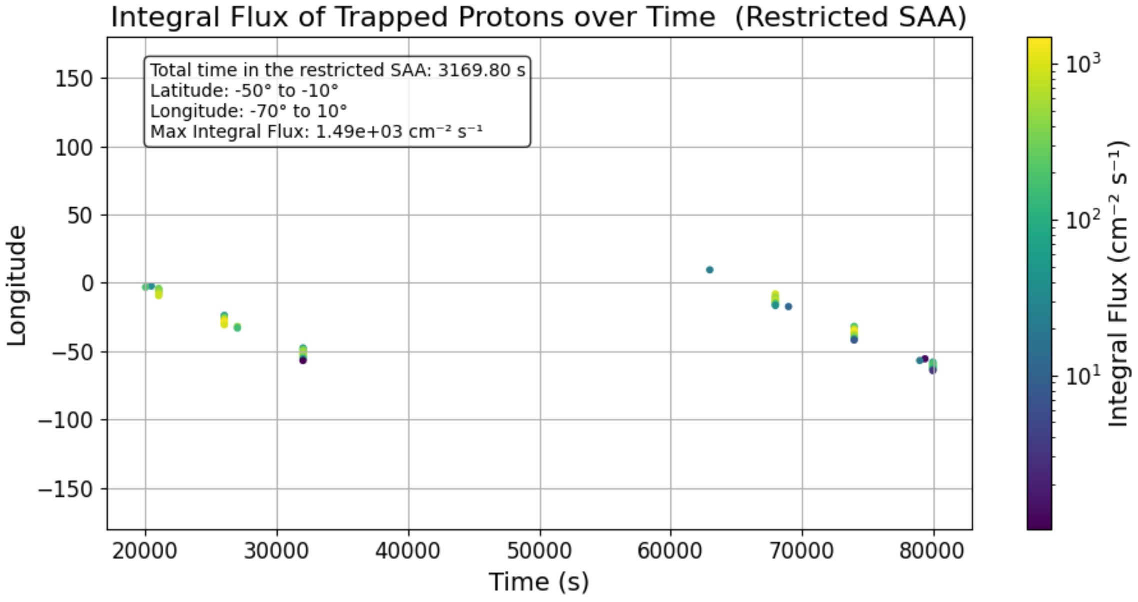


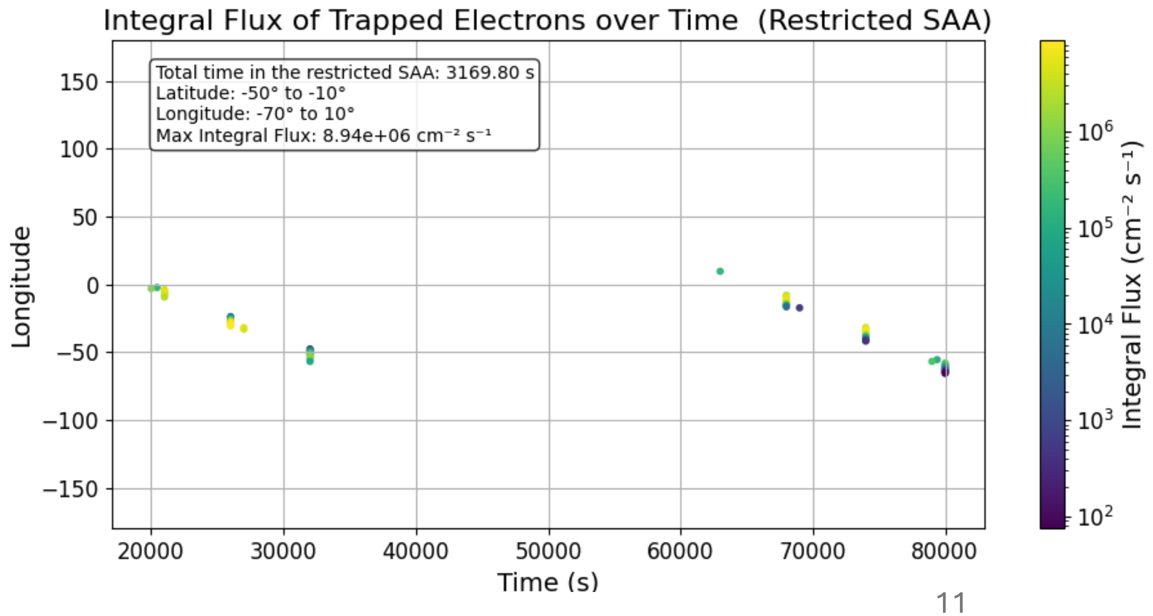
Expected Operative Time:

1360m/d

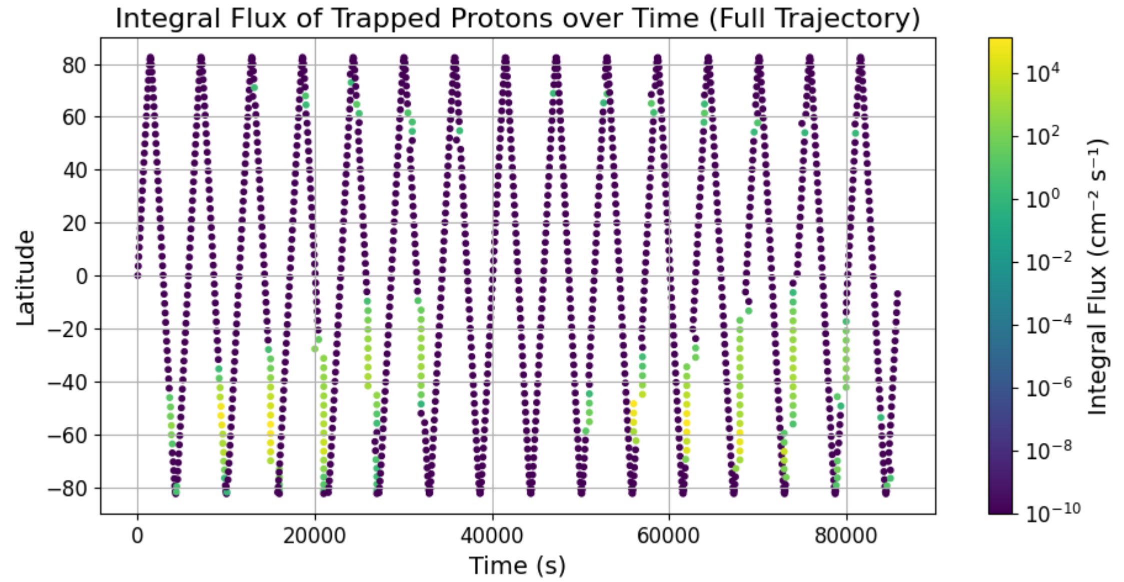
Expected Duty Cycle:

