

Innovative detector systems for space habitat radiation monitoring

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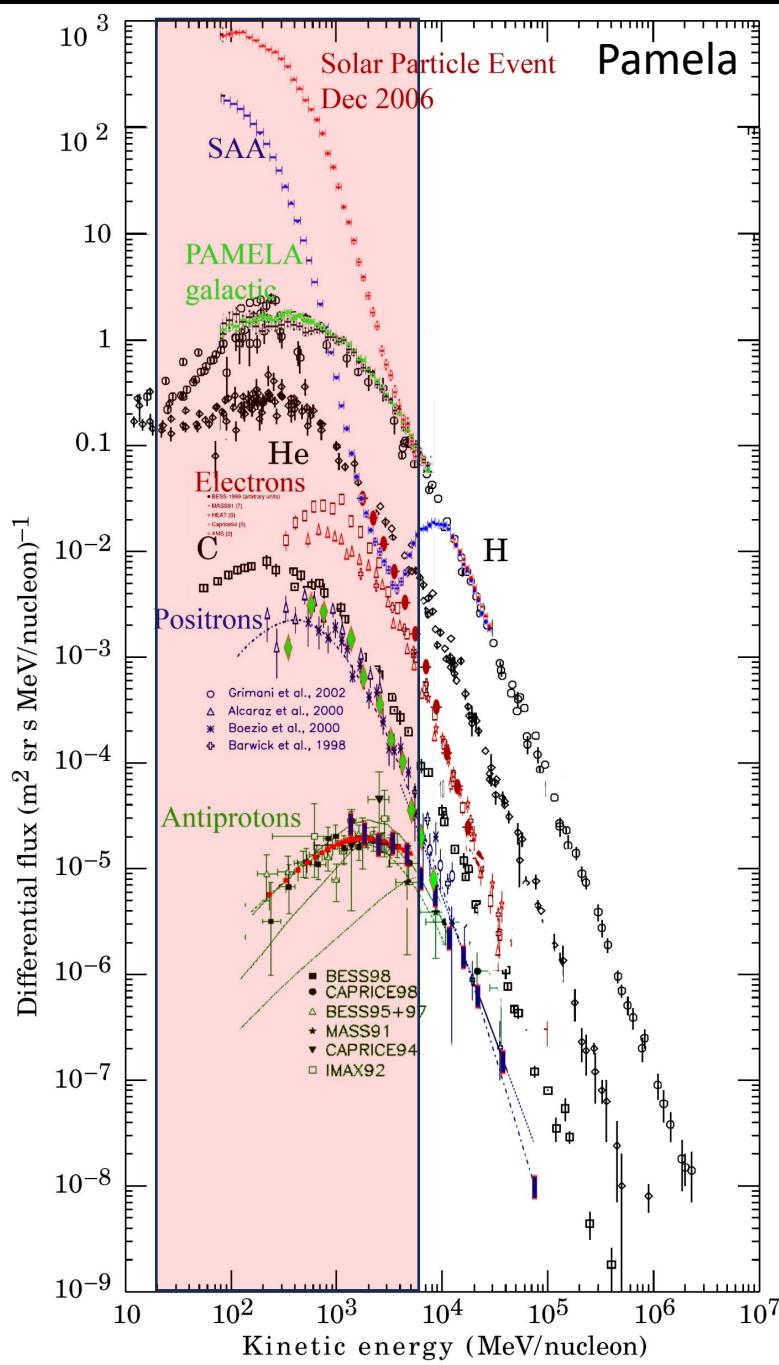
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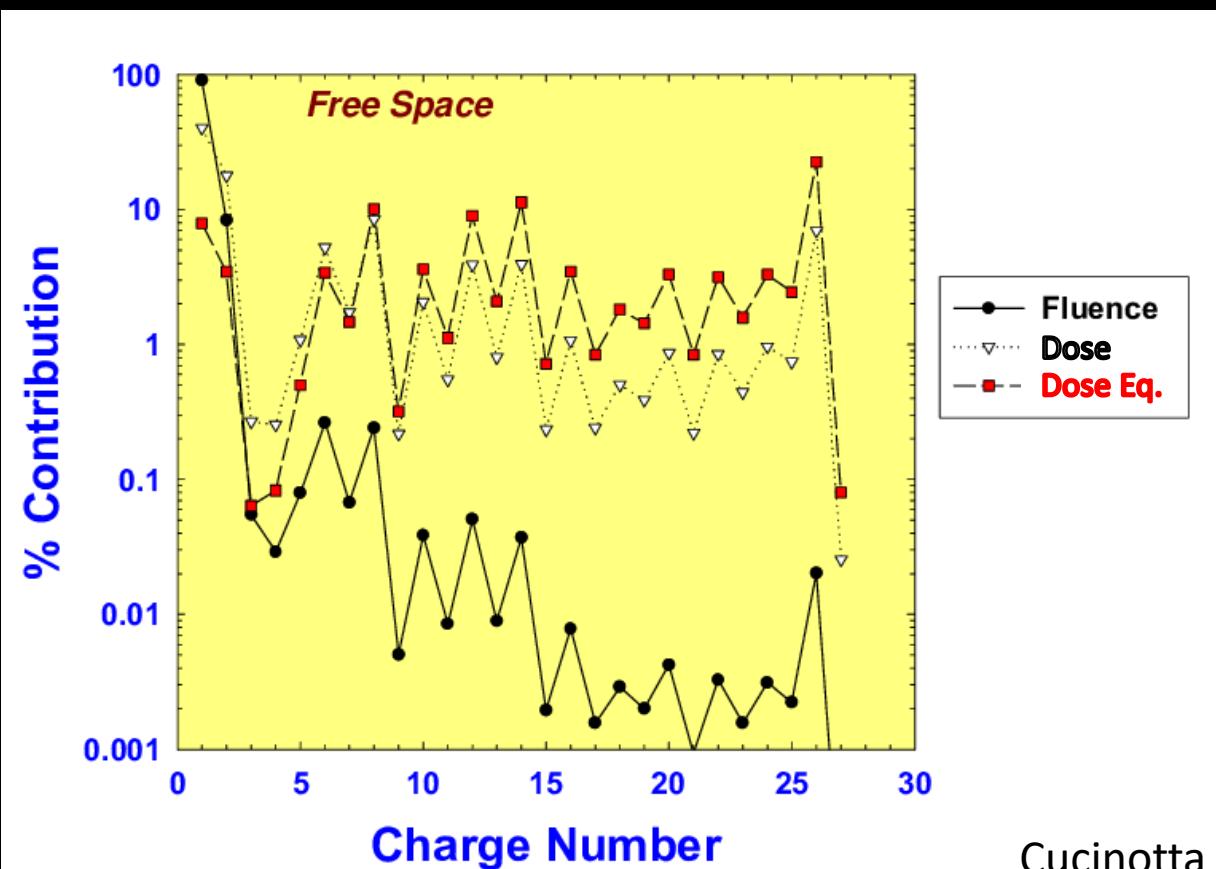
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Radiation Environment

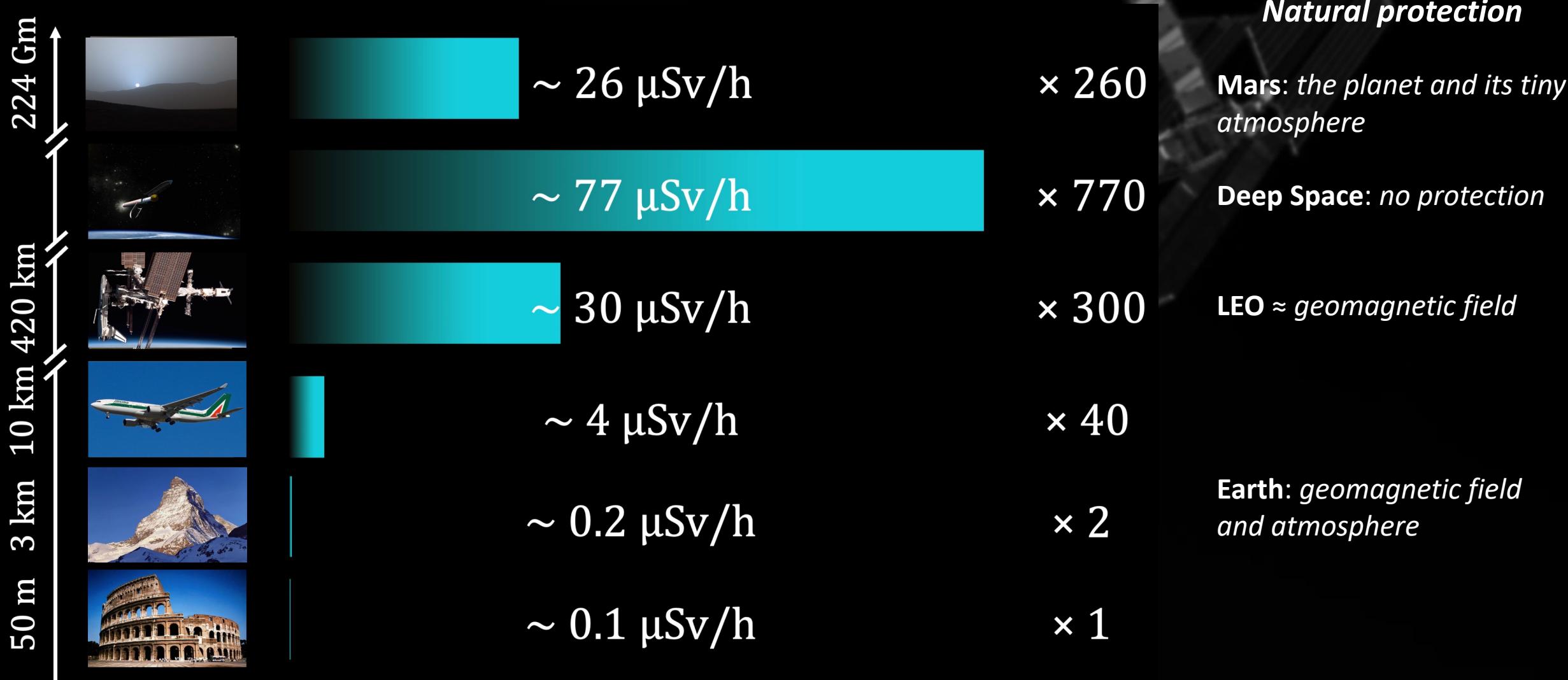


- Protons [GCR & SPE + Trapped (LEO)]
- Ions ($Z>1$, $Z\leq 26$) [GCR]
- Energy ($10 \leq E \leq 10^{3-4}$ MeV/n)
- Secondary particles + neutrons

