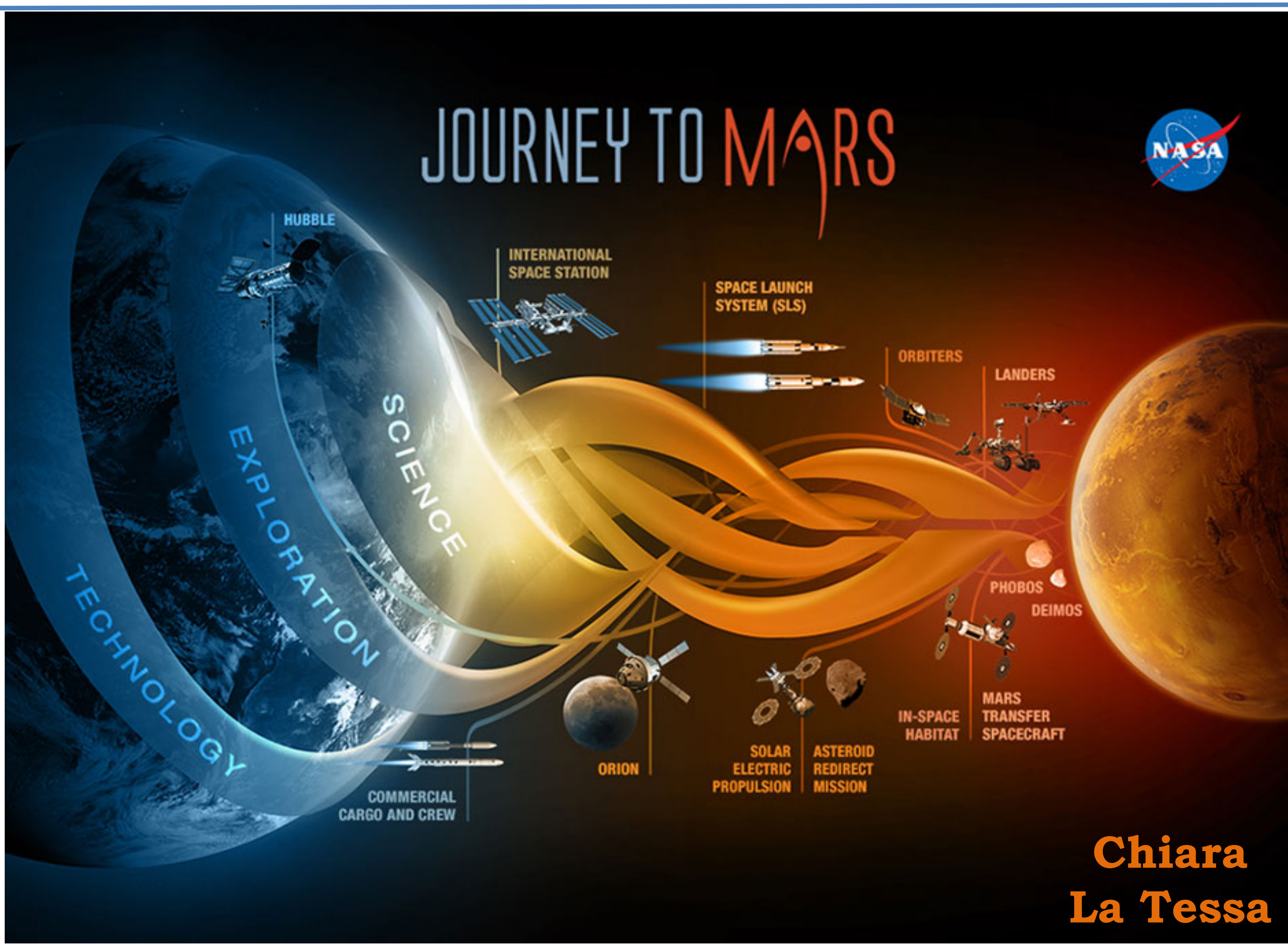
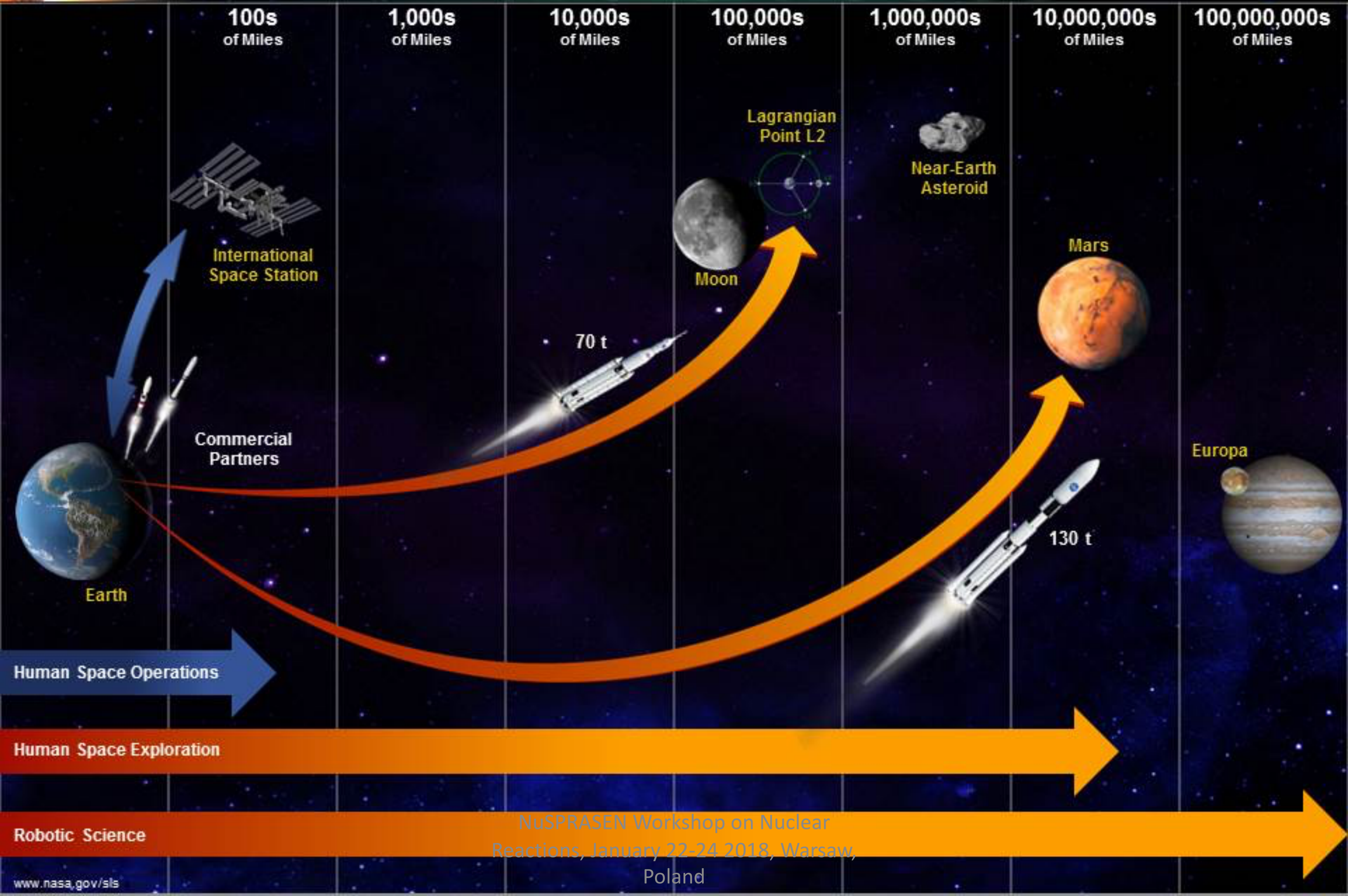
Can nuclear physics take us to Mars?