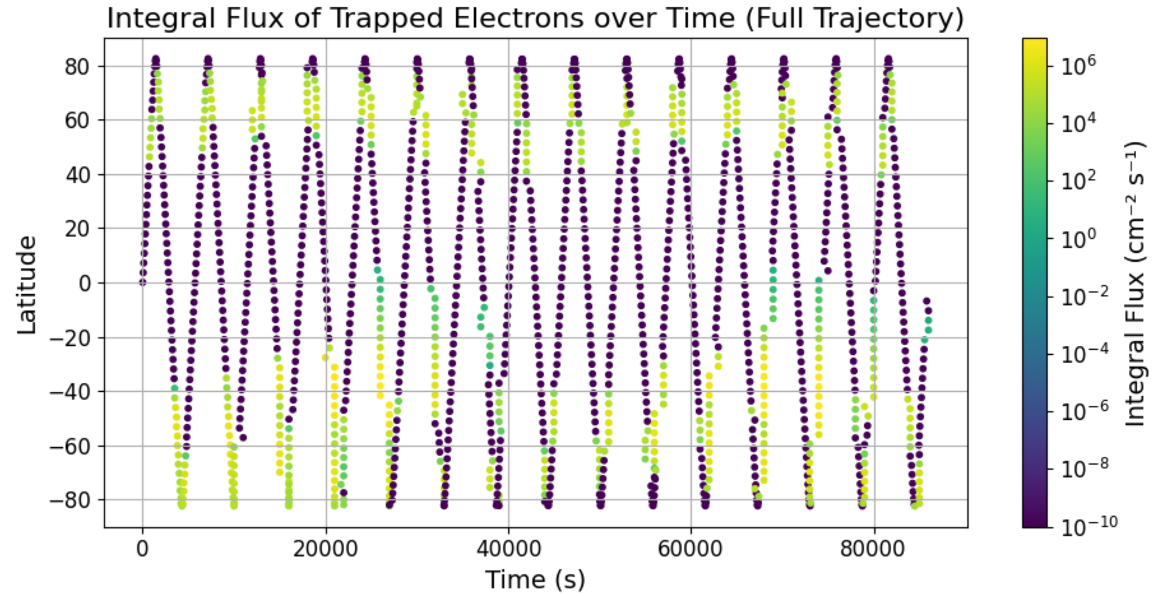
94.4%

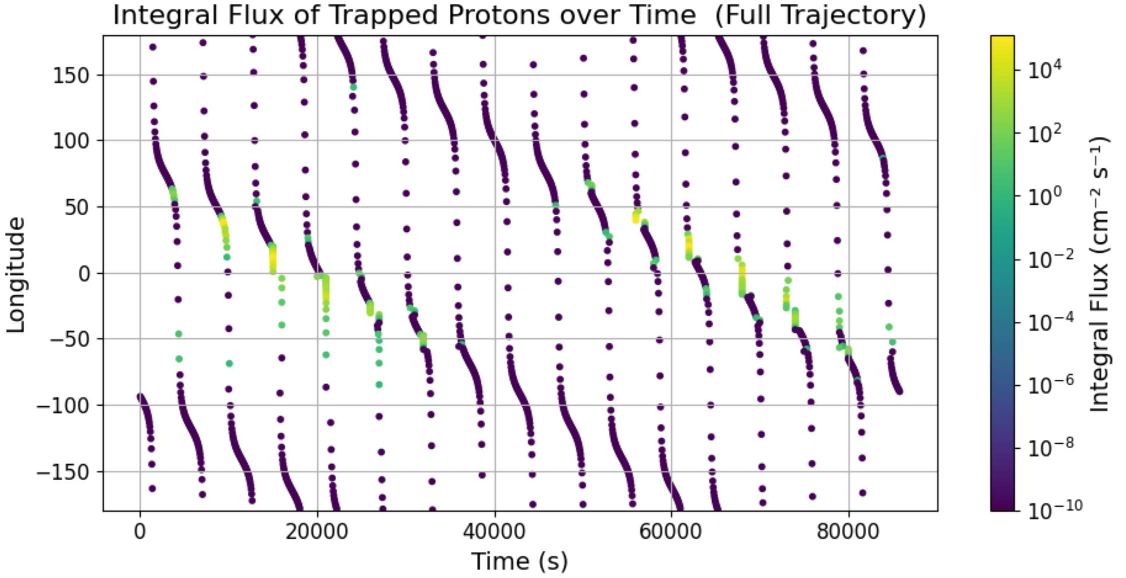


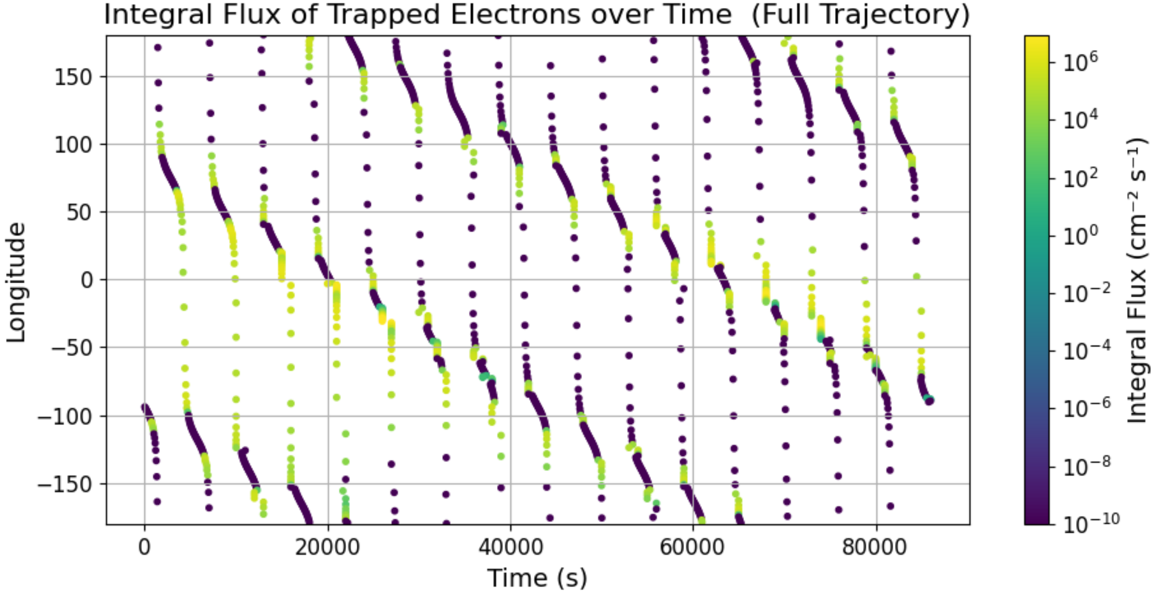


Geographical distribution of the flux over the time



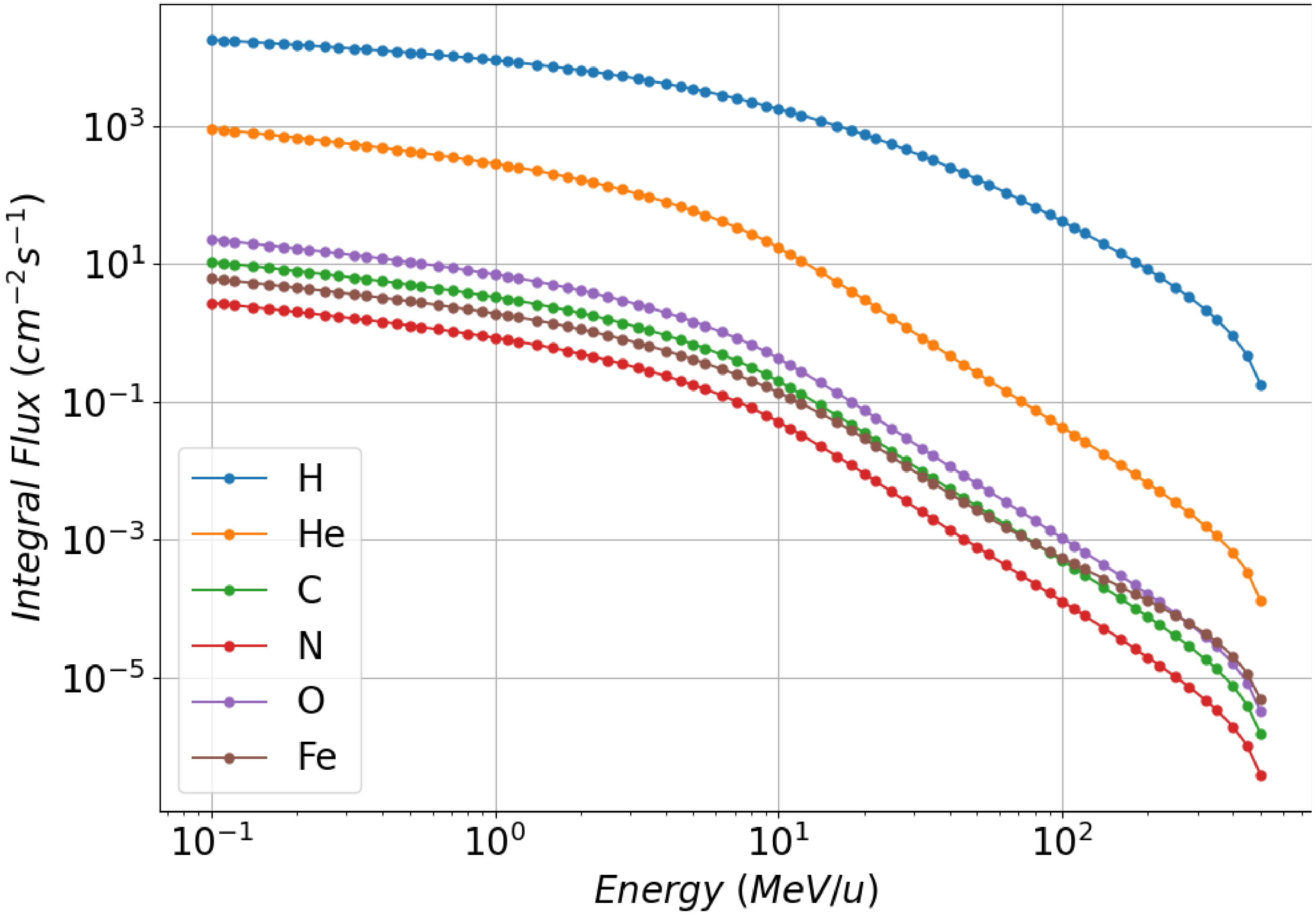






Peak fluxes of Solar Energetic Particles (SEP)

- **Solar model: CREME96 peak flux**



- Integrated flux of several SEP averaged during the "worst week scenario" of 19/10/1989
- Useful for evaluating the effects of solar particles on electronic components
- Useful for future estimation of LET and SEE.