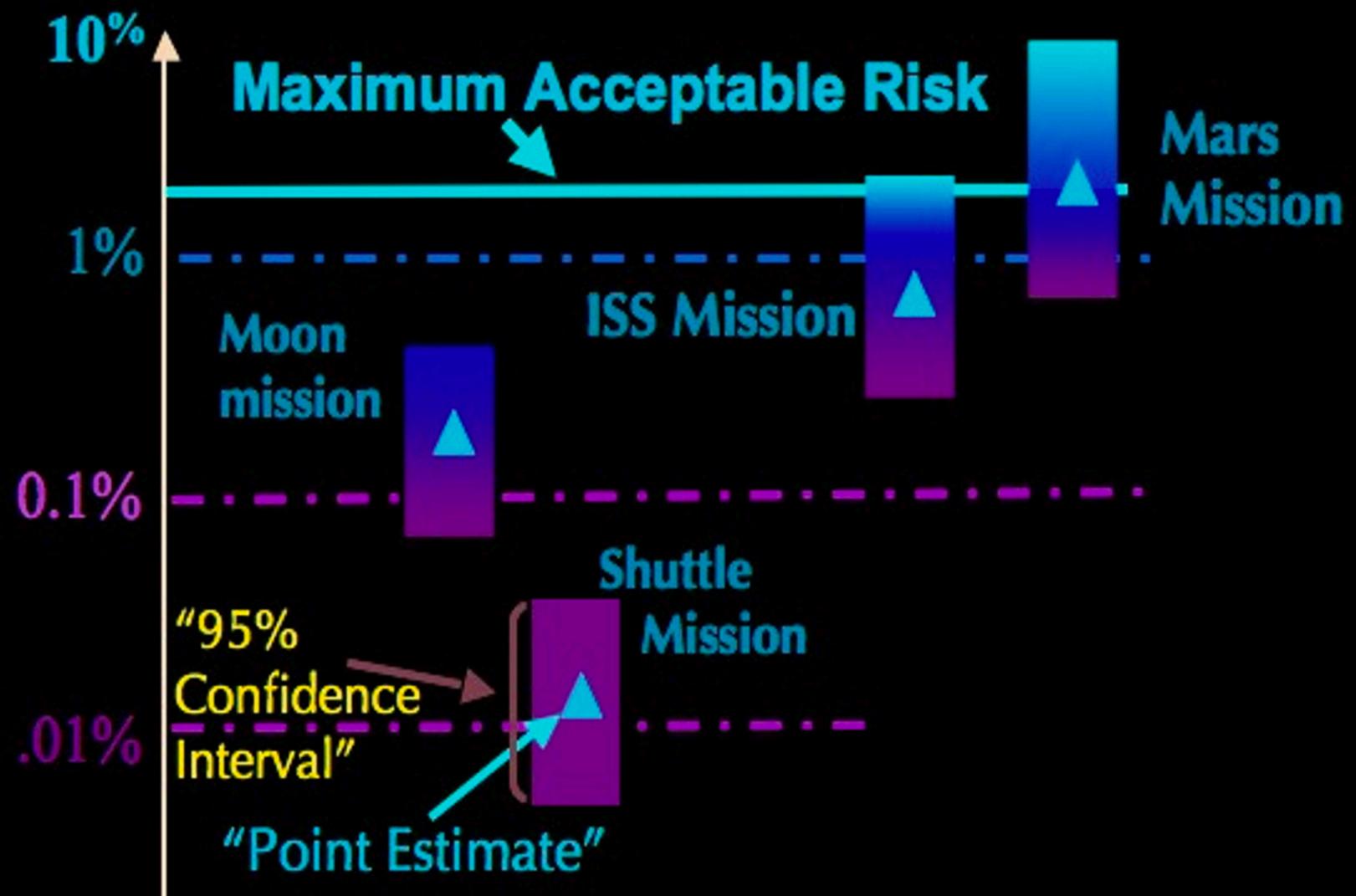


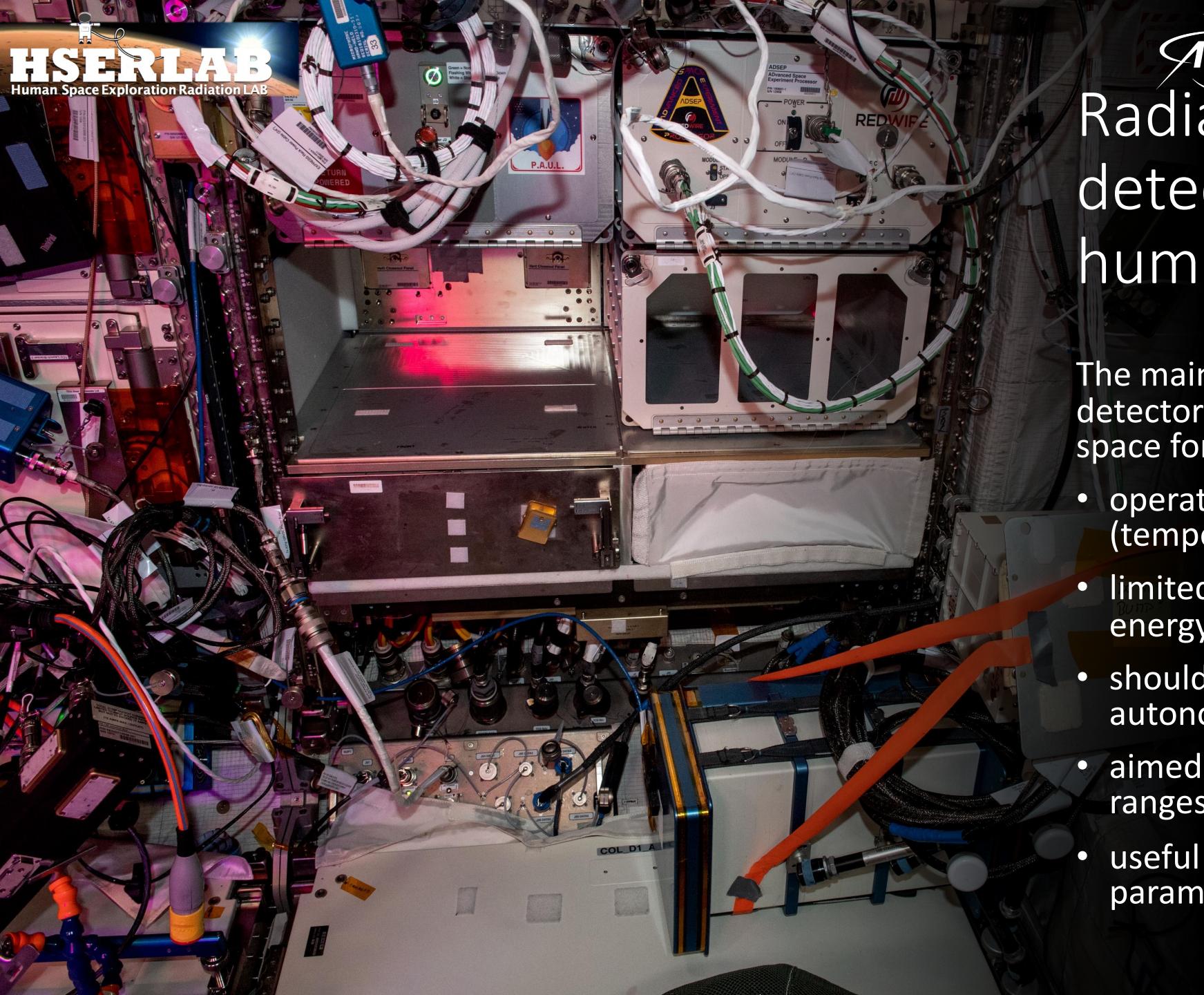
Cucinotta

Radioprotection in space



Radiation risk





Radiation detectors for human exploration

The main differences with detectors on ground and / or in space for astroparticle physics:

- operate inside a habitat (temperature, pressure)
- limited budgets (volume, mass, energy)
- should work unattended in total autonomy
- aimed at the Z and Energy ranges mentioned before
- useful to provide physical parameters for risk assesment

Detector characteristics

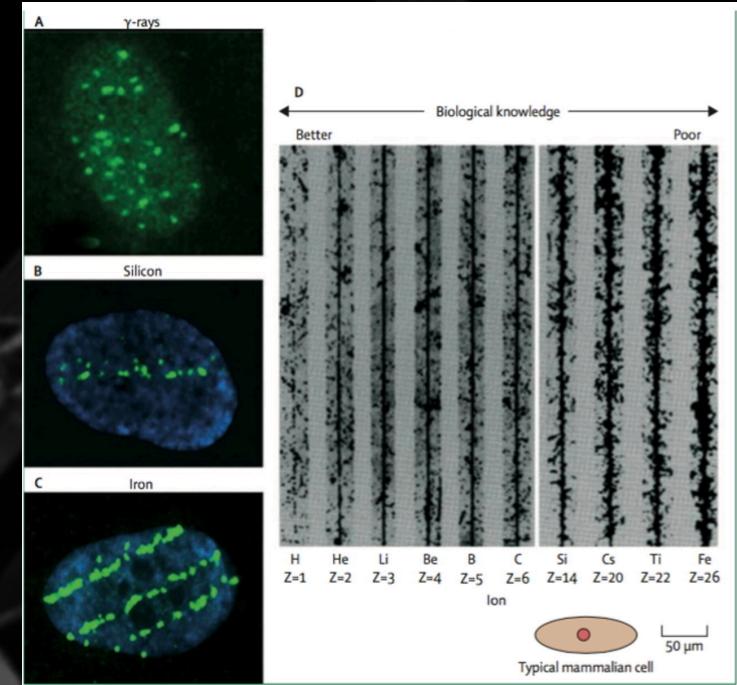
The need for small budgets may suggest to have

- Modular systems: several sensors aimed at specific radiation field targets, with a single data management unit
- Discrete systems: several systems located in different positions in the spacecraft / base, with a single data management unit

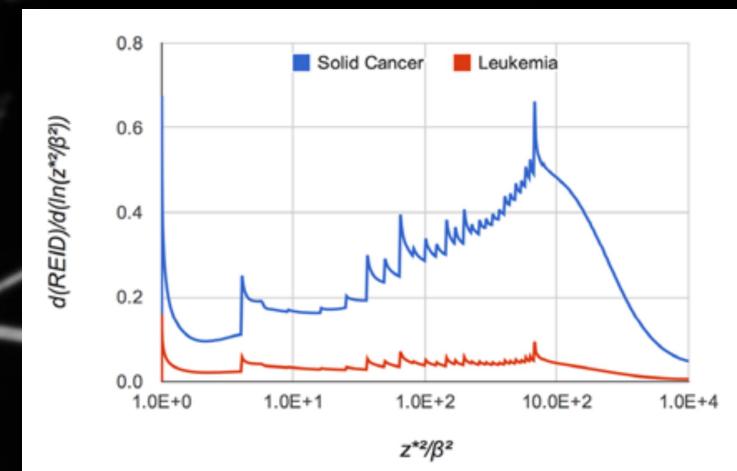
Dose and other physics variables

In principle these are the physics variables of interest for risk assessment:

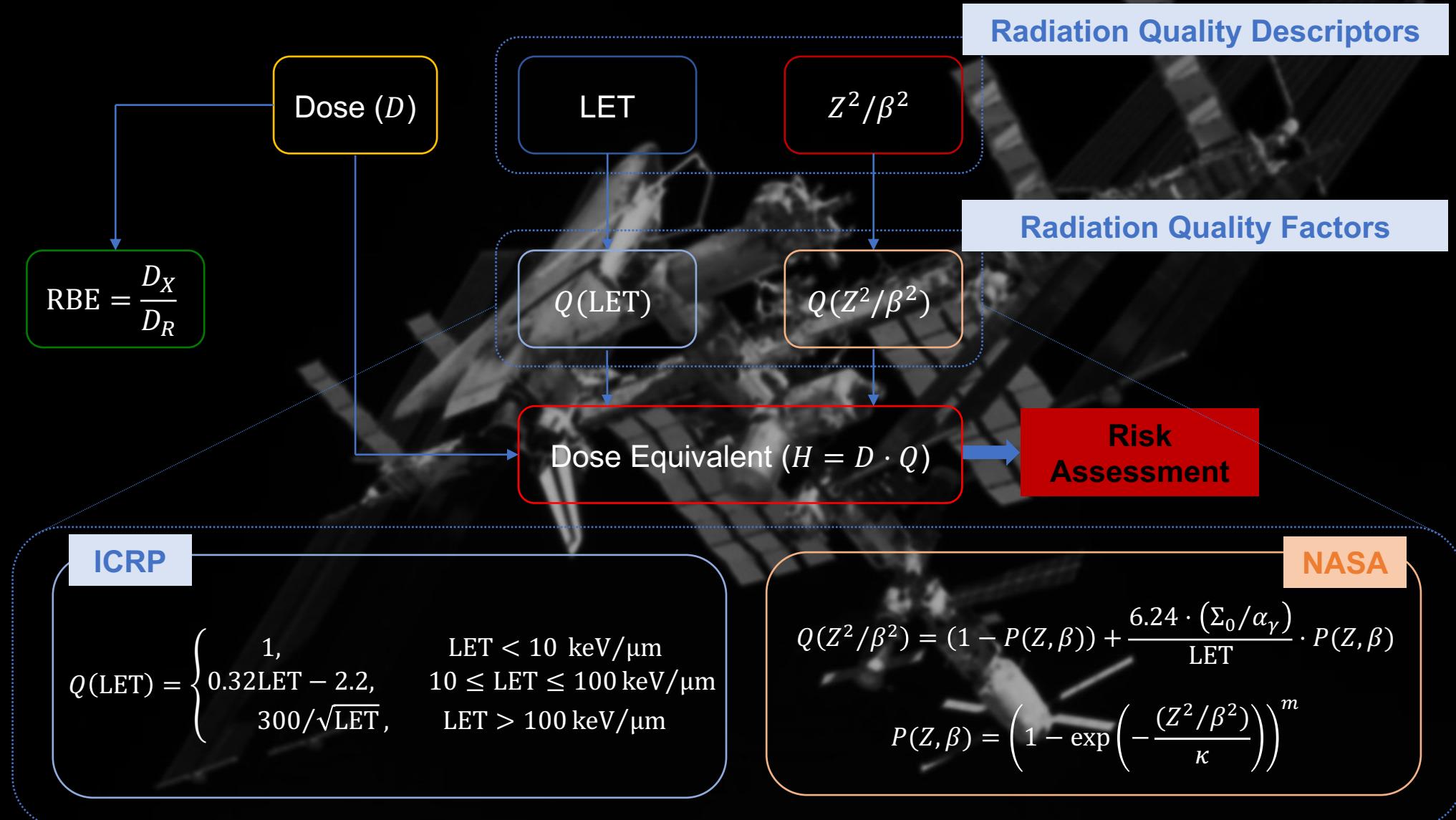
- LET
- Dose
- Z
- Kinetic energy (\rightarrow Time of Flight, β)



Risk evaluation has been based on Dose, now many biological experiments showed Dose inefficacy



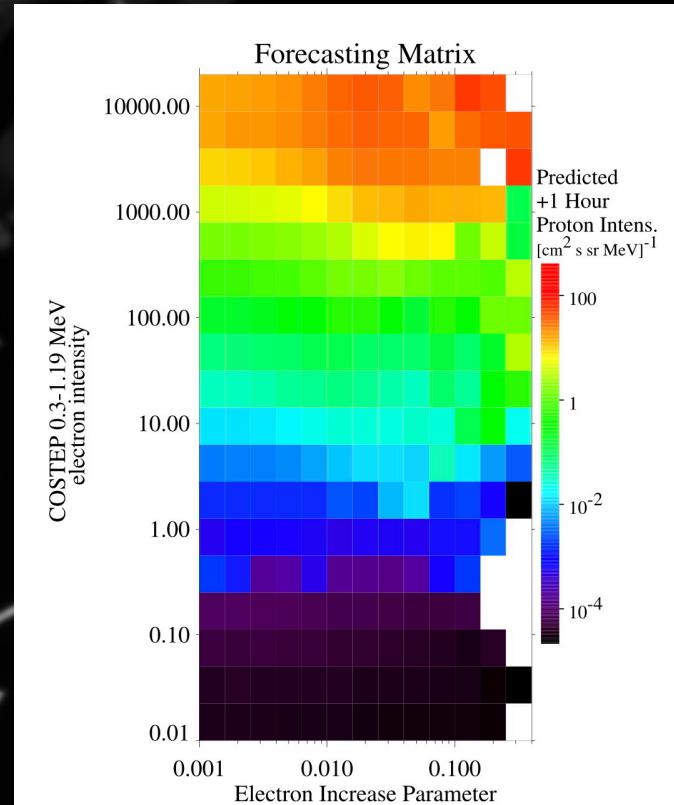
Risk evaluation



The needs for detectors for human exploration

Three major areas where detectors are needed:

- Monitoring
 - real time risk evaluation
- Model validation
- Monitor ‘outside changes’ → SPE nowcasting



Ideas for a new detector system: goals

New detectors should fullfil the mentioned needs:

- Measuring (or evaluating) ion by ion LET, Z, β , trajectory
- Be linked to risk model
- Real time autonomous presentation/alarms to the crew
- Neutron measurements

Ideas for a new detector system: sensors

Existing technologies (Si) to be transferred to space

- replace PMTs with SiPMs for light readout in fast scintillating materials
- use MAPS to improve hit resolution in pixel structure
- timing readout integrated in the tracking system with LGADs

New materials

- Scintillators with pulse-shape discrimination (PSD) capability (EJ-270, EJ-276, organic glass...- [Pinilla-Orjuela 2023](#))

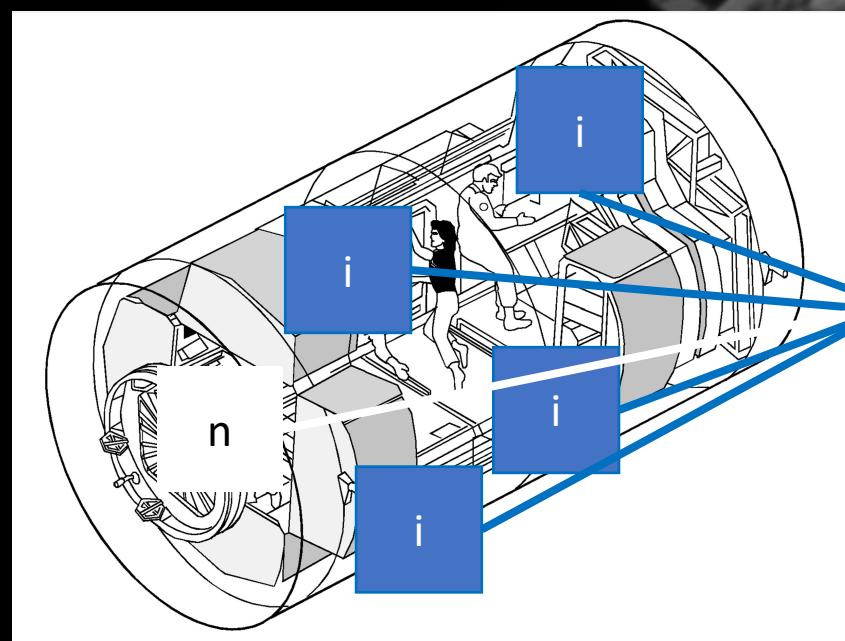
New production techniques

- 3D-printed plastic scintillators ([Kaplon 2022](#))

Considering new and existing materials to minimize budgets maximizing features

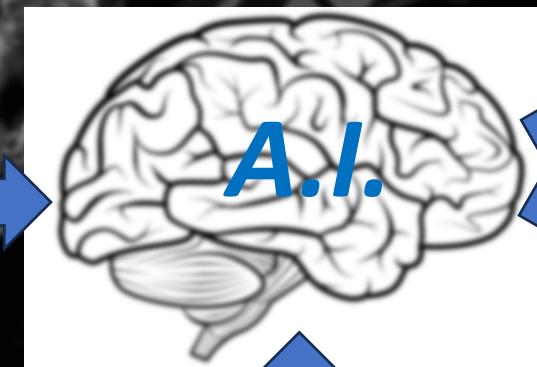
Ideas for a new detector system: architecture

- Studying the optimal distributed and/or modular detector system
- Exploiting the info from all detectors in the system
- if/when needed use AI techniques



For each
detector
location

Z
E
dir
LET



Risk Model

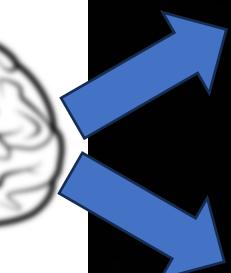
Habitat CAD



In the whole
habitat

Z
E
dir
LET

Risk



Starting from Sileye-ALTEA experience



1995-1998
Sileye 1
MIR



1998-2000
Sileye 2
MIR



2002-2006
Alteino
ISS



2006-2009
ALTEA
ISS



2010-2011
ALTEA-3D
ISS



2012
ALTEA-Shield
ISS

2020 - *
LIDAL
ISS

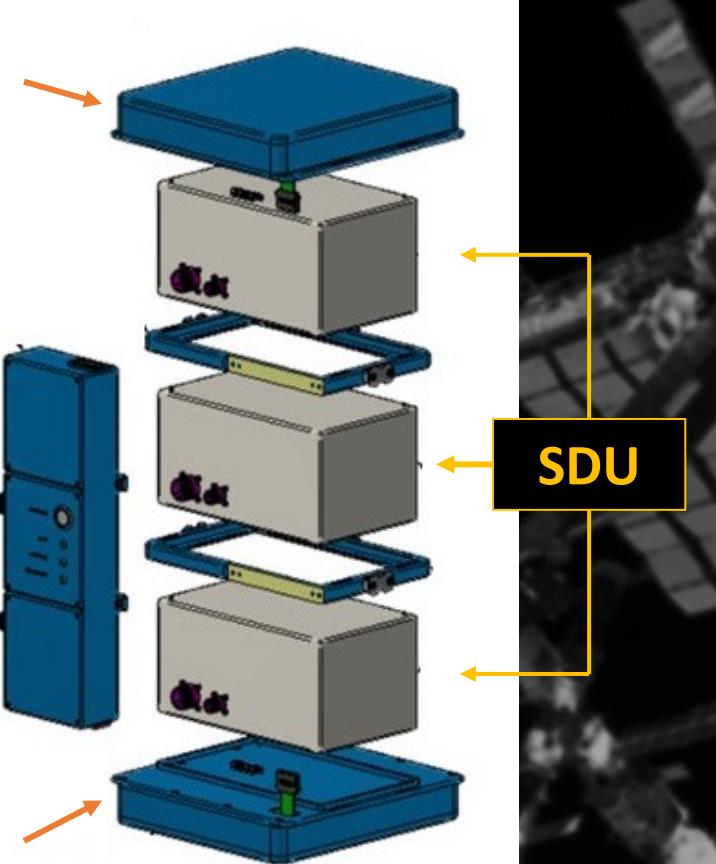


Light Ion Detector for ALtea (LIDAL)

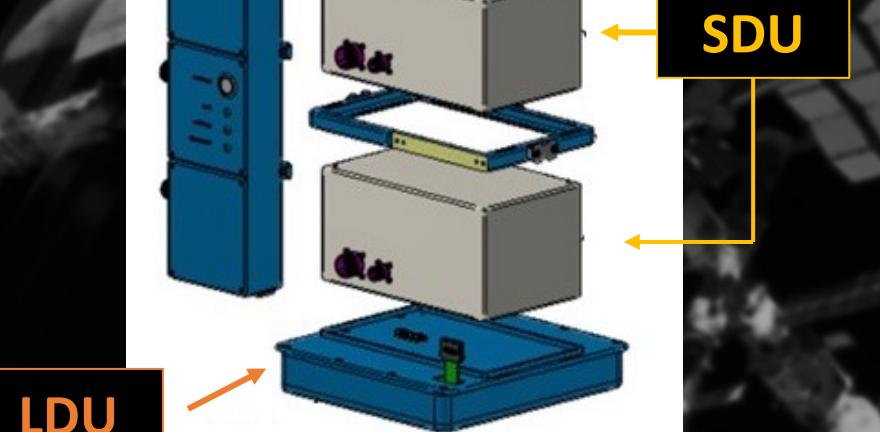
Operative between January 2020 and, at least, 2024