Chiara La Tessa

The Future of Exploration

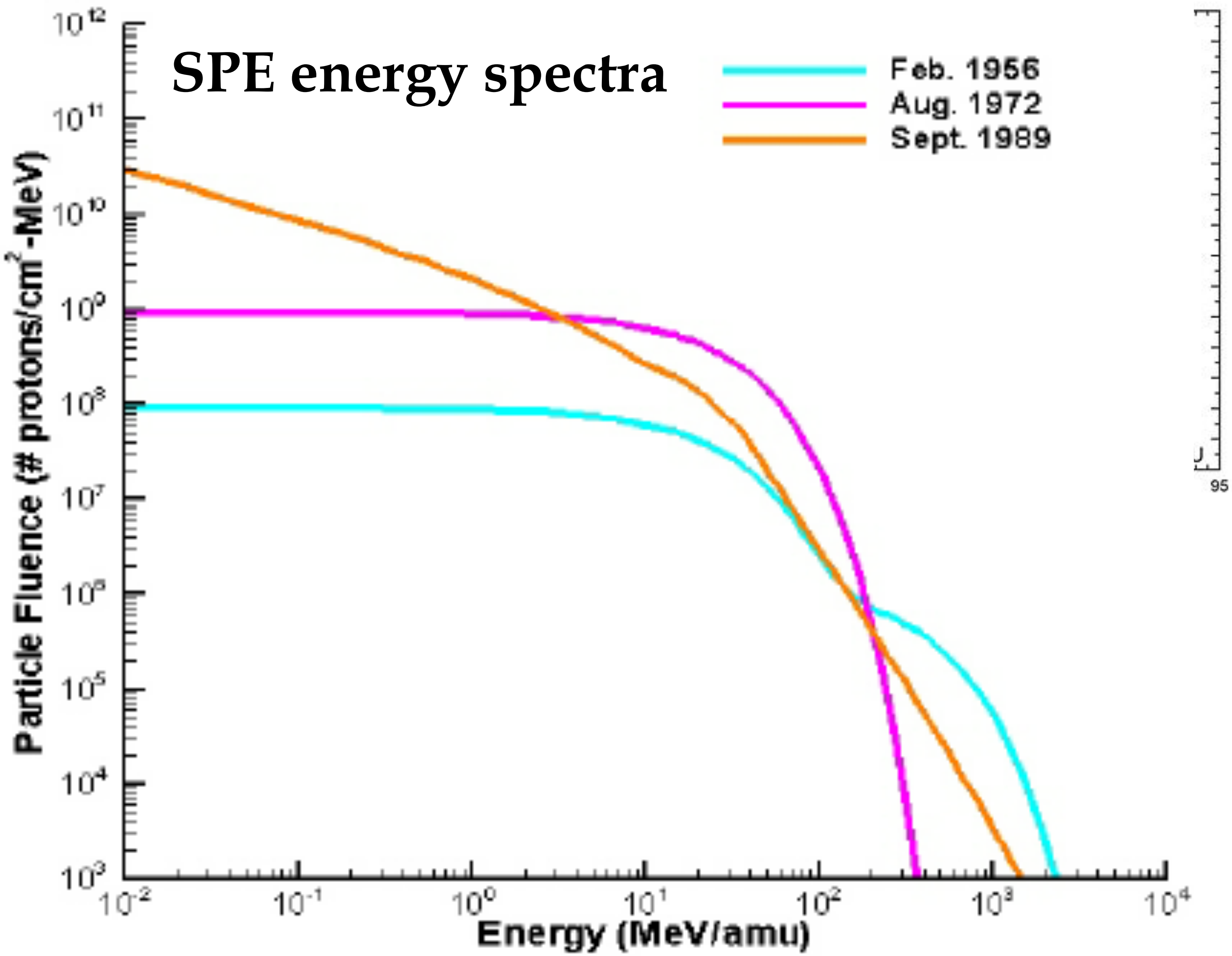


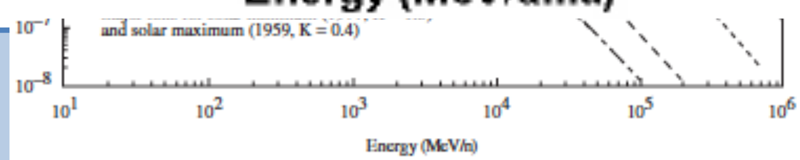
Health in Deep Space

1. Protection from space radiation (particularly very high energy heavy ions)
2. Psychosocial and behavioural problems
3. Physiological changes caused by microgravity