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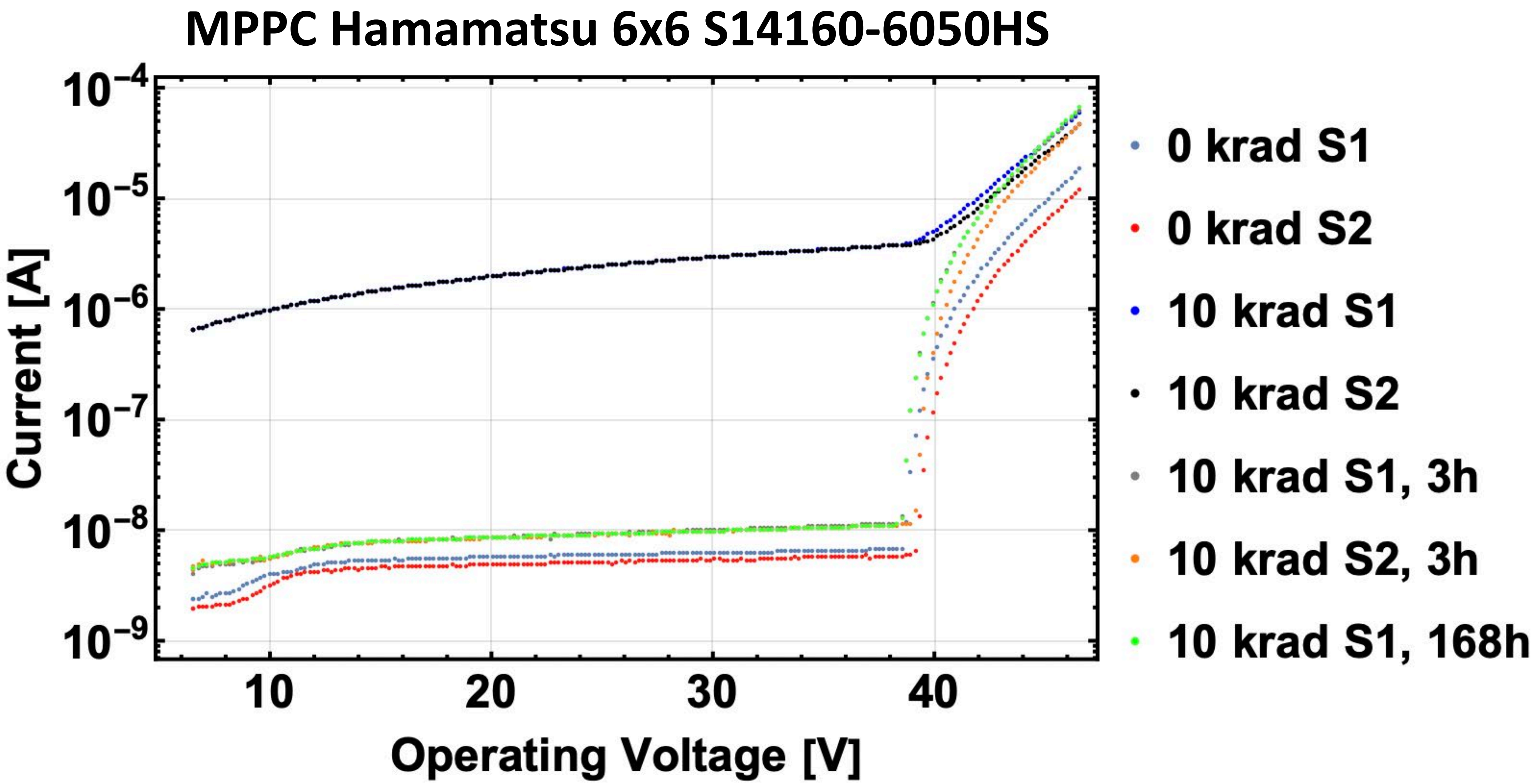