LDU



LDU



SDU (Silicon Detector Unit)

- 6 Silicon planes
- LET measure
- Particle tracking
- Self-trigger at $3 \text{ keV}/\mu\text{m}$

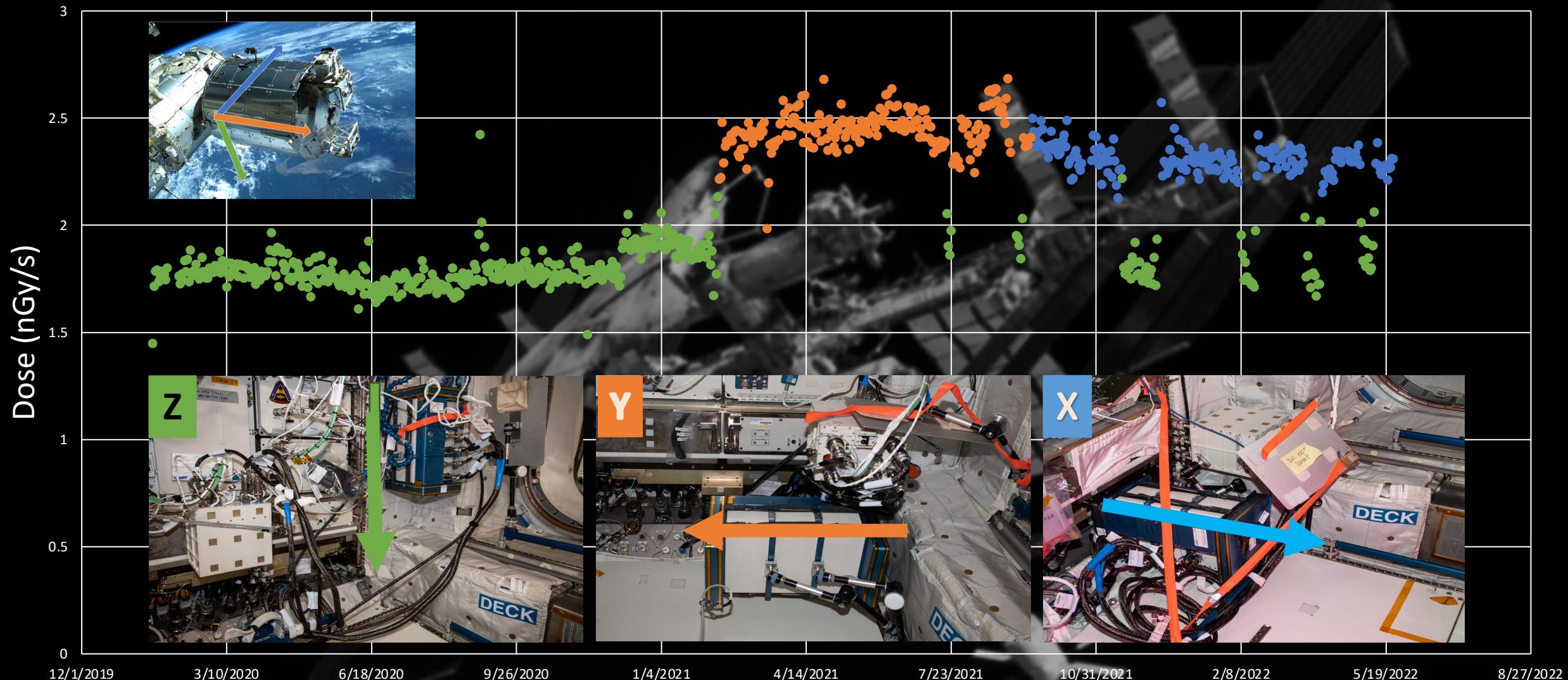
LDU (LIDAL Detector Unit)

- 8 Plastic scintillators
- Time of Flight (70 ps) measure
- Particle tracking
- SDU under threshold measurements ($2.3 \text{ keV}/\mu\text{m}$)