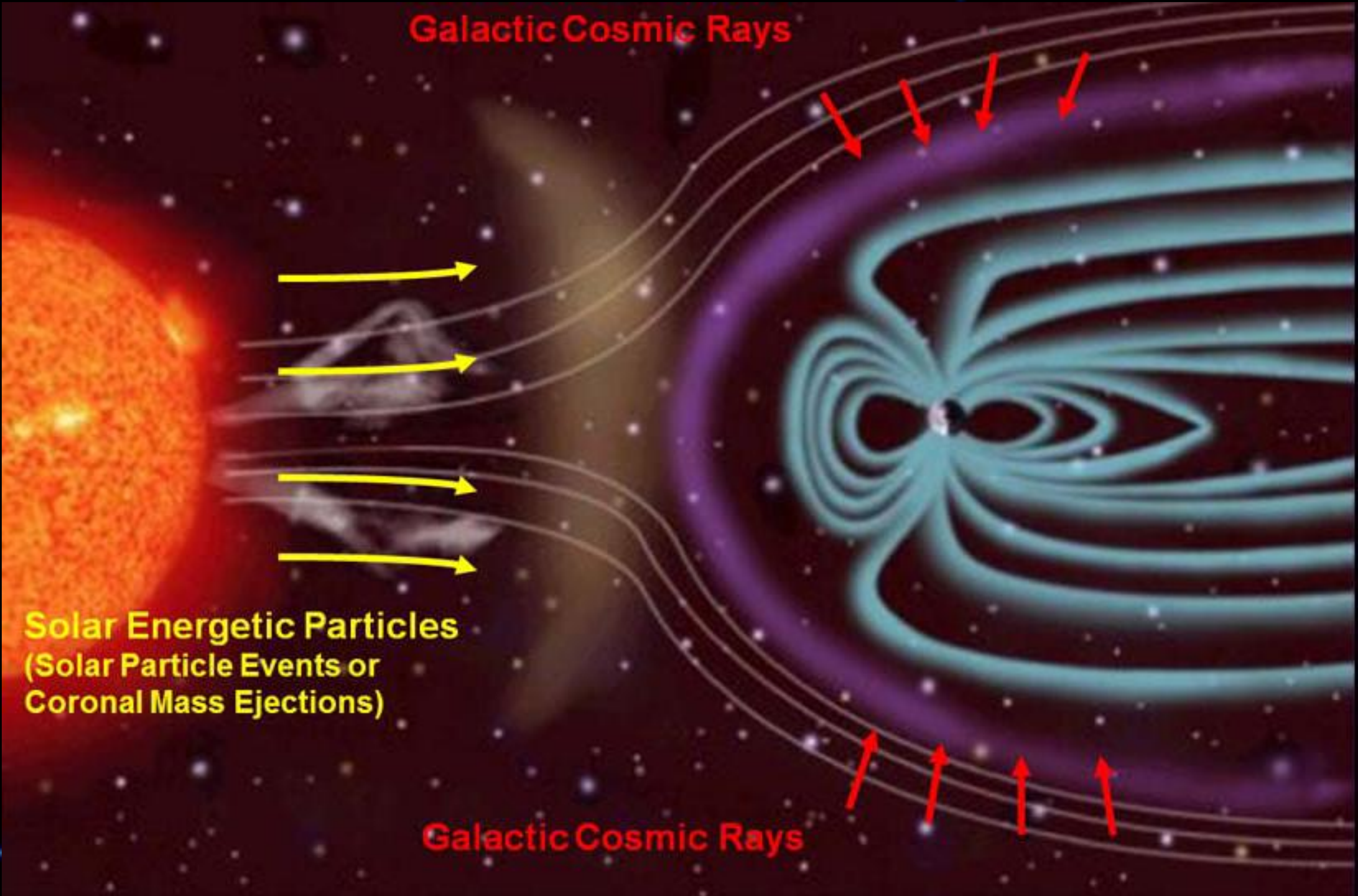
Space radiation environment

– Ga
– So
– Tra

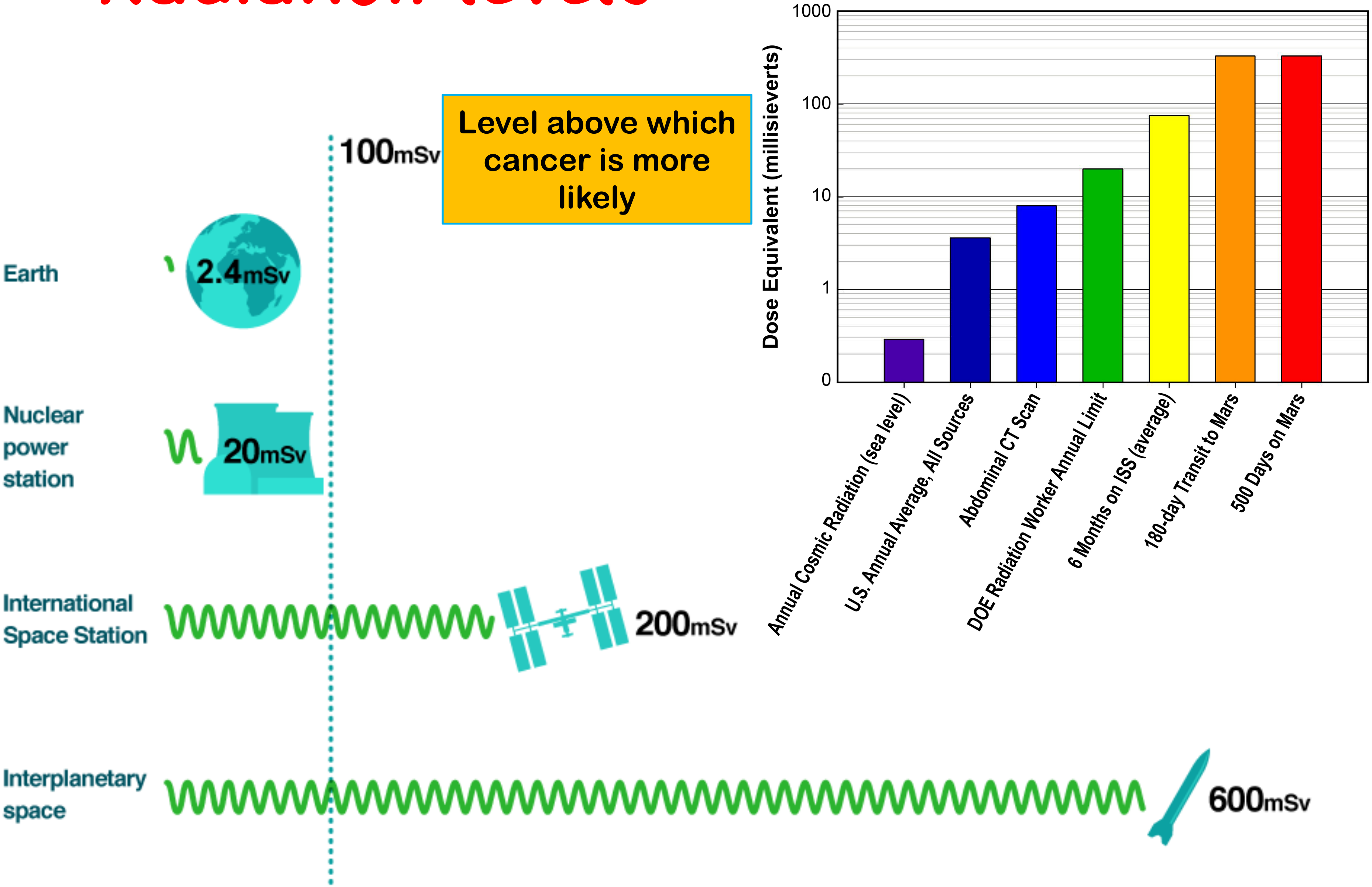




Deep-Space Radiation

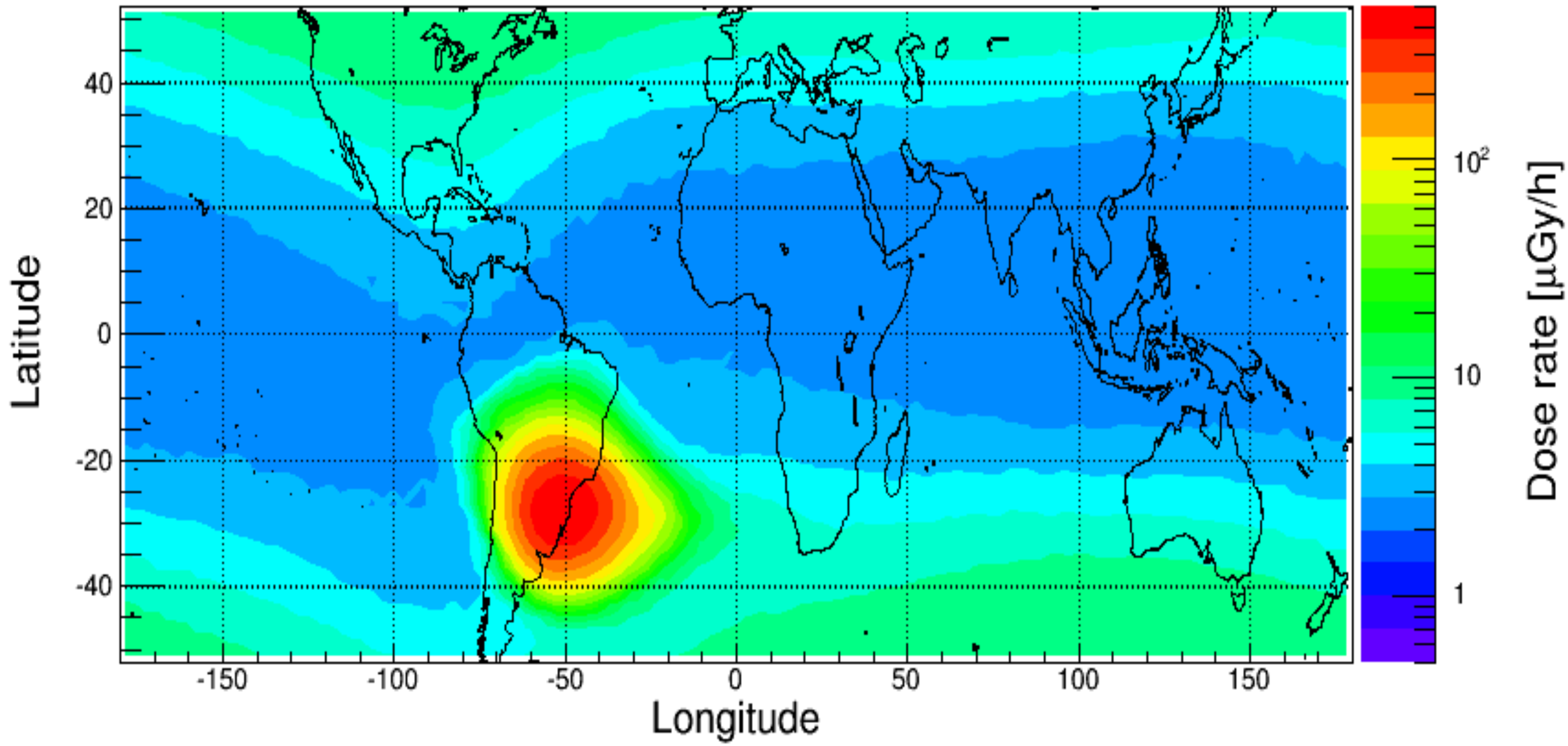


Radiation levels

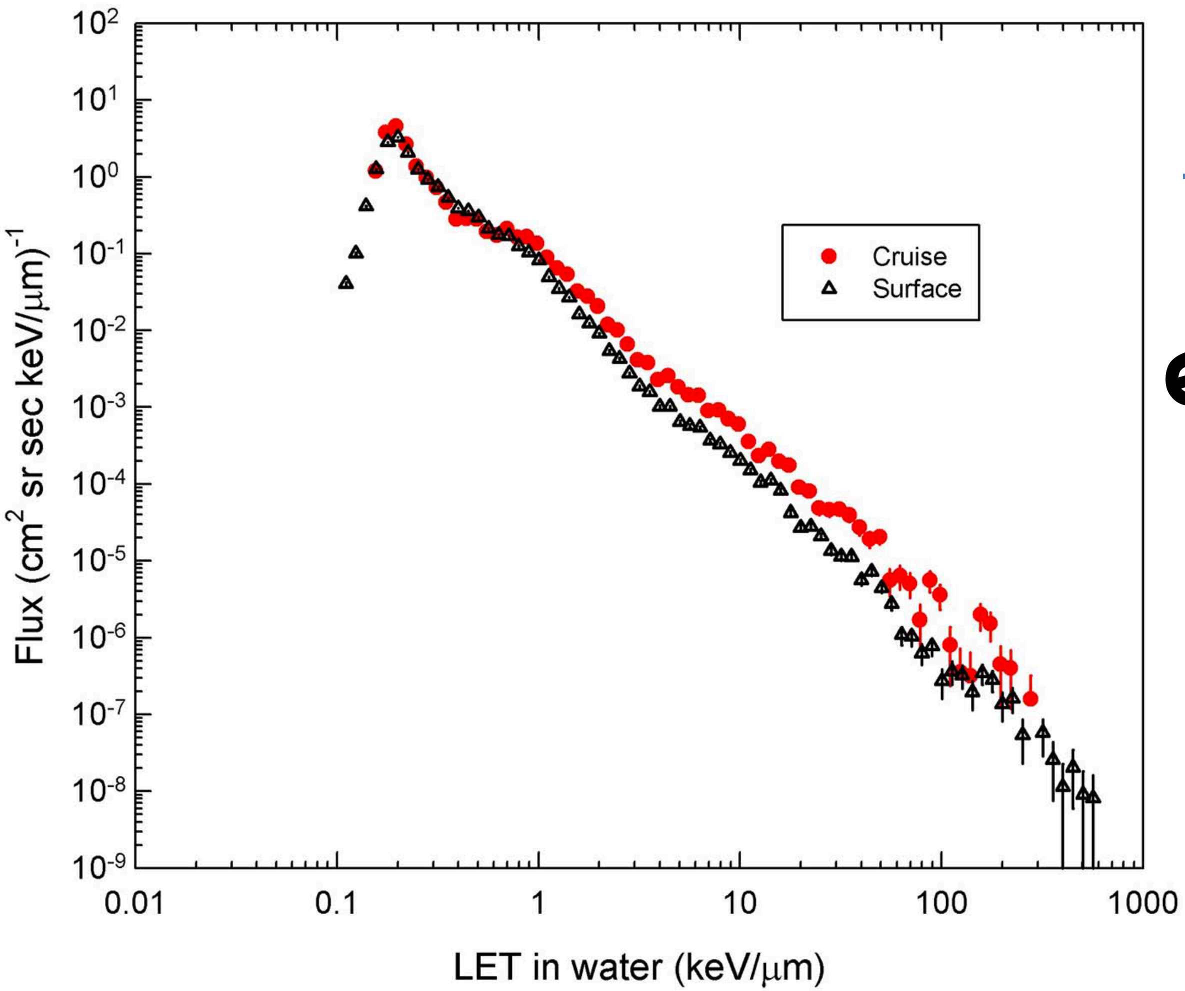


mSv = millisievert (a measure of the biological effects of radiation)

Dose distribution on the ISS



DOSIS 3D (2012 – ongoing): Variation of absorbed dose over ISS orbit (active radiation detectors)



Radiation exposure for a mission to Mars

GCR dose in different mission scenarios based on the recent MSL measurements (Zeitlin et al., 2013; Hassler et al., 2014). Inspiration Mars is a 501 flyby mission. Mars sortie assumes a 30-days stay on the planet, and Mars base 500 days. Both those design reference missions (Tito et al., 2013) assume a 180 cruise to/from Mars.