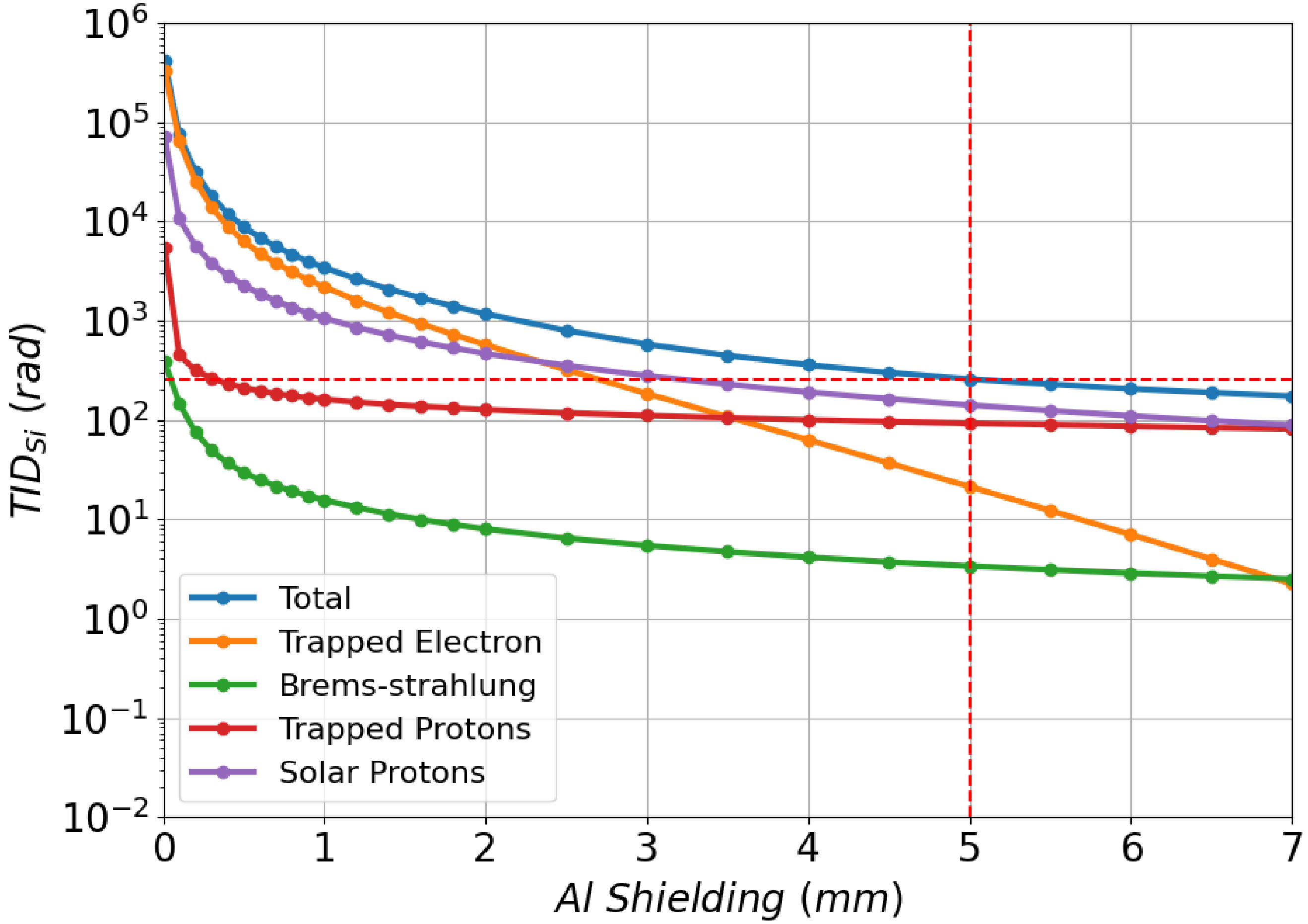
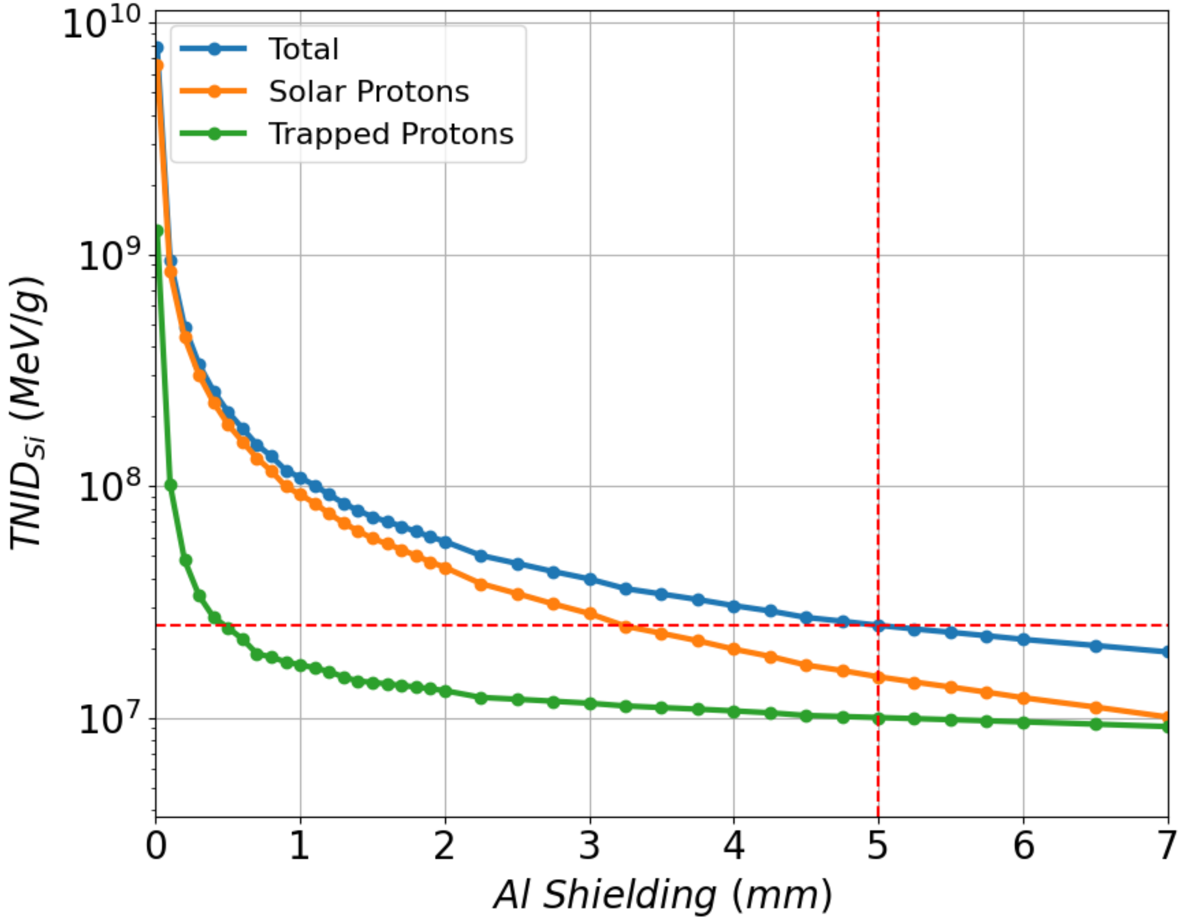
Total Ionizing Dose irradiation analysis