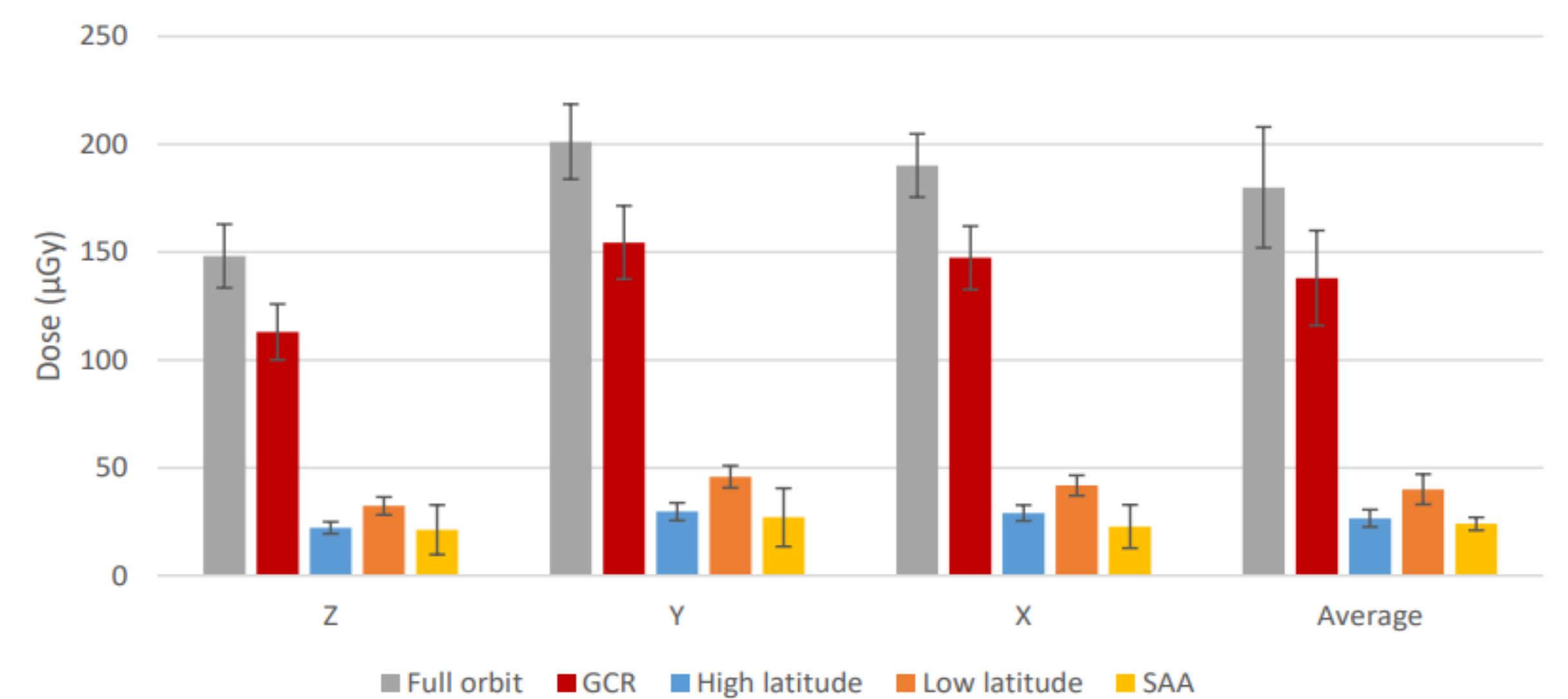
LIDAL detector on board the ISS

Scheme of LIDAL system

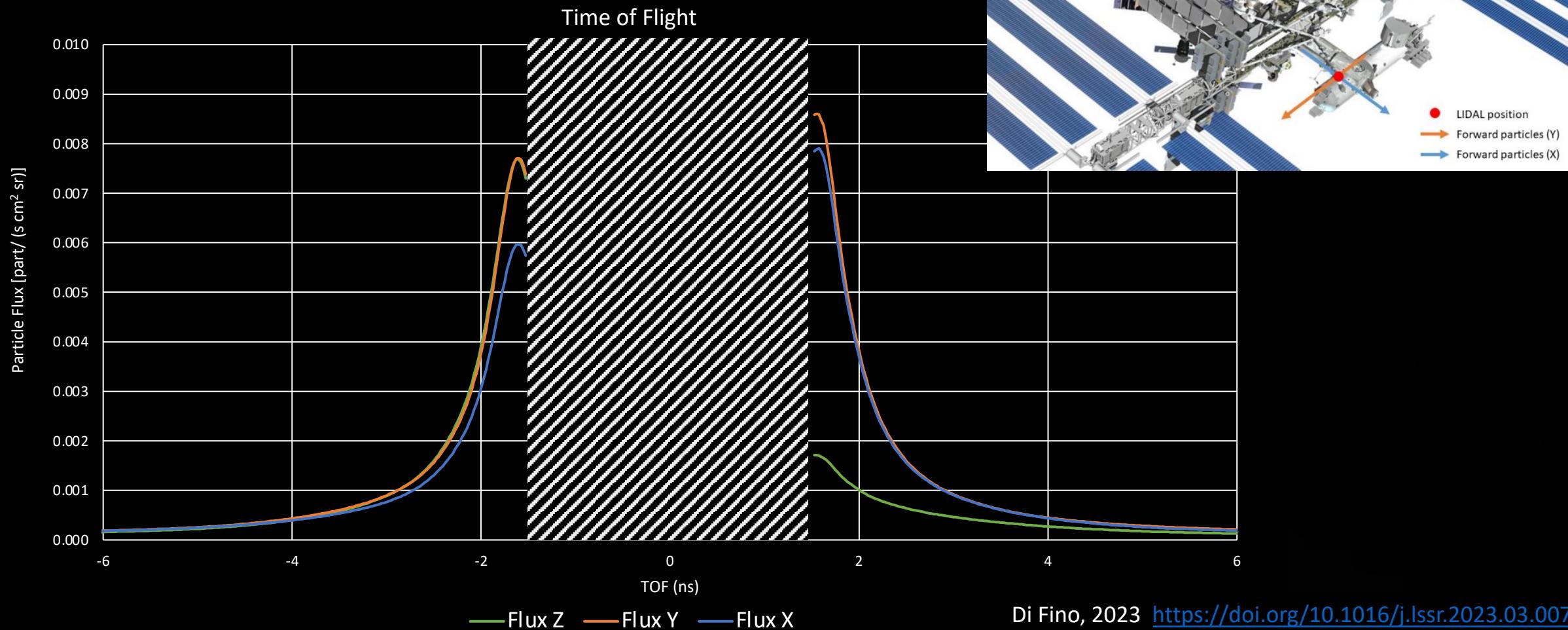
Daily Dose rate



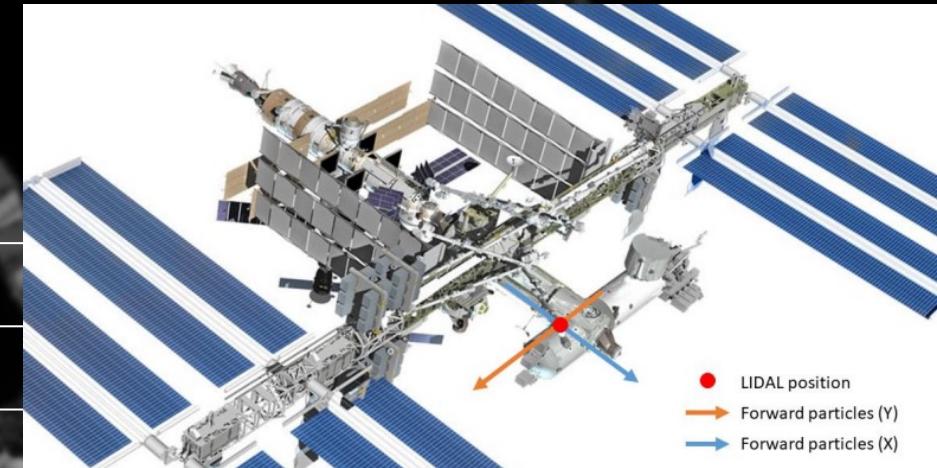
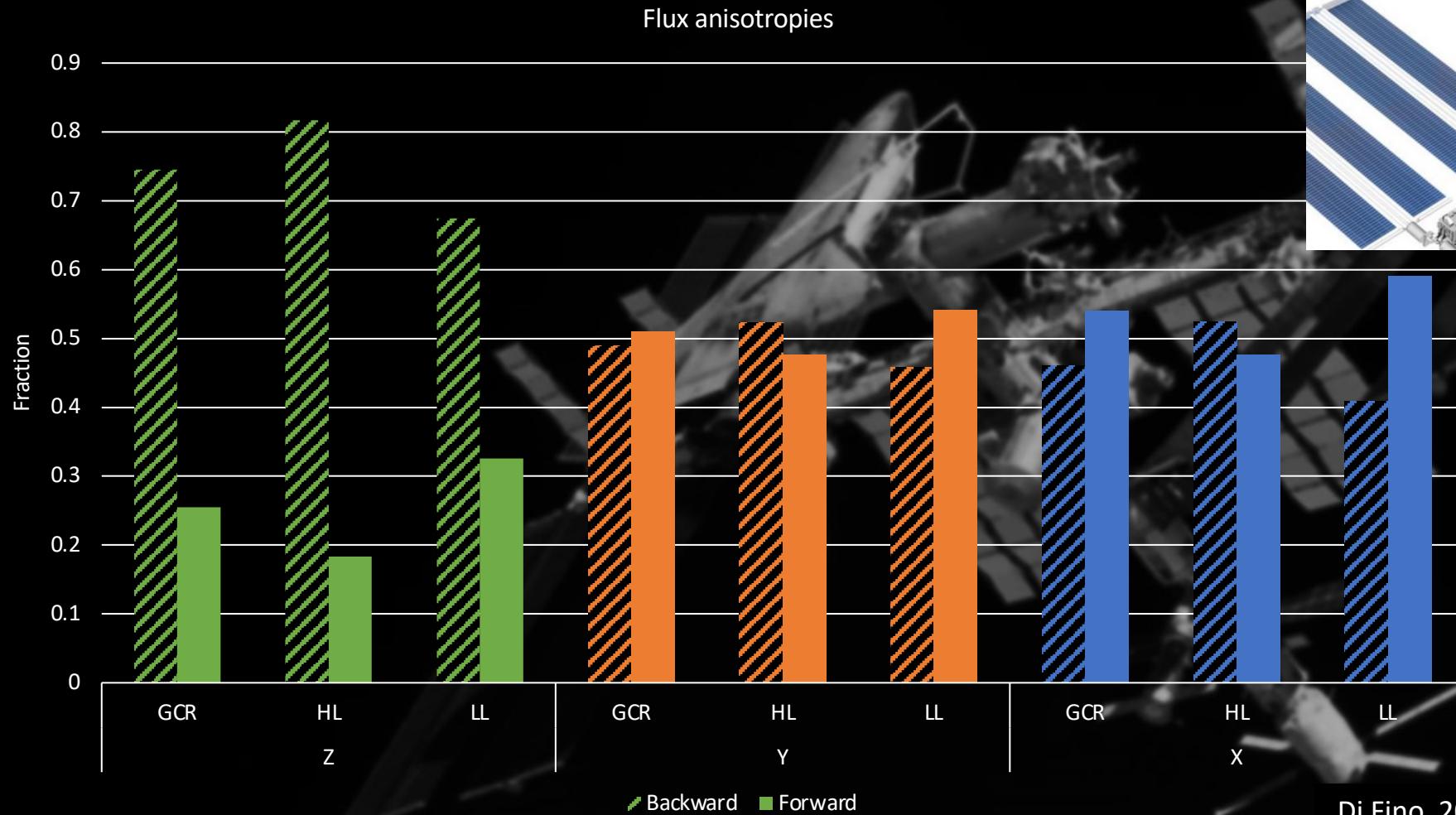
Integrated dose per day