	GCR dose rate (mGy/day)	GCR dose-equivalent rate (mSv/day)	Inspiration Mars (Sv)	Mars sortie (Sv)	Mars base (Sv)
MSL cruise (Zeitlin et al., 2013)	0.46	1.84	0.92	0.7	0.98
MSL on Mars (Hassler et al., 2014)	0.21	0.64			

Risk assessment

Ground- and space-based experiments to assess:

- Radiation environment
- Dosimetry
- Biological effects

…but this approach alone is too time and money consuming

⬇

Deterministic and Monte Carlo codes

Countermeasures

- o Passive shielding
- o Active shielding
- o Biology-based approaches

\+ Availability

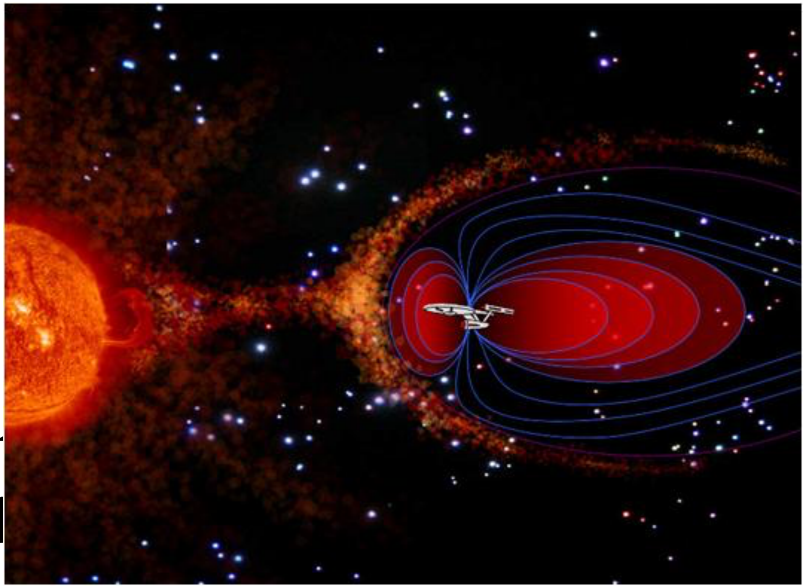
\+ The average shielding on the In
(20 g cm^{-2}) can stop most trapped
SPE

\+ Everything is a

\+ In-situ resourc

\- Load weight lim

\- Creation of high



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Review Article

Hibernation for space travel: Impact on radioprotection

Matteo Cerri[a,b], Walter Tinganelli[c], Matteo Negrini[b], Alexander Helm[c], Emanuele Scifoni[c], Francesco Tommasino[c,d], Maximiliano Sioli[b,e], Antonio Zoccoli[b,e], Marco Durante[c,*]

Physical processes of interest

- **Energy loss**
- **Lateral scattering**
- **Nuclear fragmentation**

...occurring in

- Space craft hull and structure
- Shielding
- Astronaut's body

Change of the radiation field in terms of particle species and energies

- Dose prediction is geometry-dependent

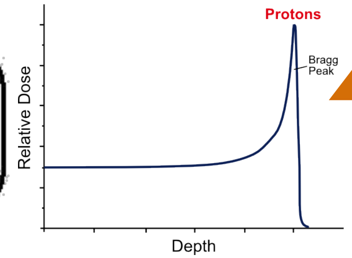
+ It can be exploited for reducing the dose

Shielding material selection

the need of a compass

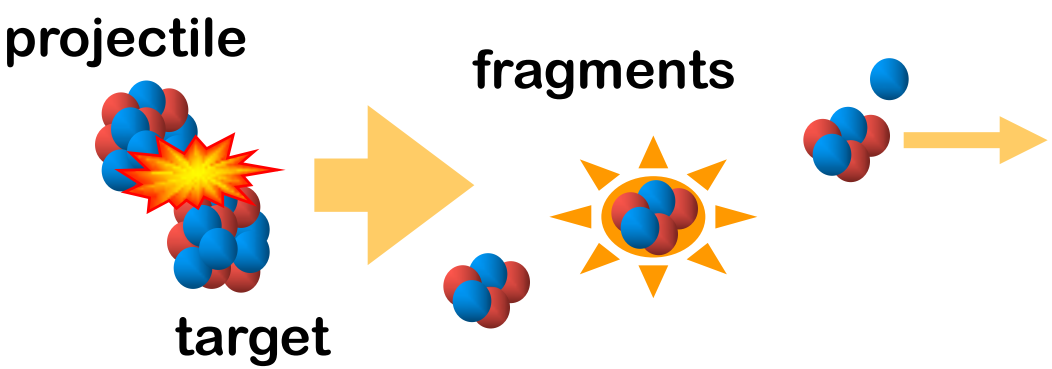
Electromagnetic interaction

$$-\frac{dE}{\rho dx}=k\frac{Z}{A}\cdot\frac{z^{*2}}{\beta^2}\left(\log\frac{2\gamma^2\beta^2 m_e c^2}{I}-\eta\right)$$

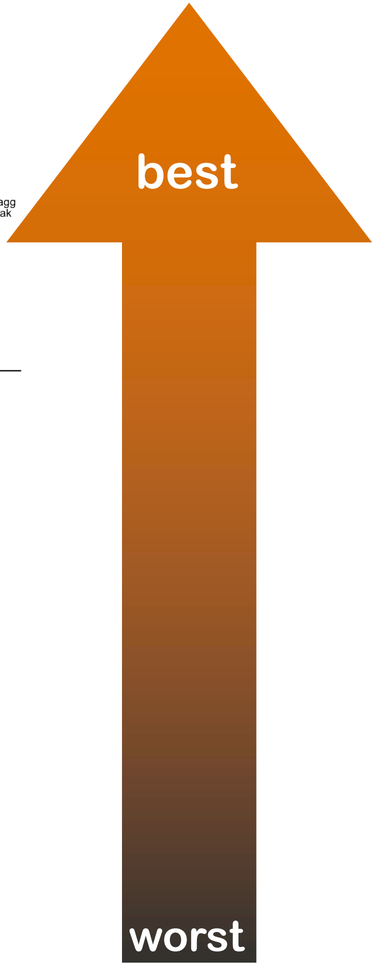


Slow down and stopping

Nuclear fragmentation



Isotope- and charge-changing



Liquid H_2

Plastic (PE)