Total ionizing and non-ionizing dose for 3y mission

Material to simulate the shielding = pure Aluminum (Al)
Material to simulate the detector = Silicon (Si)





Nuses mission: shielding configuration for zirè SiPMs

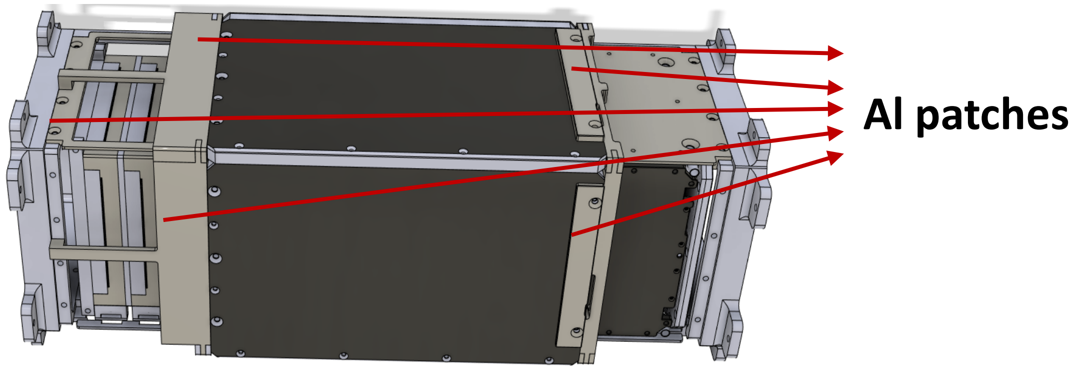
1. **Inside the tray:** $\mathrm{gr} = 0.47\frac{g}{cm^2}$,

$$\rho_{Al} = 2.68\frac{g}{cm^3}$$

$$\Delta_{Al} = \frac{0.47}{2.68} = 1.8\ mm\ Al$$

2. **Top Panel**: $\mathrm{gr} = 0.66\frac{g}{cm^2}$, $\rho_{Al} = 2.68\frac{g}{cm^3}$

$$\Delta_{Al} = \frac{0.66}{2.68} = 2.5\ mm\ Al$$



3. **PCB**: $\rho = 1.4\frac{g}{cm^3}, \rho_{Al} = 2.68\frac{g}{cm^3}$

$$\rho_{eq} = \frac{1.4}{2.68} = 0.5\rho_{Al}$$

4. **Plastic**: $\rho = 1\frac{g}{cm^3}, \rho_{Al} = 2.68\frac{g}{cm^3}$

$$\rho_{eq} = \frac{1}{2.68} = 0.37\rho_{Al}$$

5. **LYSO**: $\rho = 7.16\frac{g}{cm^3}, \rho_{Al} = 2.68\frac{g}{cm^3}$

$$\rho_{eq} = \frac{7.16}{2.68} = 2.68\rho_{Al}$$

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GSSI

Future plans with NUSES

Characterization and space qualification of SiPMs with mission values:

- Single Event Test
- Total non-Ionizing Dose Test (TBC)

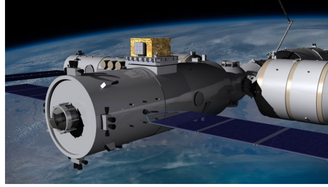
Characterization and space qualification of the electronic boards of the payloads with mission values:

- Total Ionizing Dose test
- Single Event Test

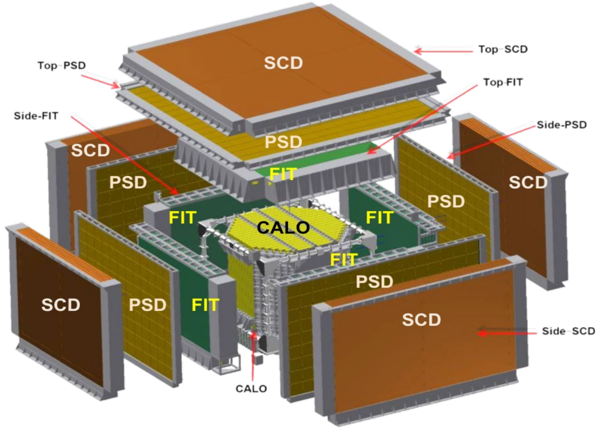
Possible internship at European space agency, ESA, and work on SiPMs:

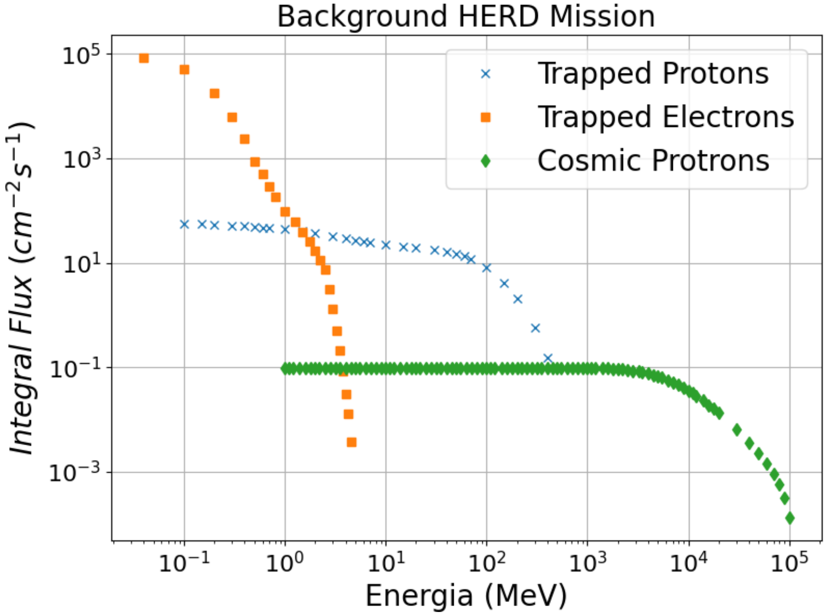
- Total Ionizing Dose test
- Thermal cycle test
- Thermal vacuum cycle test
- OutGassing test
- Writing of documentation