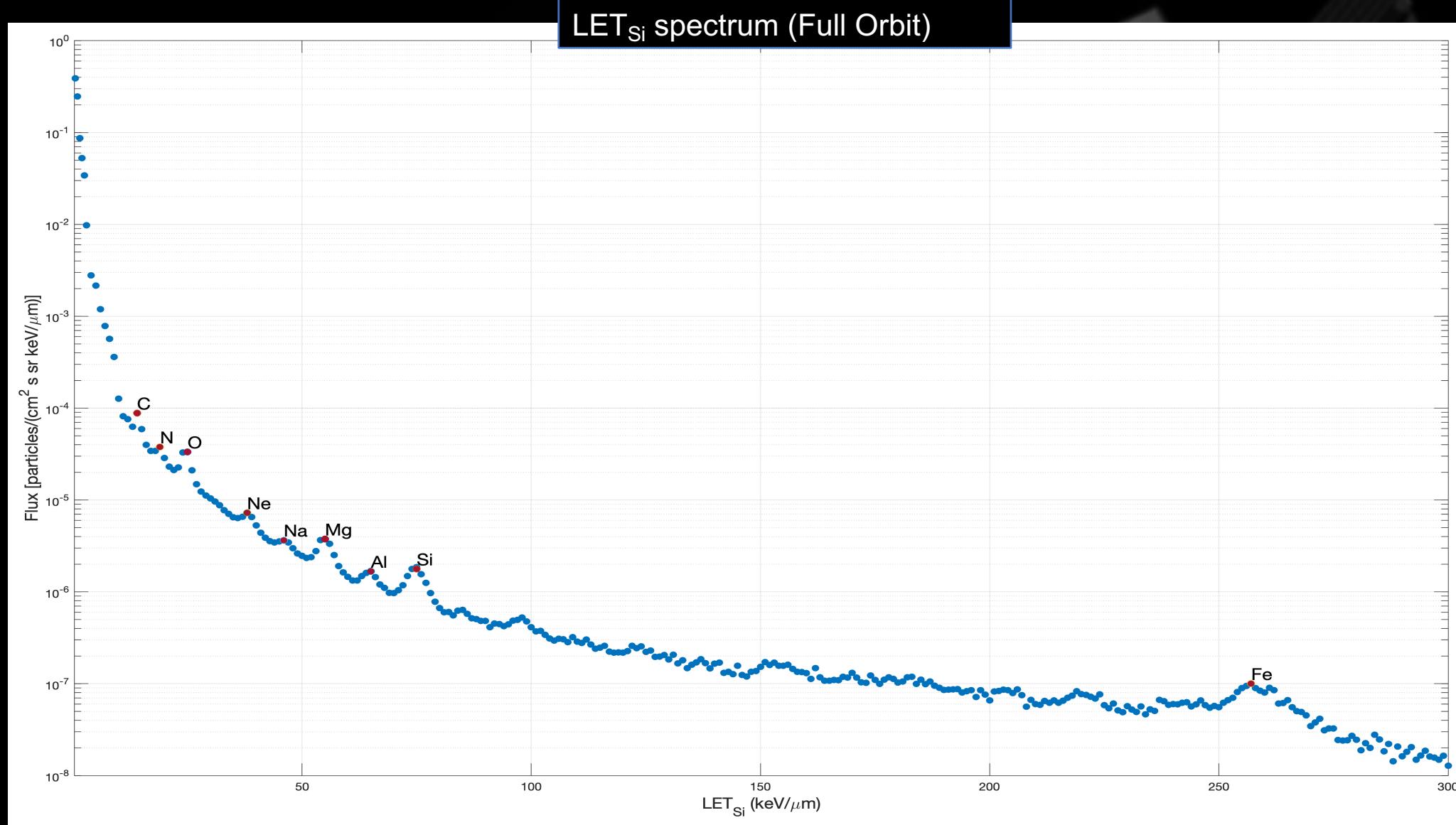
ToF spectra



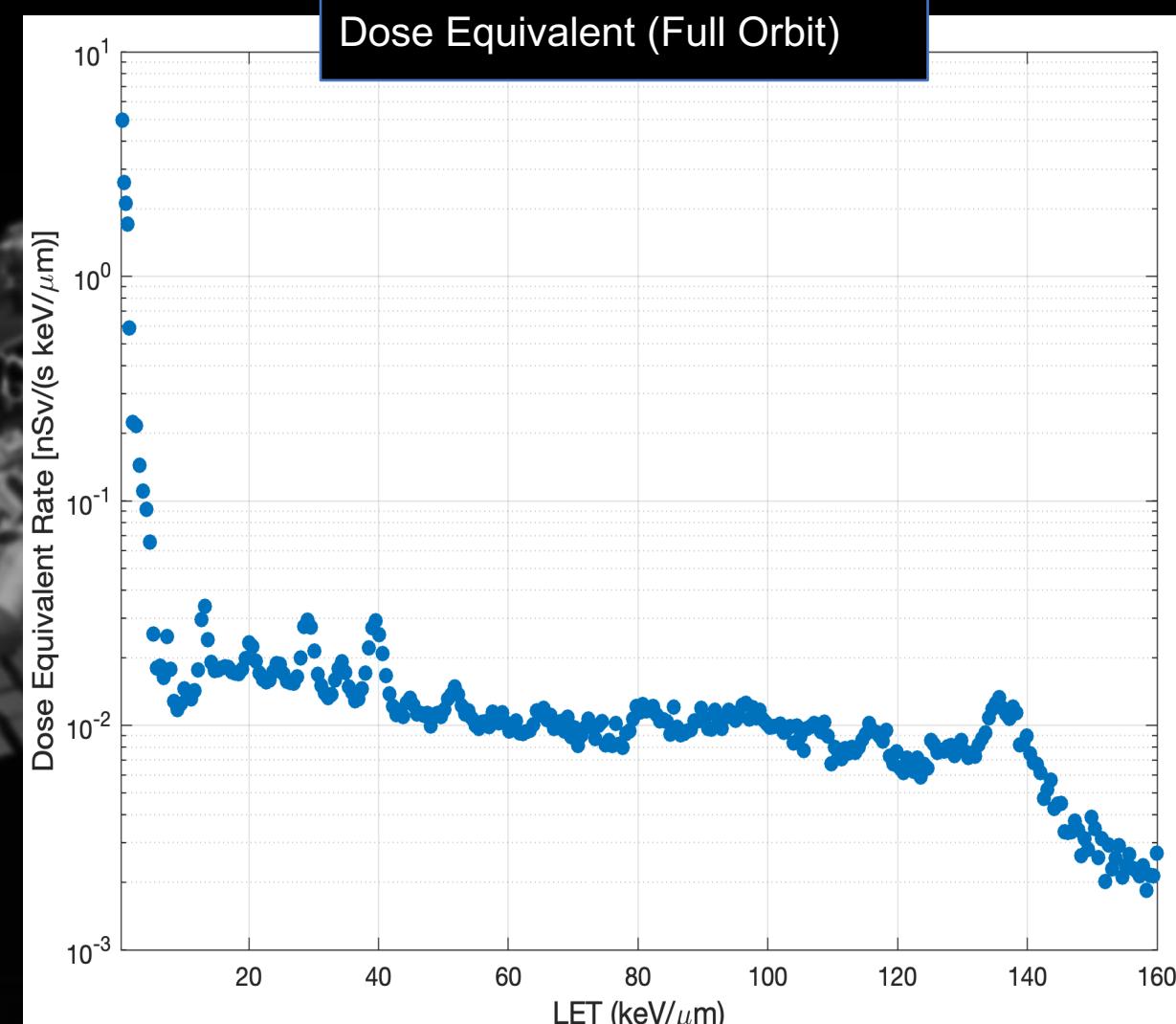
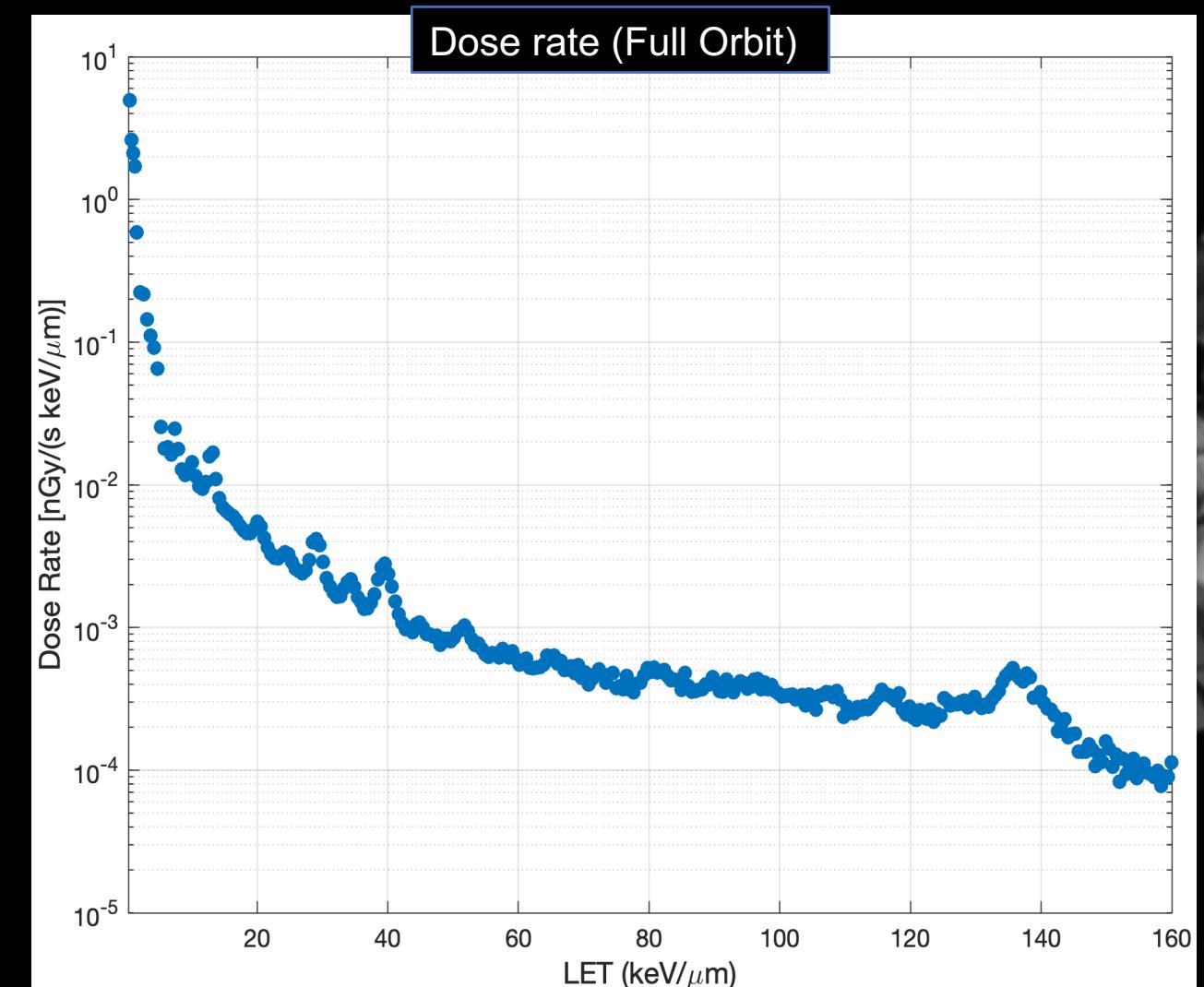
Anisotropies (ToF)



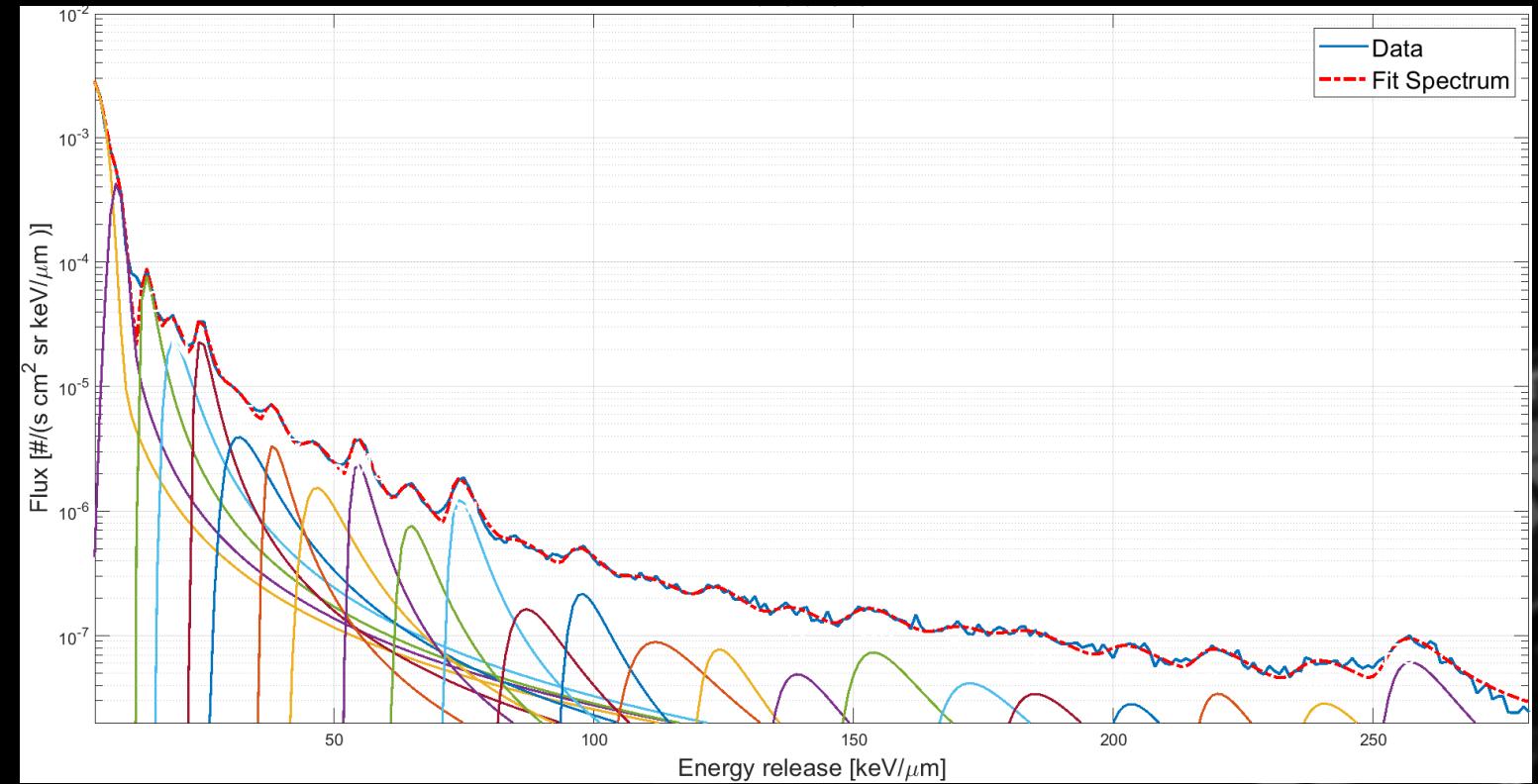
LET spectra (flux, dose, dose eq.)



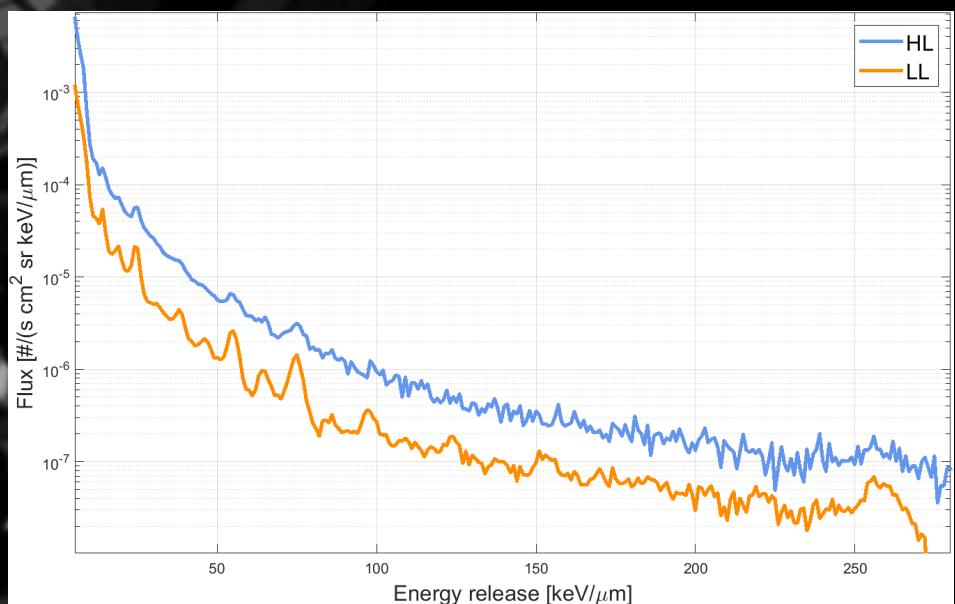
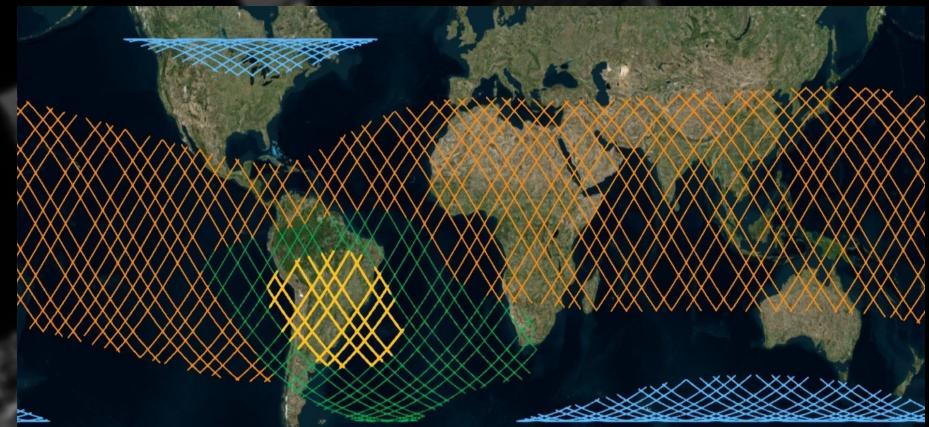
LET spectra (flux, dose, dose eq.)



From LET Spectrum...