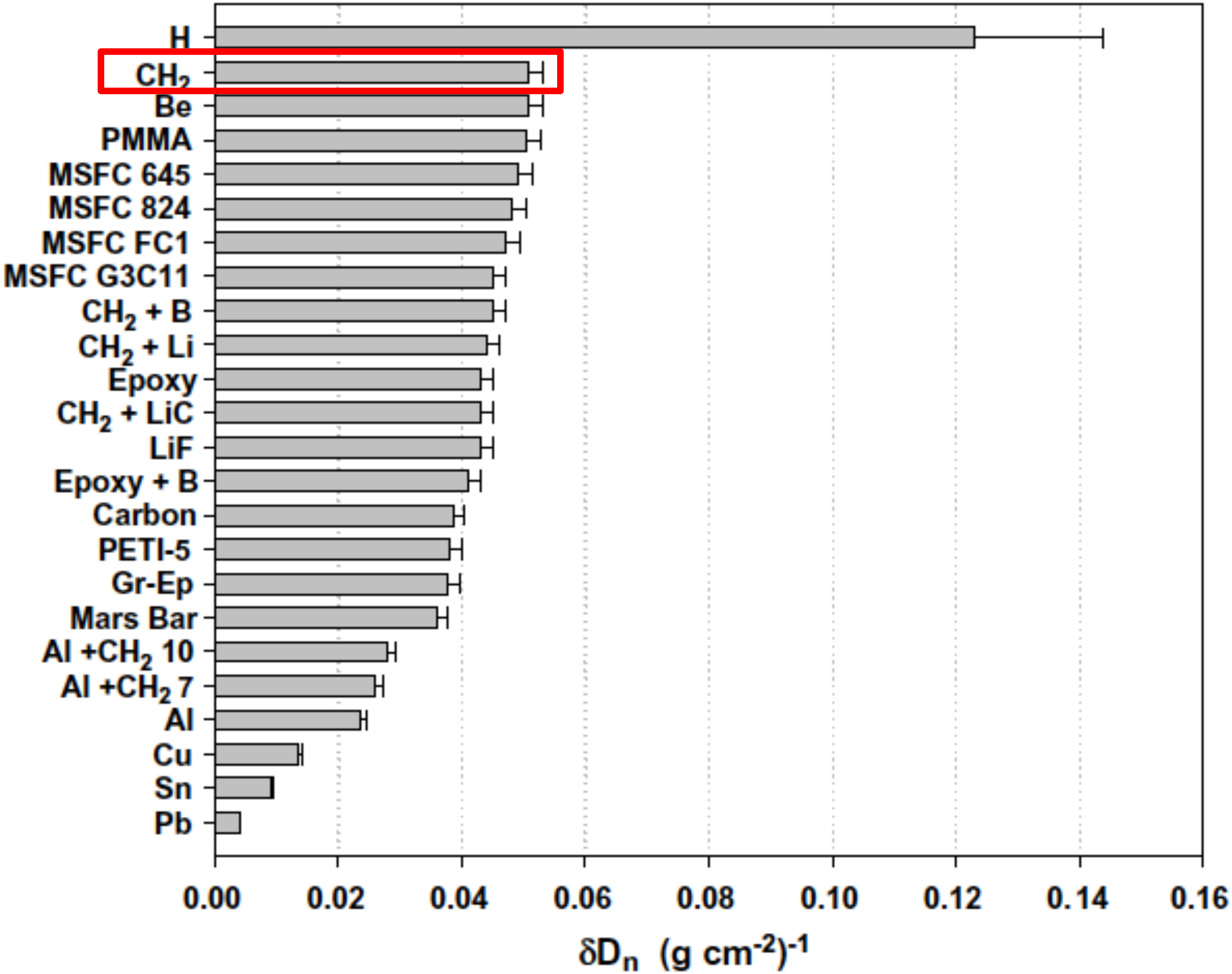
Water

Aluminum

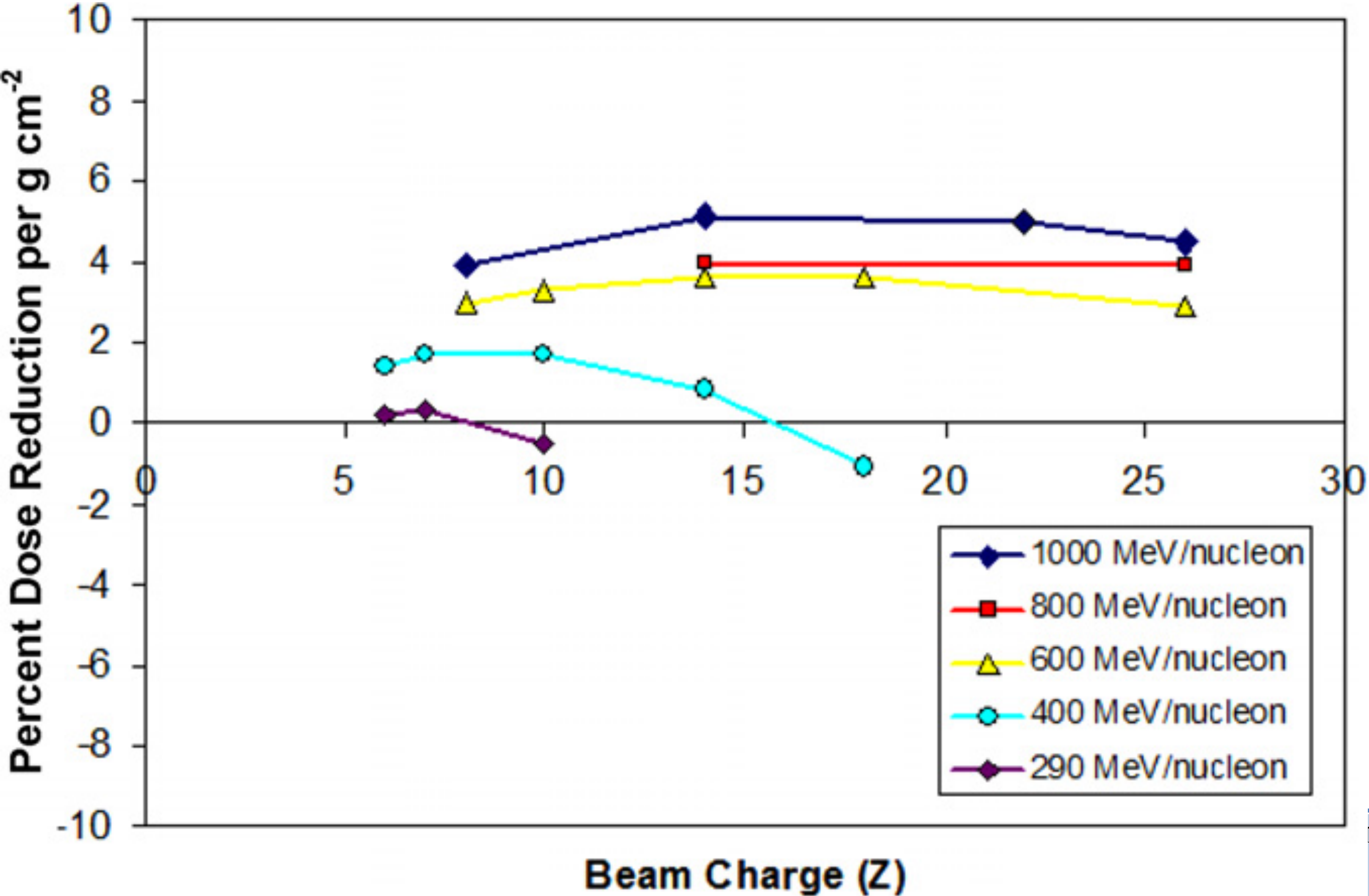
Concrete

Lead

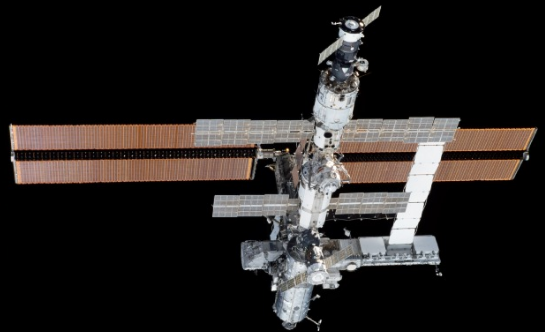
Material effectiveness as shielding (1 GeV/u ^{56}Fe as proxy of GCR)



Dose reduction after 2.83 g cm^{-2} PE



Shielding on the International Space Station



Sleep station outfitted with PE and water
Thin, flat panels are PE shields
Stowage water packaging above the sleep station

Where can nuclear physics help?

a) Shielding materials optimization

b) Radiation exposure risk assessment

↓

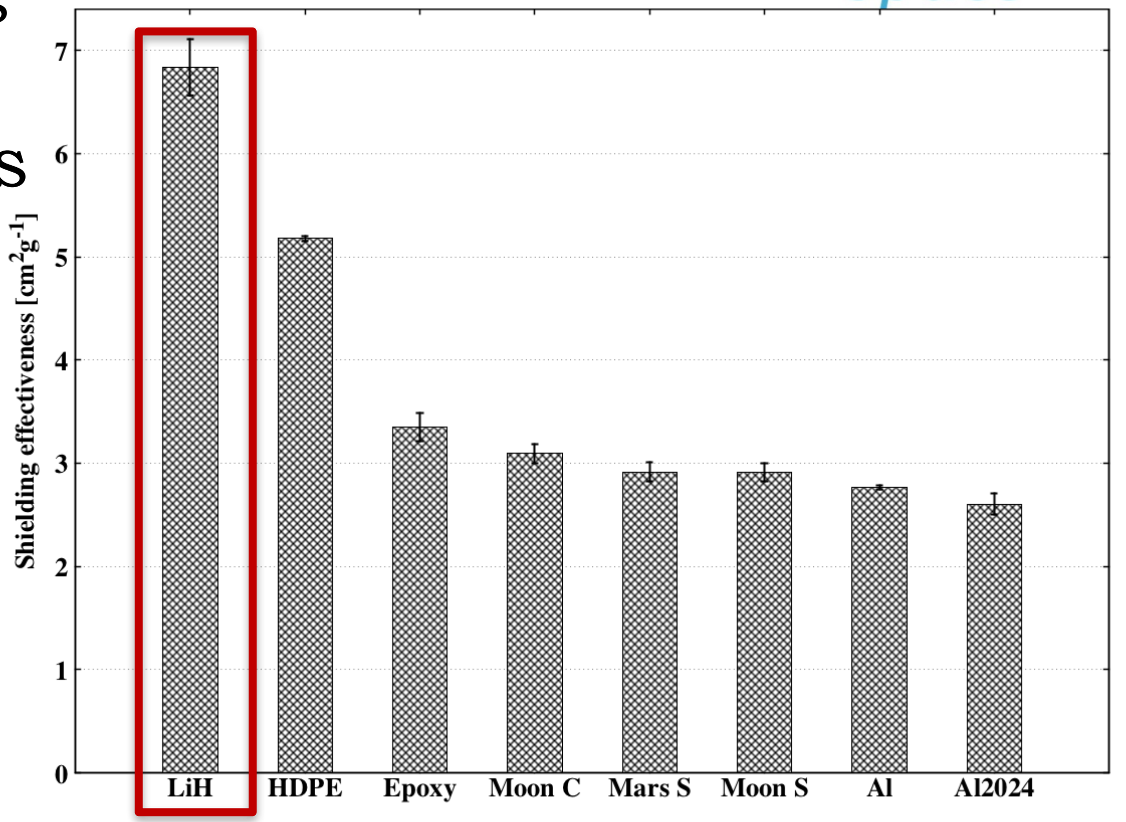
Full characterization of the radiation field in different scenarios

⌘ Improve the accuracy of theoretical models for nuclear interactions

⌘ Provide experimental data for validating and benchmarking the models

SOME ONGOING EXPERIMENTS

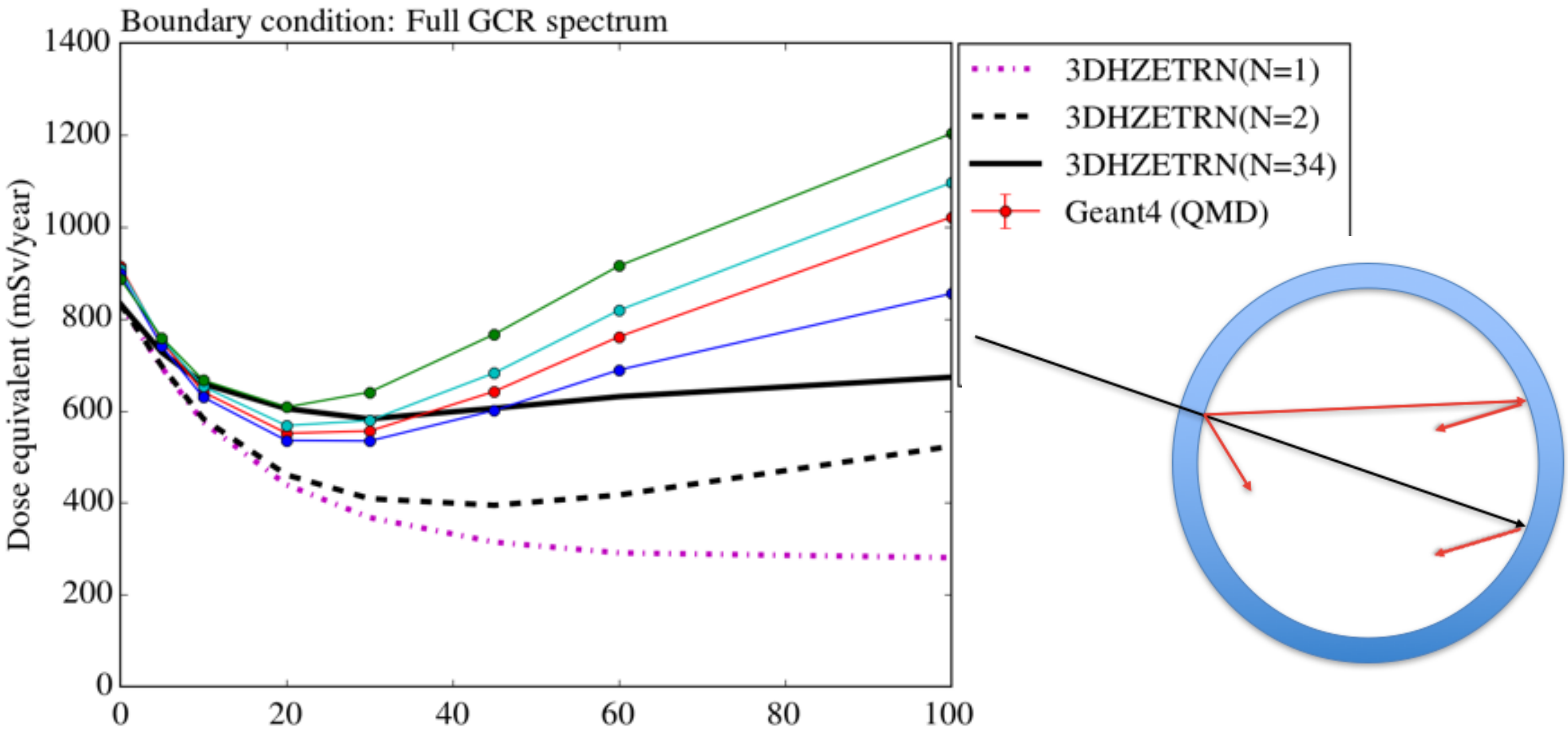
ROSSINI – Radiation Shielding from ISRU and/or innovative materials for spacecraft, EVA and habitat

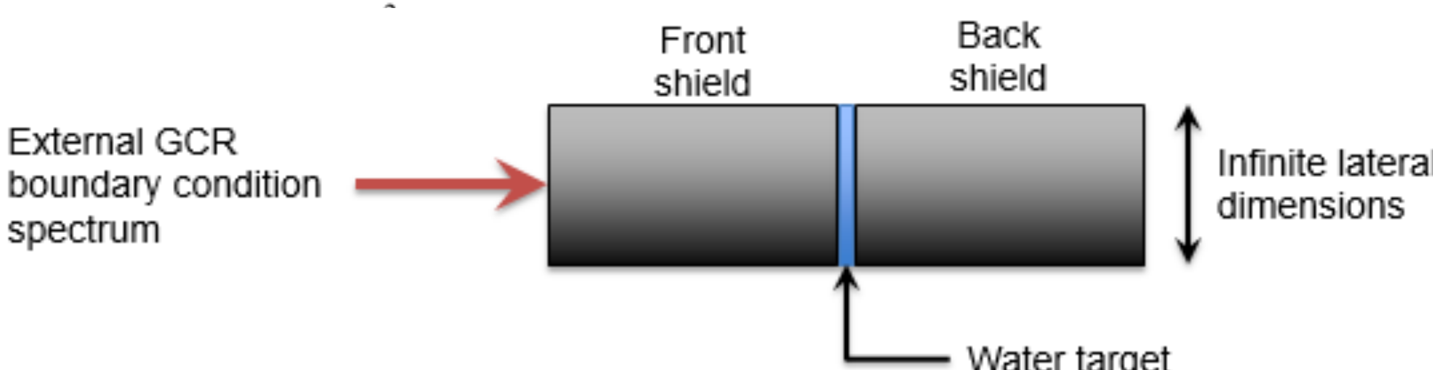


Entity of your Direction

Date Reference of the document

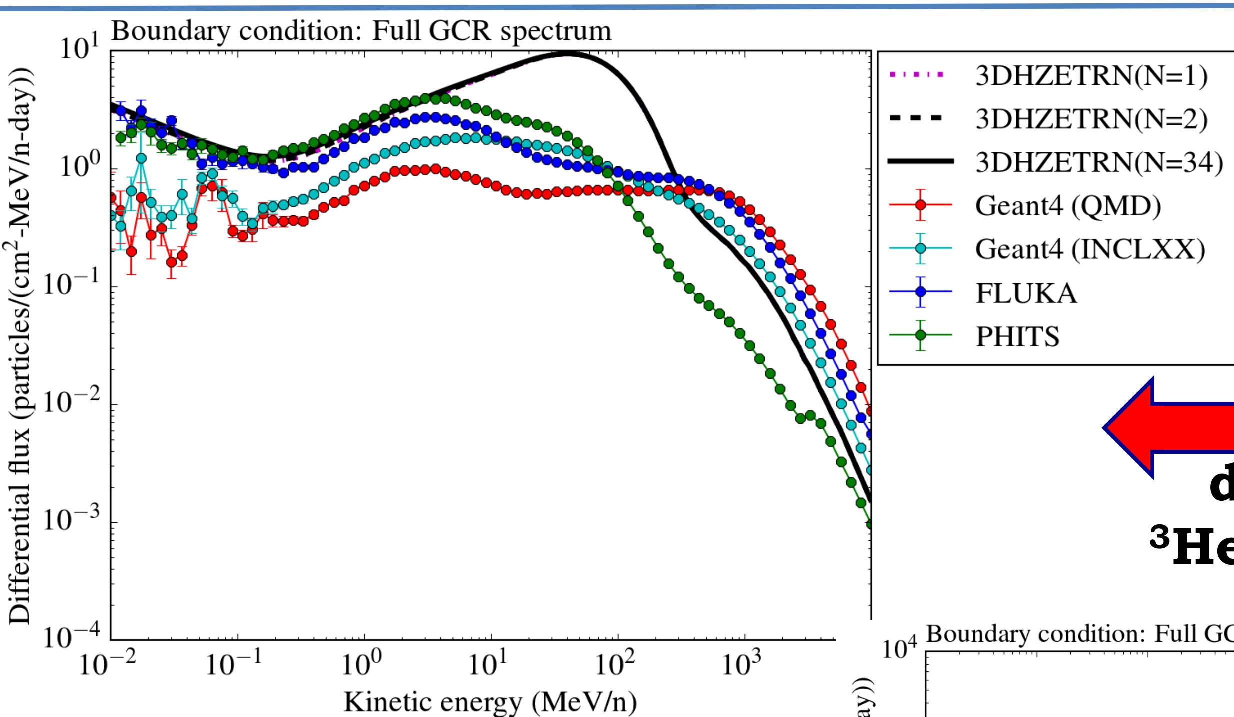
Some missing pieces of the puzzle





Trento Institute for Fundamental Physics and Applications

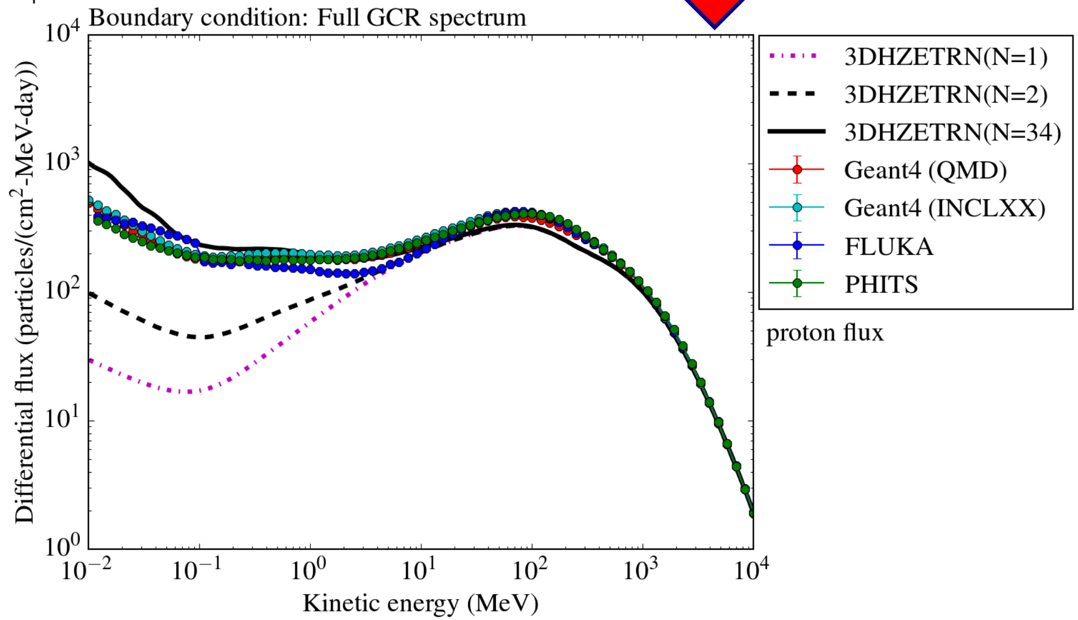
What codes predict for thick shielding



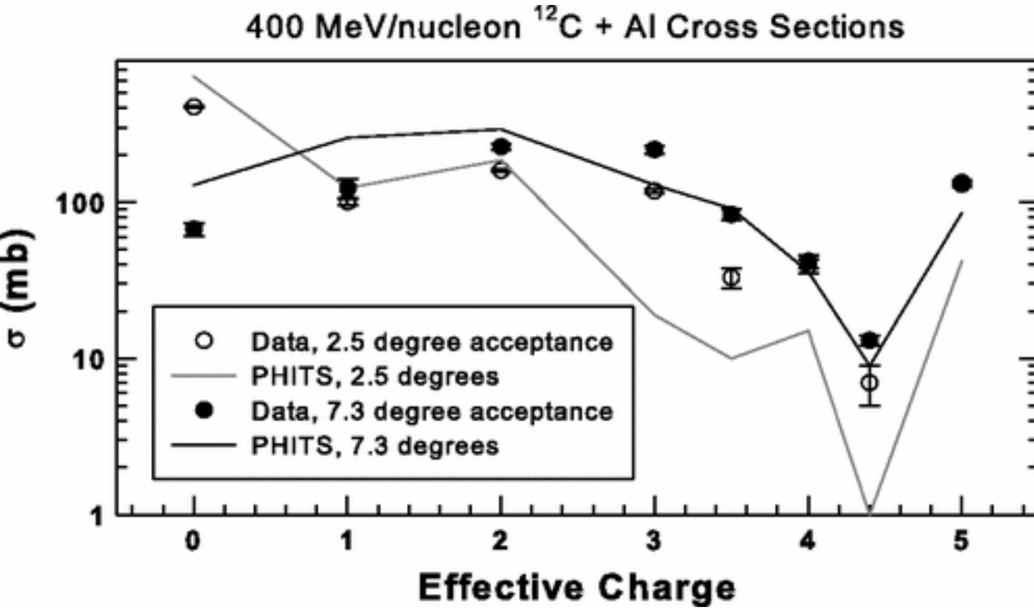
GCR spectrum interacting with 20 g cm^{-2} Al shielding

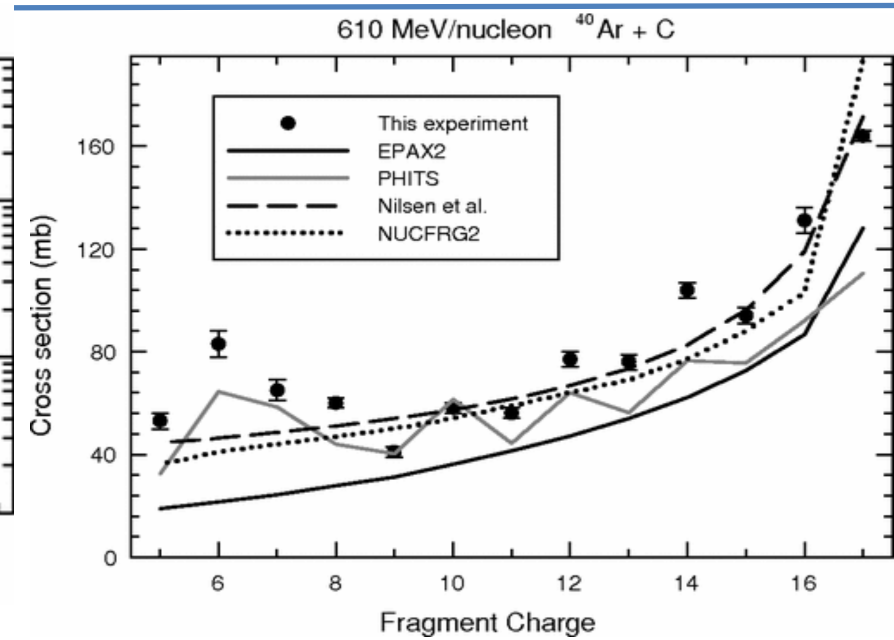
d, t, ^{3}He, ^{4}He

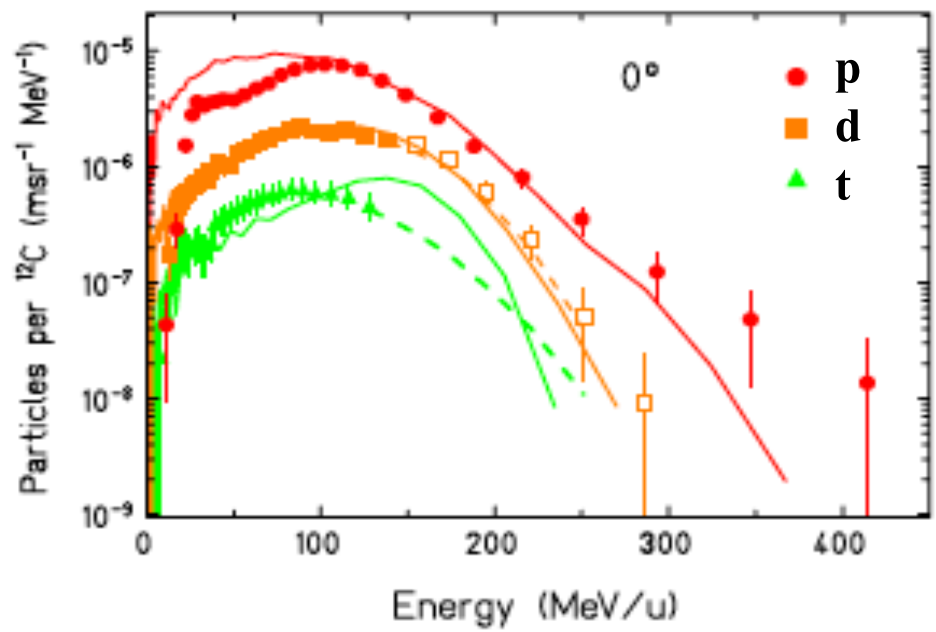
Protons

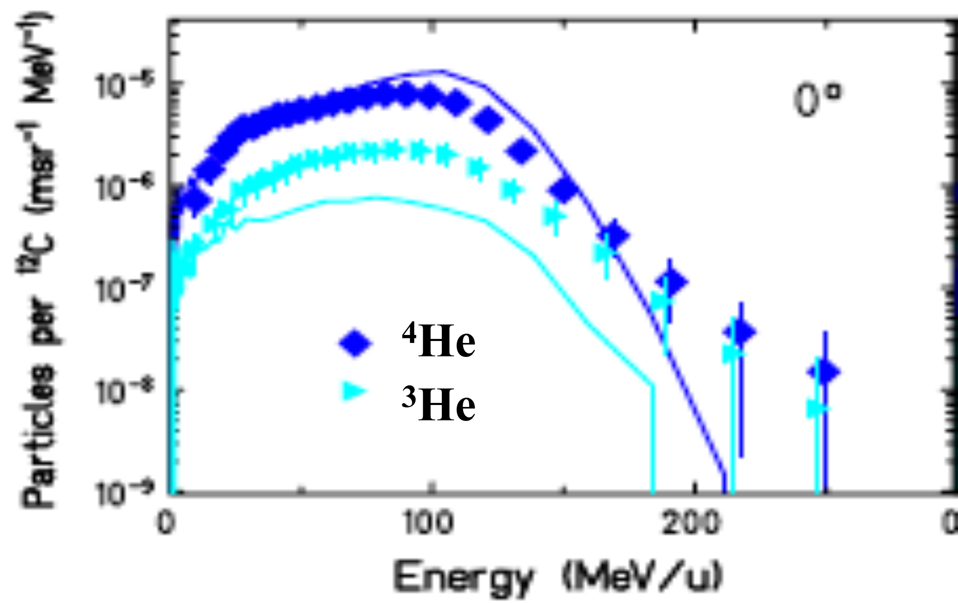


What codes predict for thin shielding

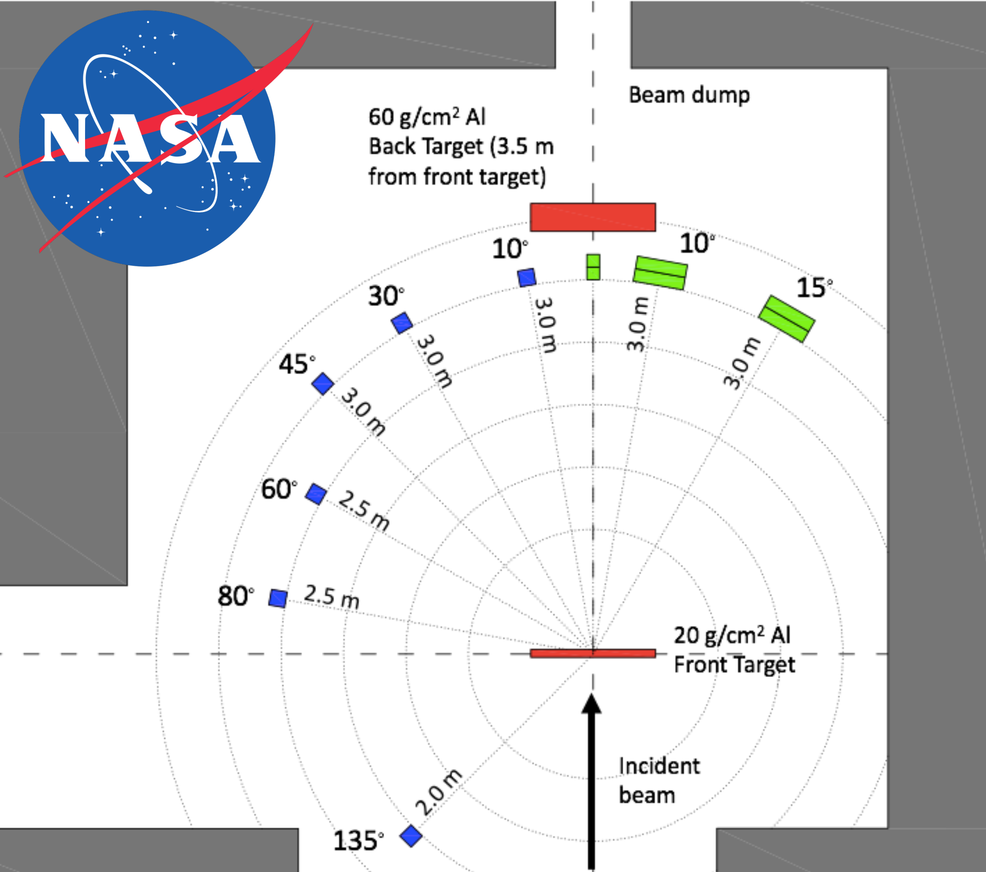








The experiment (performed at NSRL, US)



- **Beams:** H to Fe
- **Energies:** up to 1500 MeV/u
- **Targets:** elemental (C, Al) and composite (PE, H_2O)

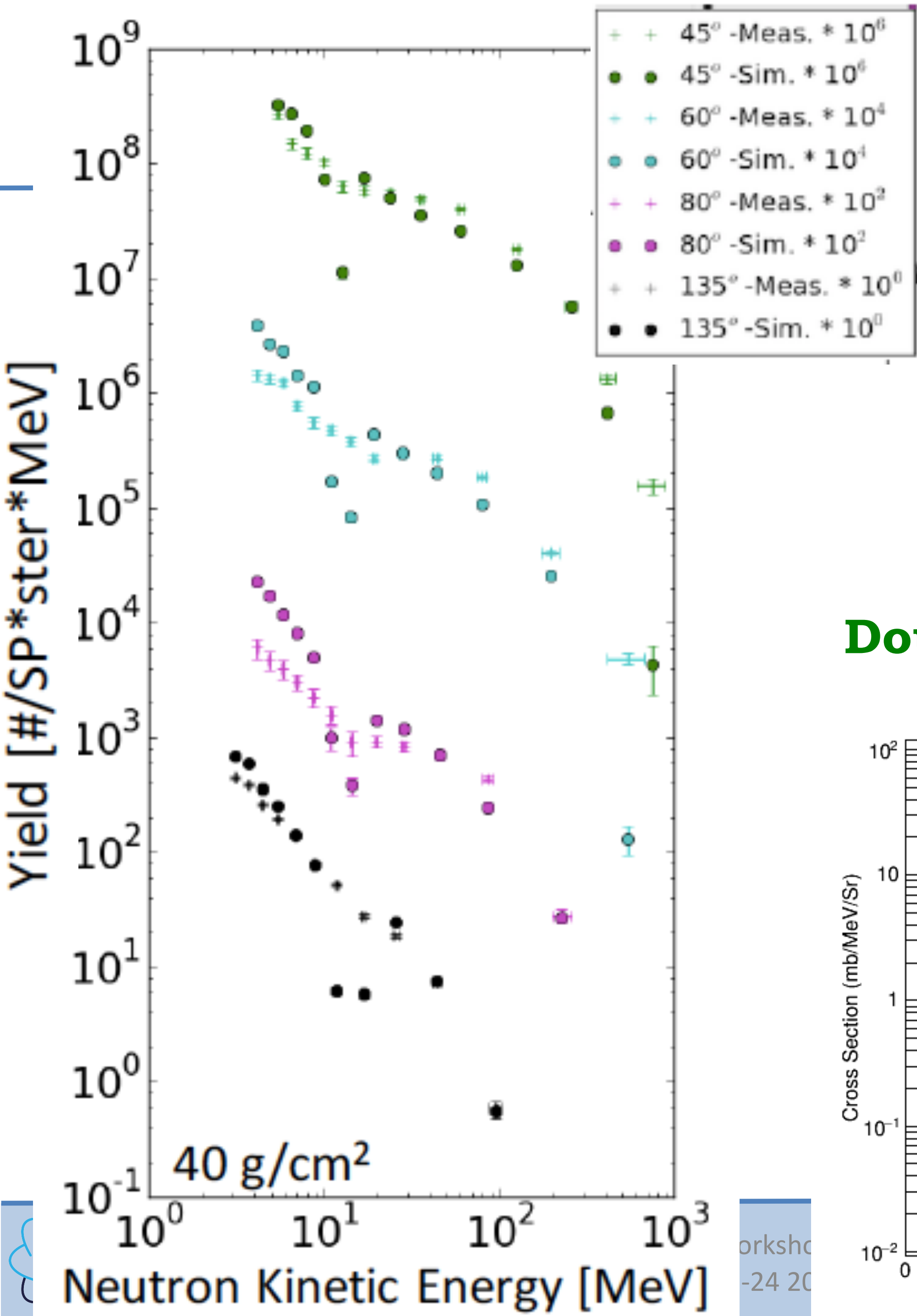
Detectors

- Pixel chamber
- Plastic scintillators
- Liquid scintillators
- NaI crystals
- BaF_2 crystals

Methodologies

- Energy deposition (ΔE and E)
- Time-of-flight (TOF)

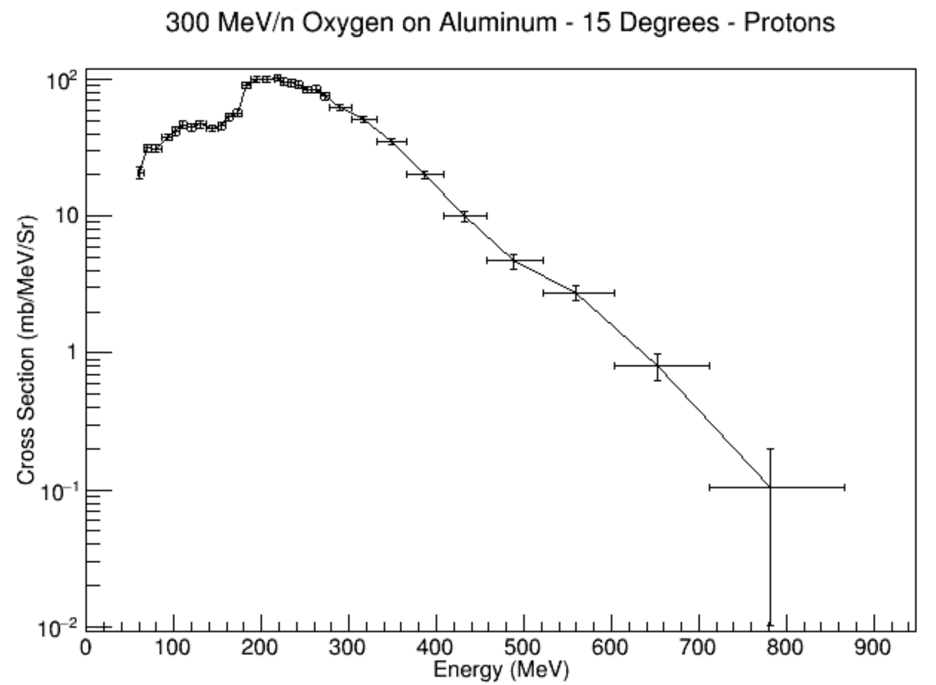
Results



Outputs:
- yield
- kinetic energy

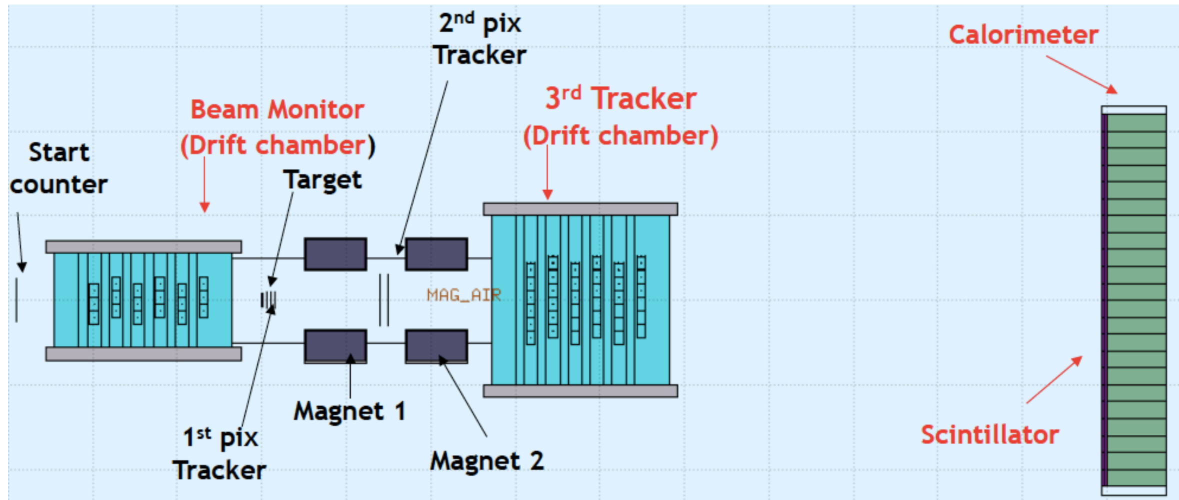
of all fragments types (including isotope discrimination) at several angles →

Double-differential cross sections

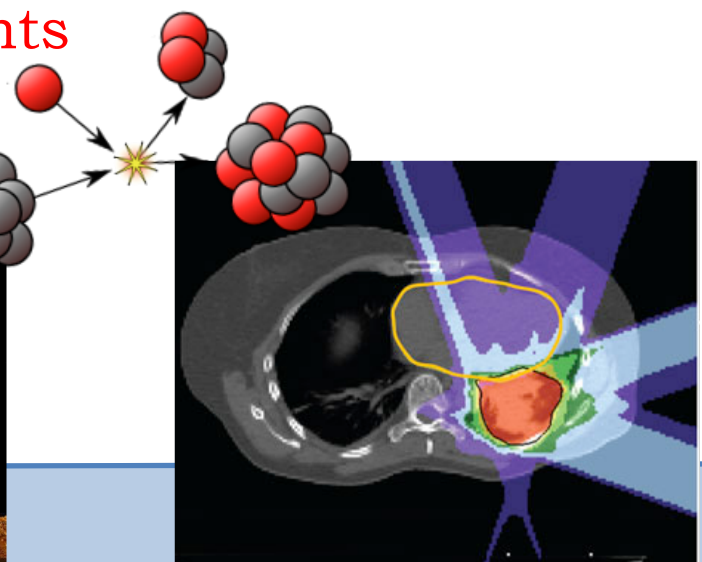


FOOT (FragmentatiOn Of Target)

Focus on the cross section for target and projectile fragmentation in Particle Therapy and for radioprotection in space



Combines magnetic, TOF and calorimetric measurements



Inverse kinematic approach

Movable setup, data taking foreseen at CNAO/HIT in 2019

Summary

- High-energy ions represent a main limitation to space exploration
- Currently the best strategy is passive shielding
- The combination of ground and space-based experiments can help understand the radiation hazard
- Deterministic and Monte Carlo codes provide radiation risk assessment for all scenarios

Nuclear physics plays a key role in improving the existing theoretical models and in providing measurements for validating and benchmarking them

Thank you for your attention