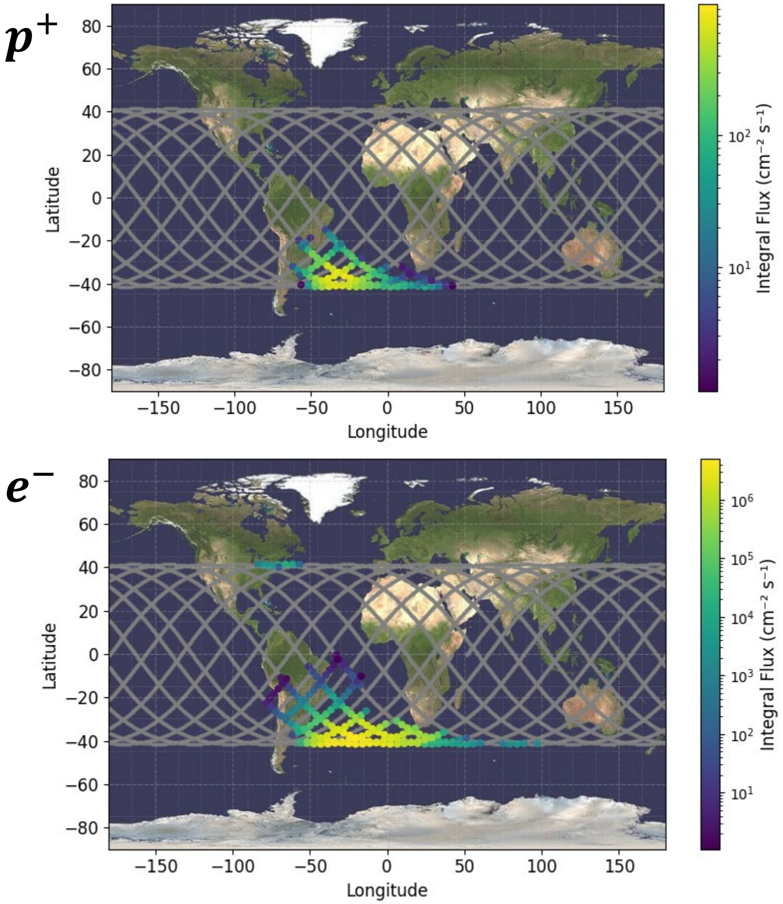
Radiation Characterization for the HERD mission

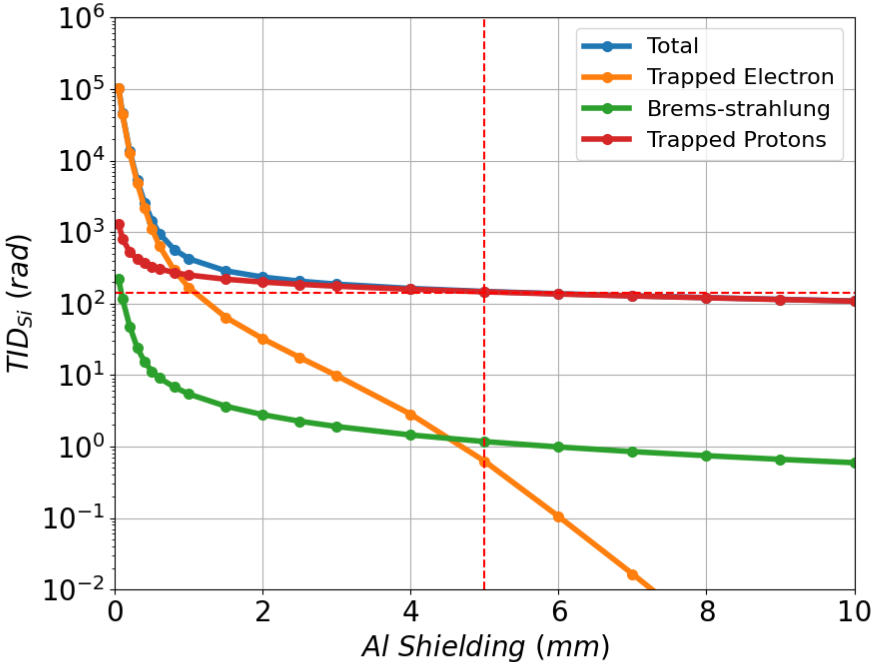


- International scientific collaboration led by China and with relevant contributions from Italian, Spanish & Swiss institutes
- The HERD detector is planned to be installed in 2027 on board of the China's Space Station (CSS)
- Equatorial orbit, with altitude of 400 km and inclination of 41°