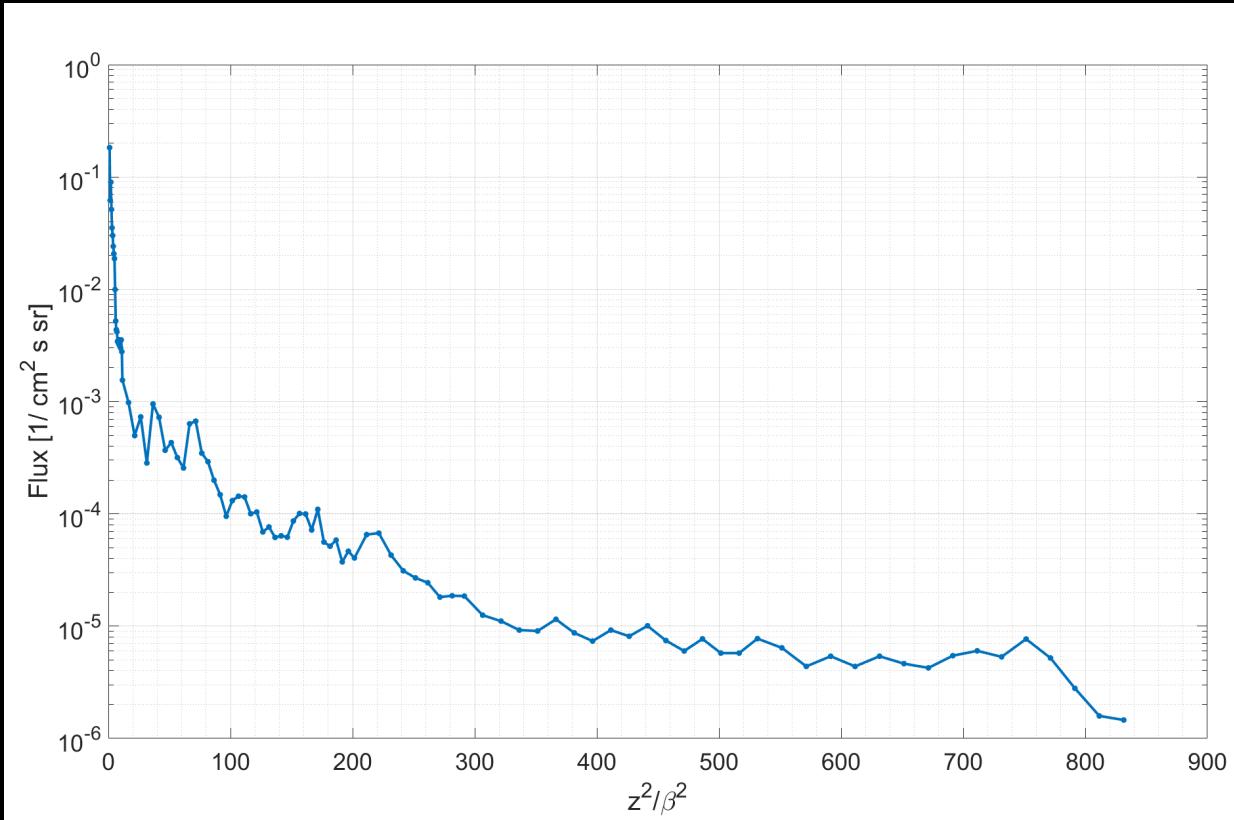


LET measured with silicon detectors
Probabilistic identification (landau fit)
Ions Identification from Boron to Iron

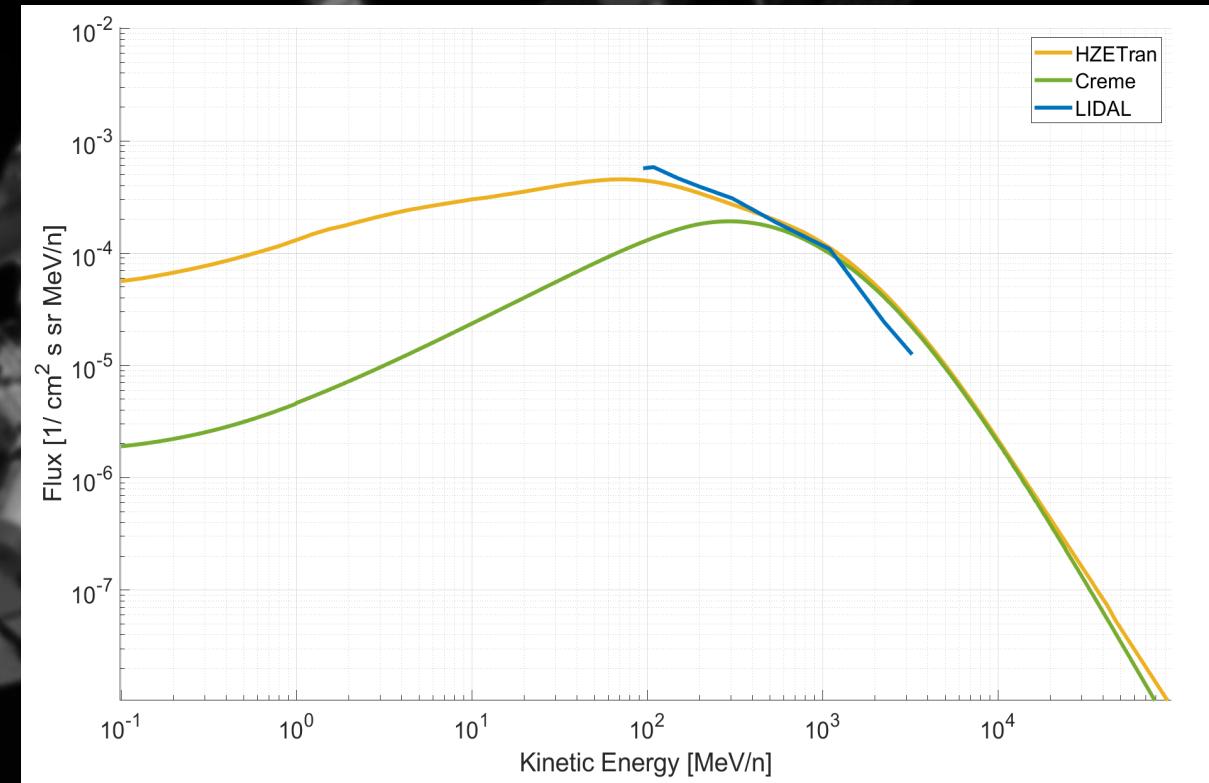


... to Z^2/β^2 and Kinetic energy spectra

Z^2/β^2 Spectrum



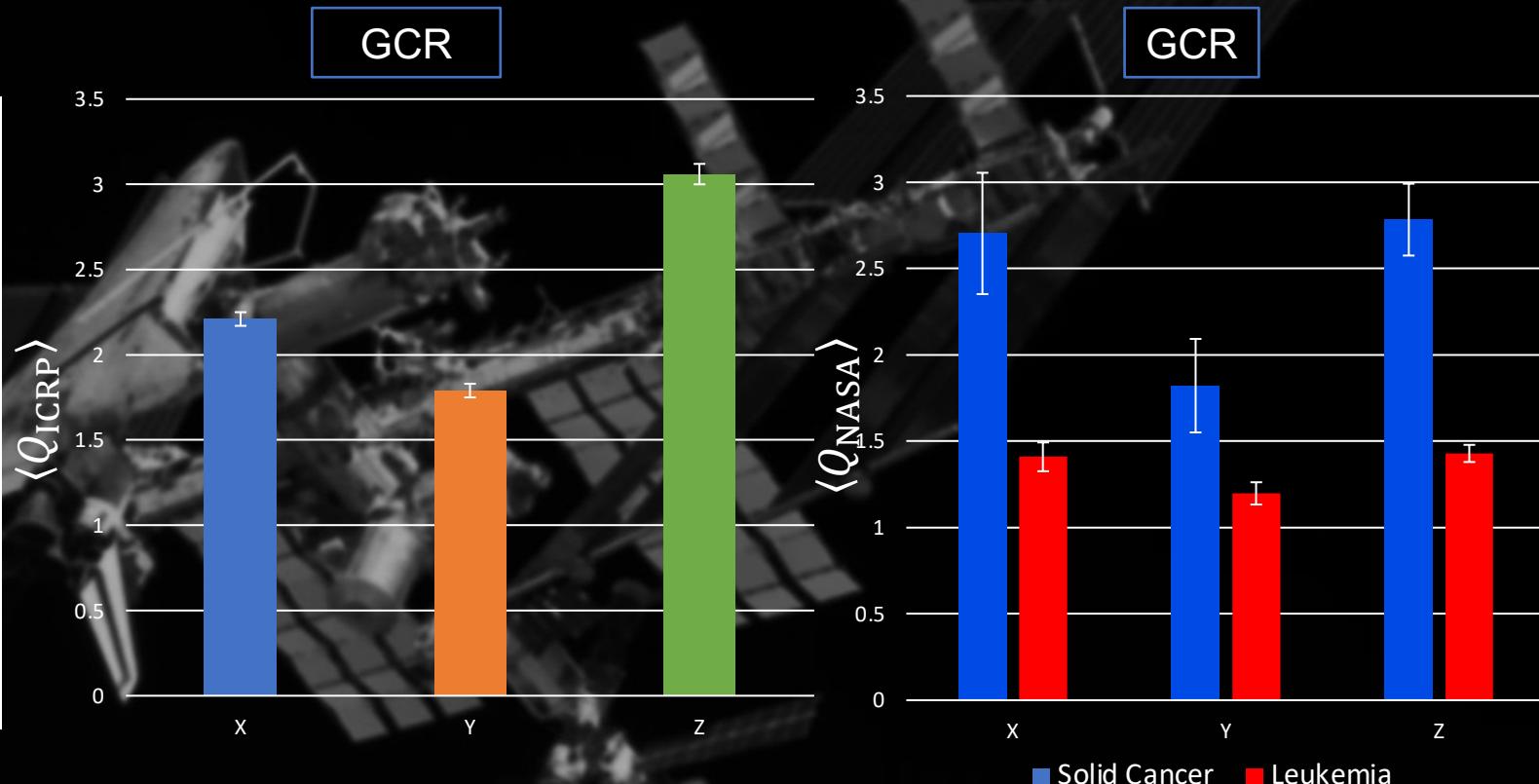
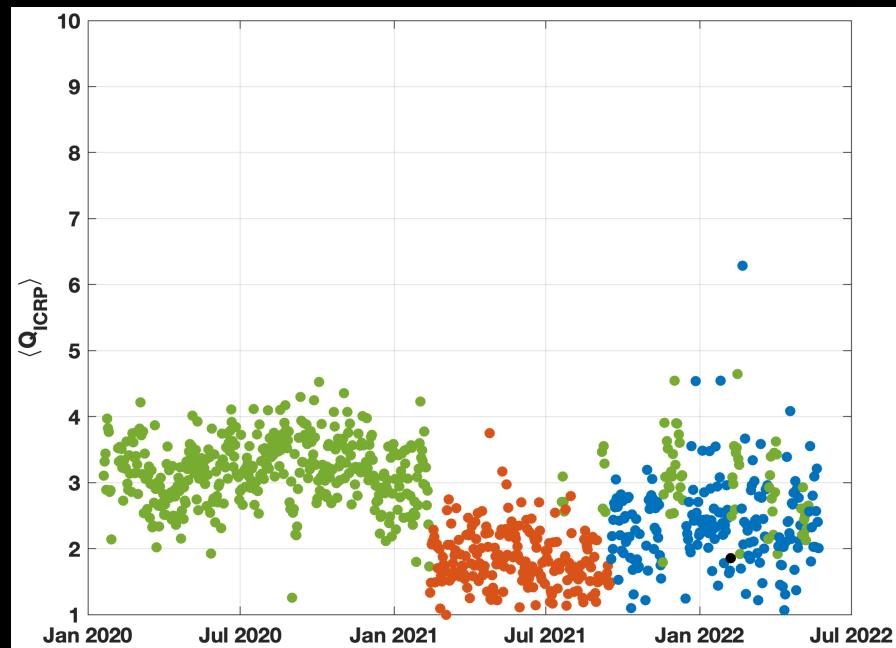
Kinetic Energy spectrum compared to models



Low Z^2/β^2 (≤ 12) correspond mainly to protons and He nuclei obtained using only the information on ToF

Higher Z^2/β^2 have been reconstructed with the previously described algorithm

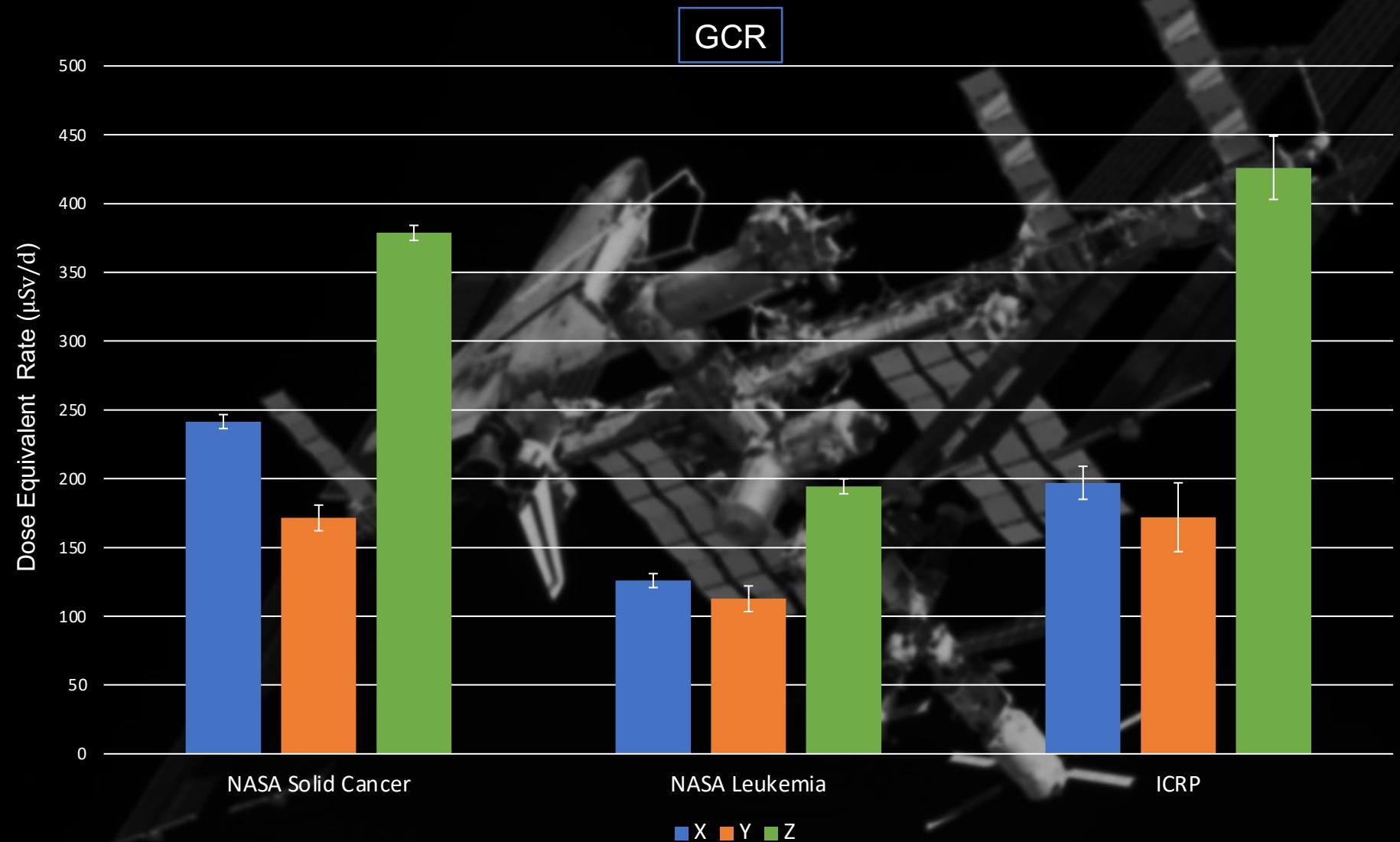
Daily Average ICRP and NASA Quality Factors



ICRP Daily Average Quality Factor

NASA Daily Average Quality Factor

NASA and ICRP Dose equivalent



Conclusions

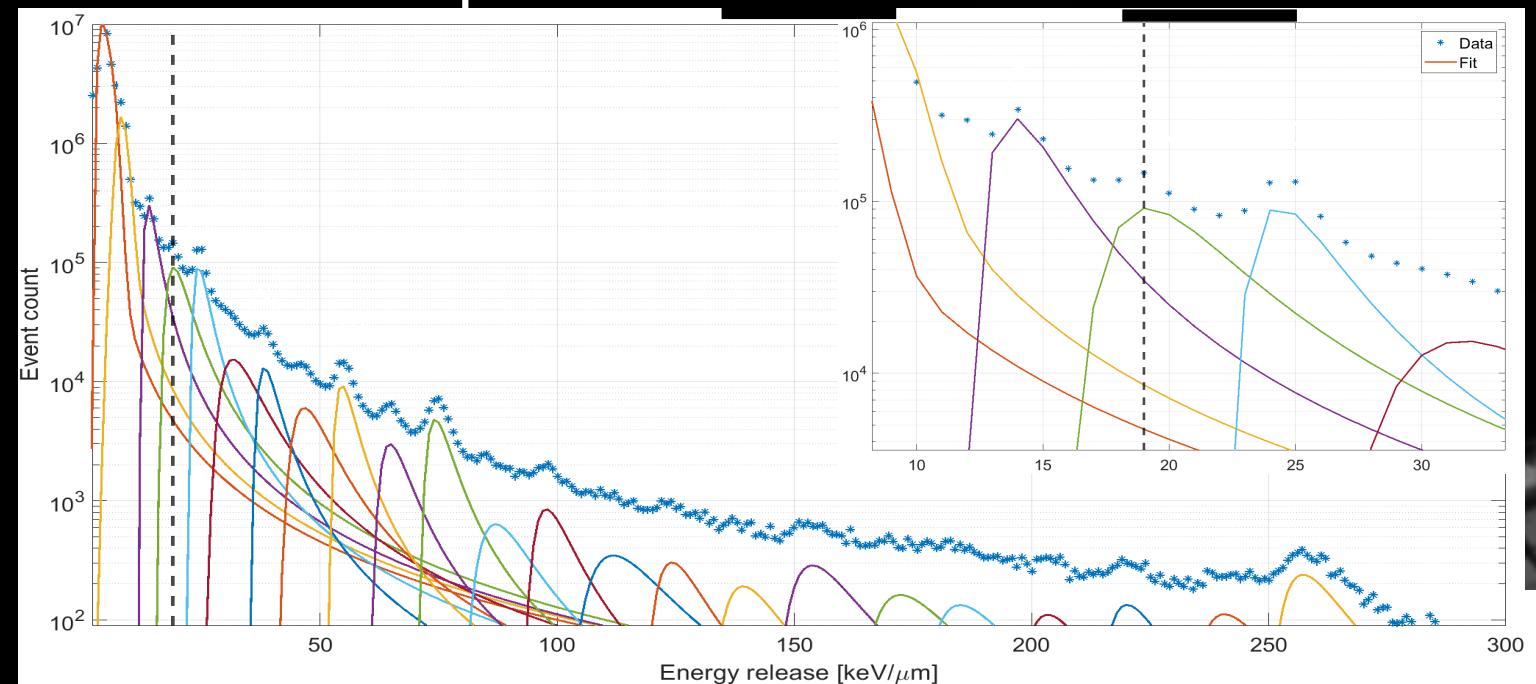
- The characterization of the radiation environment in human habitats in space is of mandatory importance to evaluate the radiation risk for the astronauts.
- Dose is not enough, need Z and β information.
- Anisotropies due to the uneven shielding could affect measurements.
- LIDAL, measuring LET and TOF, got the first Z^2/β^2 measurements inside a space habitat.
- Multiple advanced detectors are needed to better map radiation environment, to validate transport models, to have risk estimates,
let's talk about that!

A black and white photograph of the International Space Station (ISS) against a dark background. The station's complex structure, including its solar panels and various scientific instruments, is visible. A small satellite is also seen in the lower right foreground.

Thank you!

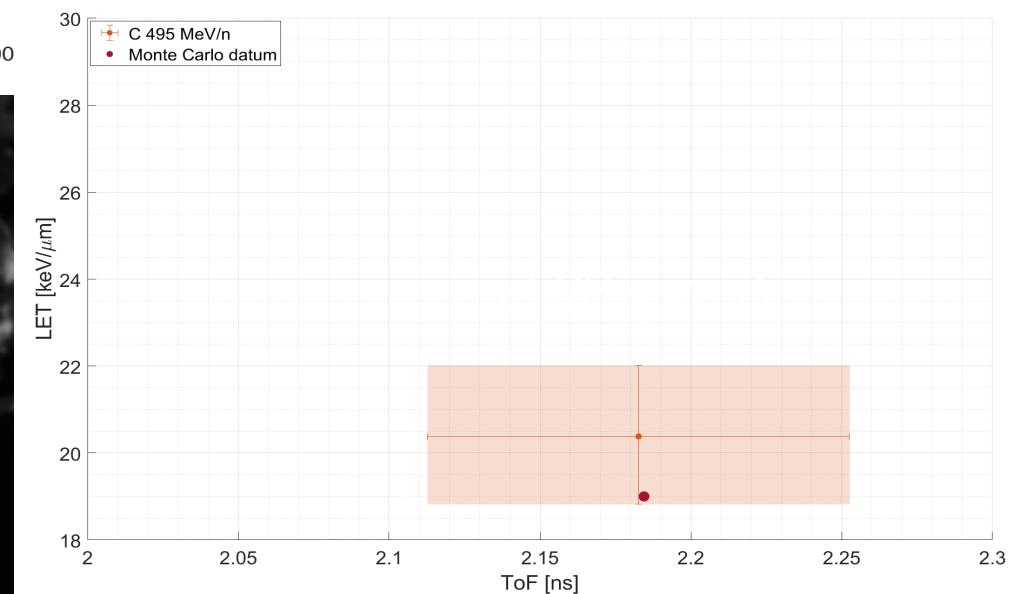
Contacts: luca.difino@asi.it

Z and β evaluation



Ions Probability at Energy Release 19 keV/ μ m	
H or He or Li or Be (0.16 %)	
B (4.4%)	
C (14.6%)	
N (80.3%)	

Simulation



The information of ToF is added
And acceptance windows on ToF and LET are opened
according to a Bethe-Bloch simulation

The Kinetic Energy is selected
according to the Best Match on ToF

LIDAL System

Dimensions ($w \times l \times h$): $19 \times 25 \times 54$
 cm^3

Field Of View (FOV): 18°

Geometrical factor: $13.5 \text{ cm}^2 \text{ sr}$

Direction	Period	Active days
Z	19/01/2020- 12/02/2021	450
Y	13/02/2021- 16/09/2021	203
X	17/09/2021- 24/05/2022	187

LIDAL in the 3 directions
in the Columbus module