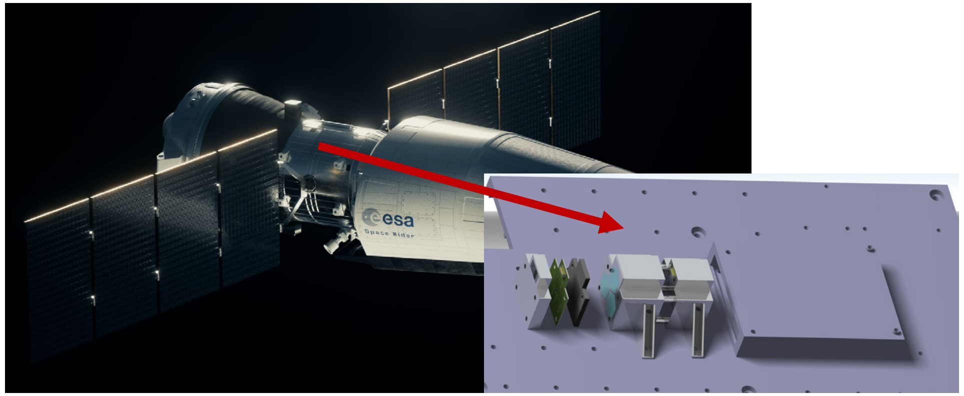


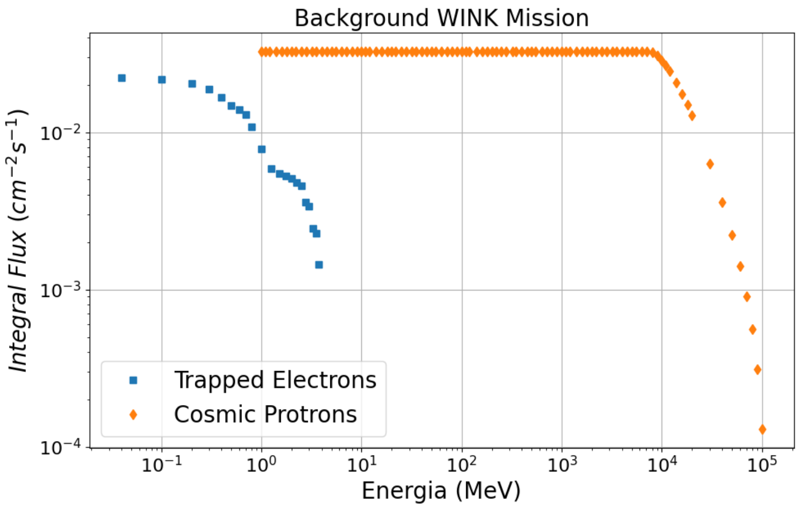


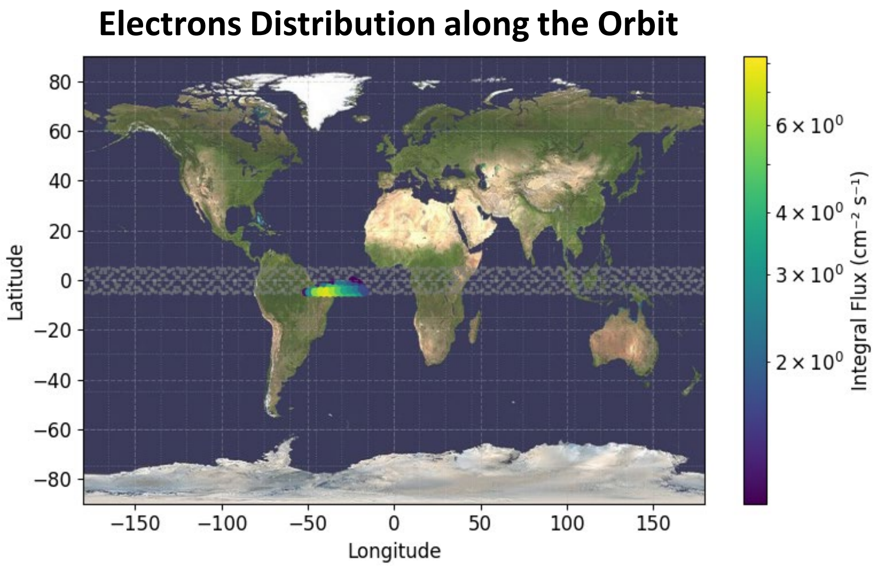


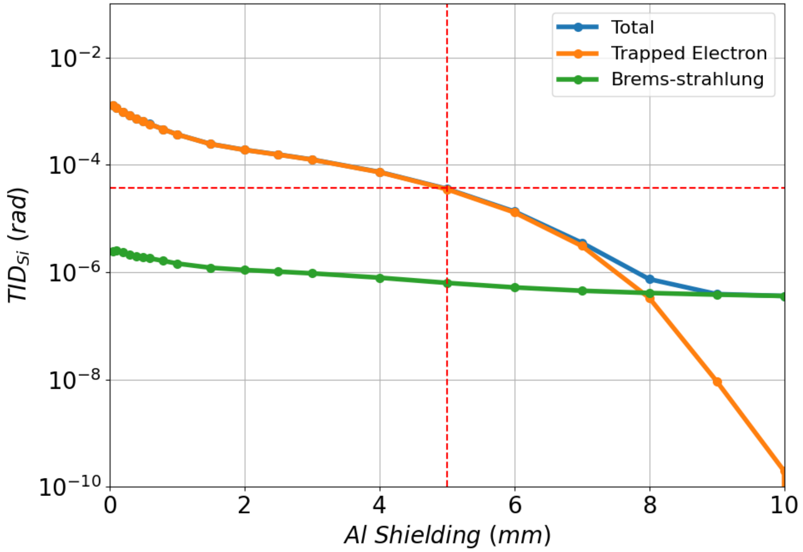
Radiation Characterization for the WINK mission

- Prototype of the Crystal Eye mission headed by the GSSI
- The WINK detector is planned to be installed in 2026 on board the ESA Space Rider spacecraft
- LEO orbit, with altitude of 411 km, eccentricity of 0° and inclination of 5°
- Expected time of the mission 2 months









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Summary

Radiation Hardness for the NUSES space mission:

- Complete analysis of the expected radiation environment for the NUSES mission, in full compliance with ECSS regulations;
- Complete mechanical model definition and radiation shielding simulation of TID and TNID damage and preliminary TID testing on SiPMs;
- Next steps include finalizing new TID and SEE tests, perhaps TNID, for complete characterization of the sensor and readout boards. Possible further mechanical characterization tests of SiPMs during the period at ESA.

Definition the radiation environment for the HERD and WINK space missions that highlighting the strong dependence of the chosen orbit on the hazard environment.

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Workshops and conferences

- ASAPP conference Perugia 19-23/06/2023;
- Ensuring Electronic Reliability Against CERN's Radiation Environment, seminar Napoli 01/12/2023;
- NEW TRENDS AND CHALLENGES IN OPTIMIZATION THEORY APPLIED TO SPACE ENGINEERING conference L'Aquila 13-15/12/2023;
- SST – PhD National Days – 06-08/06/2024 – L'Aquila;
- RADSHIELD ESA/ESTEC 12-15/06/2024 – TALK;
- Società Italiana di Fisica SIF – 09-13/09/2024 -Bologna – TALK;
- Conference in Memory of Veniamin Sergeyevich Berezinsky – 01-03/10/2024 – L'Aquila;
- International Astronautic Congress IAC – 13-18/10/2024 – Milano;

Collaboration meetings

- Talks during working group meetings of HERD 09/11/2023
- Talks during working group meetings of NUSES 26/01/2024

Schools

- 6th HEP C++ course and hands-on training - Essential, virtual, 6-10 mar. 2023
- GEANT4 beginners course "First steps with Geant4 2024", virtual, 15-19 apr. 2024
- 13th international IDPASC school and workshop, Palermo, 17-27 sept. 2024

Other activities

- Working in Bari to test the mechanic structure of the HERD PSD, 12-16 apr. 2023
- Working in Bari to test the mechanic structure of the HERD PSD+ Zirettino prototype, 03-07 jul. 2023
- Test beam at CERN PS for the Zirettino prototype, 3-10 sept. 2023
- Test beam at CERN SPS for the Zirettino prototype, 24-31 oct. 2023
- Test beam at INFN-LNF for the Zirettino prototype, 19-26 feb. 2024
- Test beam at PIF Zurich for the GST DC/DC converter test, 12-17 may.2024

Outreach activities

Scientific publications

- PoS ICRC2023 (2023) 1538
- NIM-A 1068 (2024) 169794
- NIM-A 1068 (2024) 169706
- IWASI (2023) pp. 184-189, doi: 10.1109/IWASI58316.2023.10164305
- NIM-A 1069 (2024) 169888

Exams during the first year

1. Introduction to nuclear and particle physics
2. Introduction to radiation detection techniques
3. Cosmic Radiation and Radiation Hadness Assessment
4. Front-end electronics and DAQ systems for radiation detection
5. Numerical modeling of space structures
6. Project Management
7. Space Policy and Governance

BACKUP

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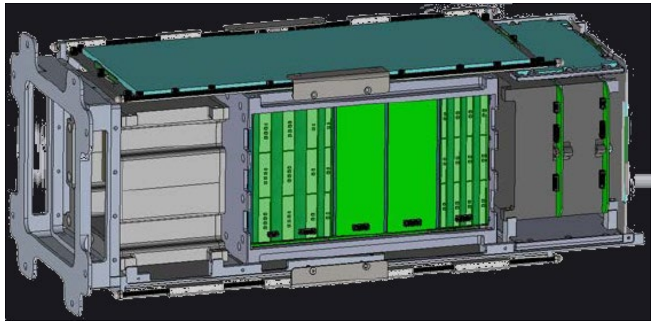

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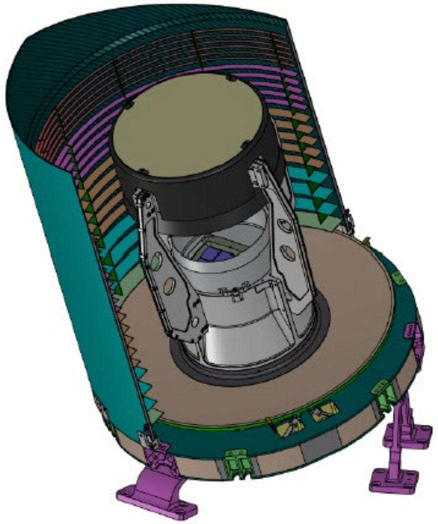

- To measure **UHE cosmic rays** and enable **neutrino astronomy** through space-based atmospheric Cherenkov light detection

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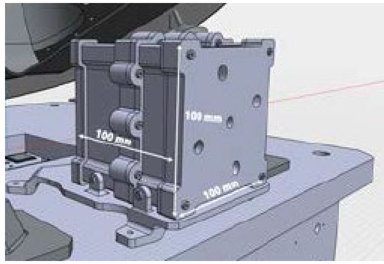

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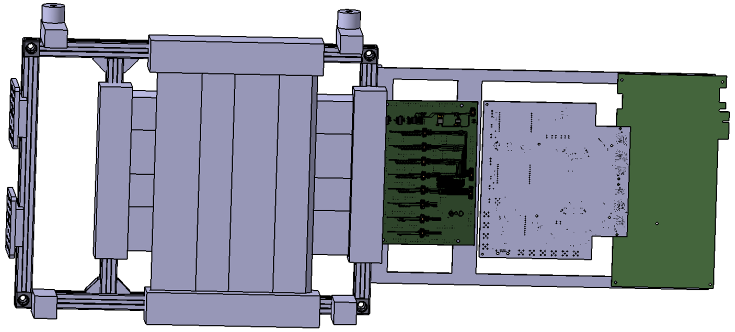
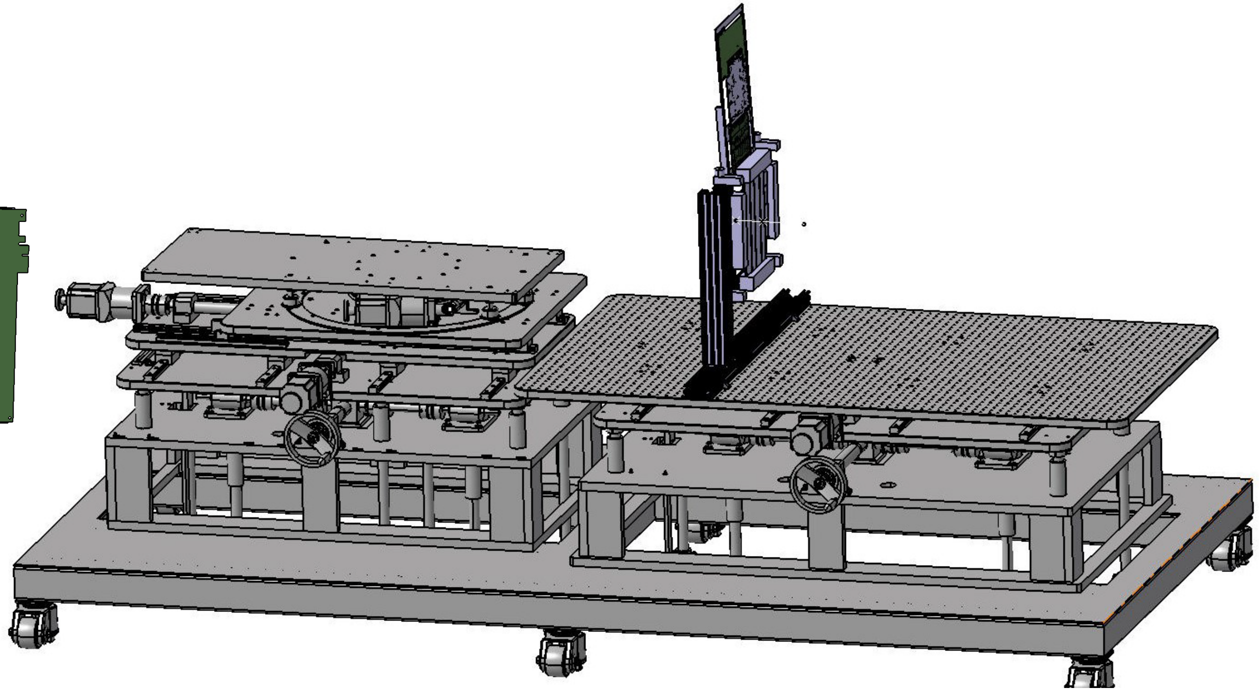
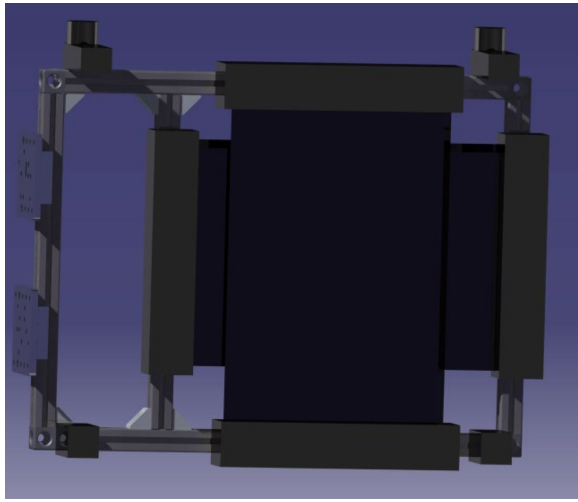
Mechanical design of HERD PSD and WINK prototype

HERD, PSD:







CRYSTAL EYE, WINK: