Space radiation risk advancements through neutron radiobiology and in-orbit ion monitoring

UNIVERSITÀ DI PAVIA – Dipartimento di Fisica "Alessandro Volta"
UNIVERSITÀ DI PAVIA – Department of Molecular Medicine
CNAO Centro Nazionale di Adroterapia Oncologica
TOR VERGATA Università degli Studi di Roma
ASI Agenzia Spaziale Italiana

RADBIO phys
radbiophys.unipv.eu
Contact : geraldine.gonon@unipv.it

GONON G.[1], SEMERANO R.[1], RIANI C.[1], LONATI L.1, MENTANA A.[1], PREVITALI A.[2], MAGGI M.[2], SCOTTI S.[2], FACOETTI A.[3], PULLIA M.[3], GUARDAMAGNA I.[1], L. NARICI[4], L. Di FINO[5], BAIOCCO G.[1]

[1] *Laboratory of Radiation Biophysics and Radiobiology, Department of Physics "A. Volta", University of Pavia, 27100 Pavia, Italy.*
[2] *Unit of Immunology and General Pathology, Department of Molecular Medicine, University of Pavia, 27100 Pavia, Italy.*
[3] *Medical Physics Unit & Research Department, CNAO National Center for Oncological Hadrontherapy, Pavia, Italy.*
[4] *Physics Department, University of Rome Tor Vergata, Rome, Italy.*
[5] *Italian Space Agency, Rome, Italy.*

ABSTRACT

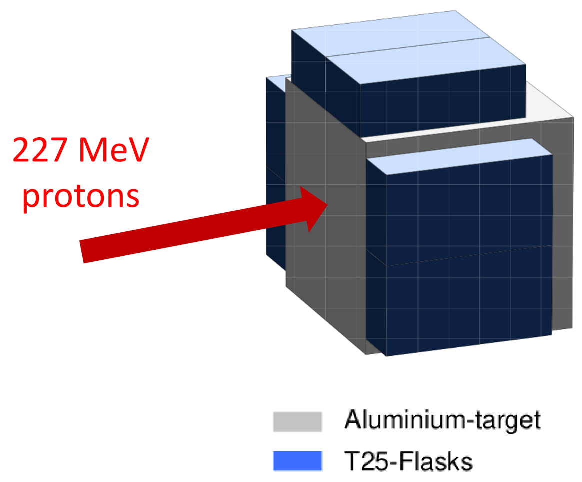
In space, astronauts are exposed to a complex radiation field with charged particles and secondary neutrons causing detrimental biological effects through heterogeneous energy deposition. Within the ASI-funded n-SPACE project, neutron effects are investigated through in-vitro cell culture irradiations at CNAO, where high-energy protons striking an aluminum block, representative of space-vehicle walls, generate a neutron field characterized through Monte Carlo simulations. DNA damages are quantified measuring double-strand breaks (γ-H2AX) and pyrimidine dimers (CPDs) following neutron exposures. Additional radiobiological analyses include cell viability, clonogenic survival, cytokine release.

In parallel, within the ASI-funded OBP project, the LIDAL light-ion detector, integrated into the ALTEA system and deployed on the ISS in 2019, provides real-time monitoring of heavy and light ions. In both cases, theoretical Relative Biological Effectiveness modelling, coupling radiation transport and track-structure simulations, can be applied, finally enhancing mechanistic understanding of radiation-induced DNA damage and strengthening risk assessment for terrestrial and space-flight environments.

1 The *n-SP.A.C.E.* project : *n*eutrons in *SPA*ce - a *C*harged *E*ndeavor

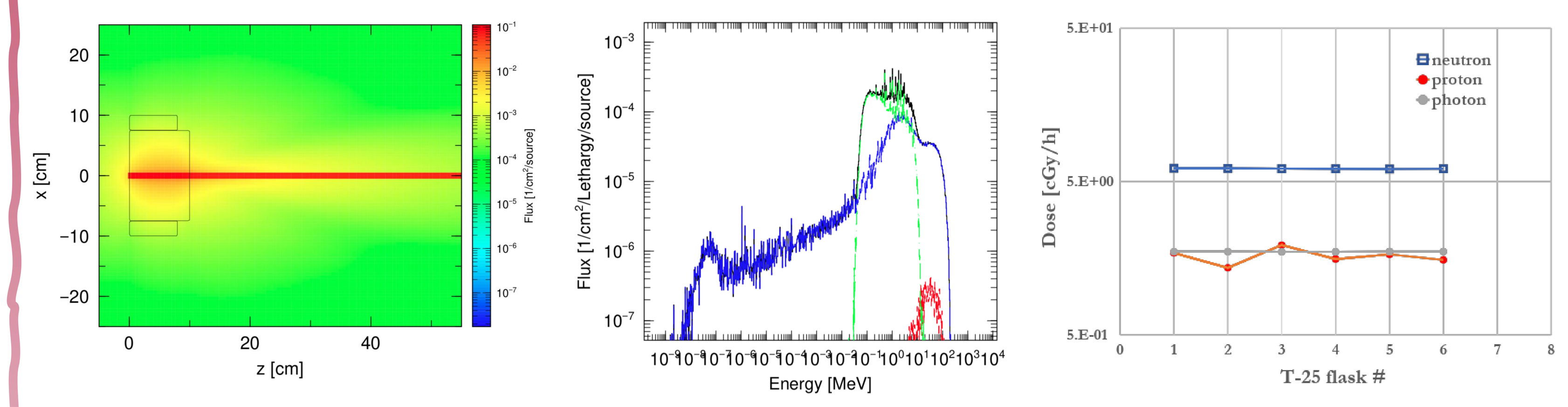
EXPERIMENTAL PROCEDURE

- Cellular models
  - HaCaT – immortalized human keratinocytes
  - HUVEC – human endothelial cells
  - Astrocytes - model for central nervous system tissue
- Irradiation
  - Production of secondary neutrons via **protons beams, Ebeam= 227 MeV** on **Al target** of 15 × 15 × 10 cm3
- Neutrons energy peak : 2-3 MeV
- Neutrons dose-rate : ~6,1 cGy/h (≈60% of total dose)



	Dose (%)	Dose (cGy) 1h exp.	Dose **(cGy)** 2h exp.	Dose **(cGy)** 3h exp.
Neutrons	~ 60%	6.1	12.2	18.3
Protons	~ 15-17 %	1.5	3	4.5
Photons	~ 15-17 %	1.7	3.4	5.1
Total		**9.3**	**18.6**	**27.9**

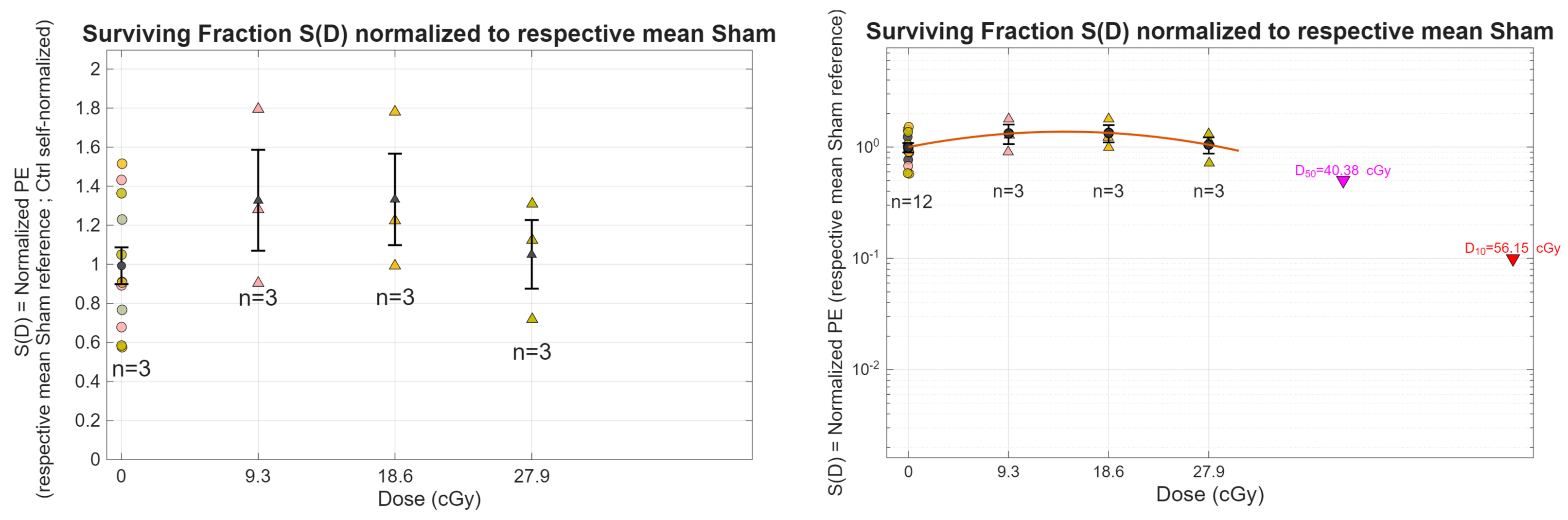
Neutron Field Evaluation via Monte Carlo Simulations



Biological endpoints : preliminary data

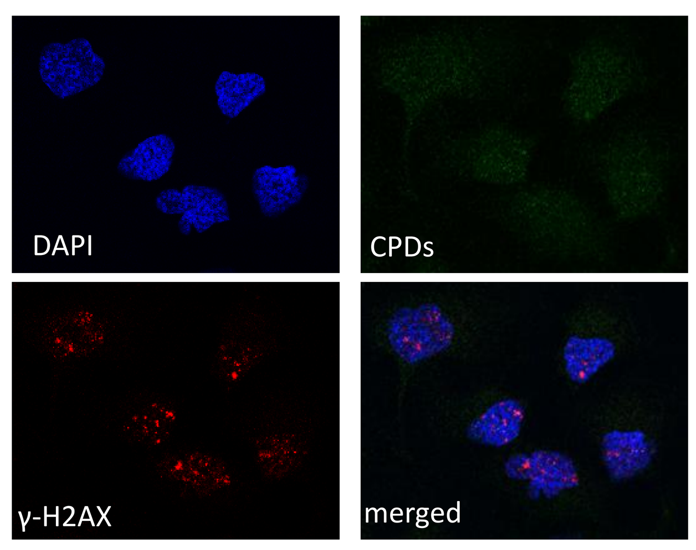
Cell Survival

✓Clonogenic survival assay → measures long-term cell survival after radiation



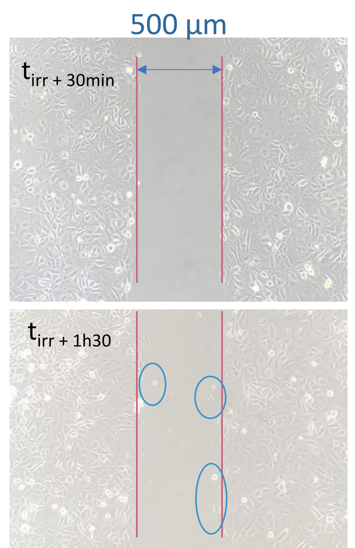
DNA Damage and Repair

✓γ-H2AX (confocal microscopy)
→ marker of DNA double-strand breaks
✓γ-H2AX (flow cytometry) *=> not shown*

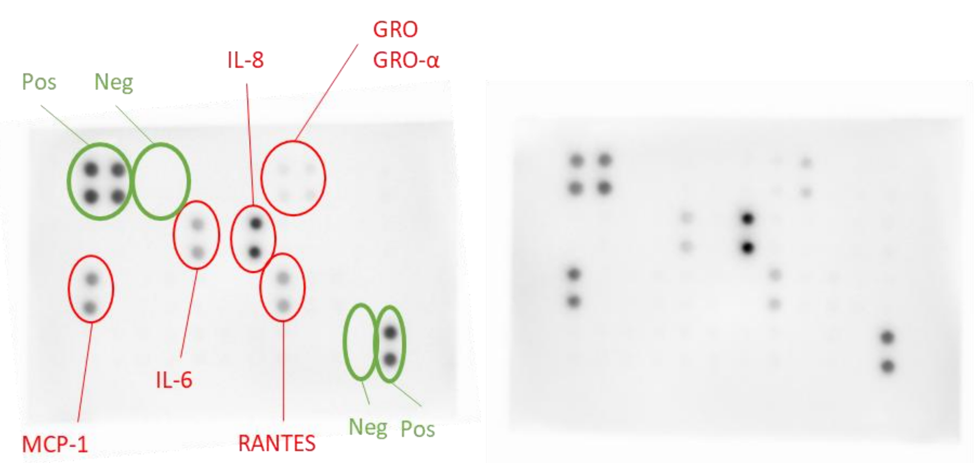


Functional Cellular Response

✓ Wound healing (cell migration assay)
→ measures cell migration and tissue repair capacity



✓ Cytokine array on cell culture media
→ measures cell signaling response to stress



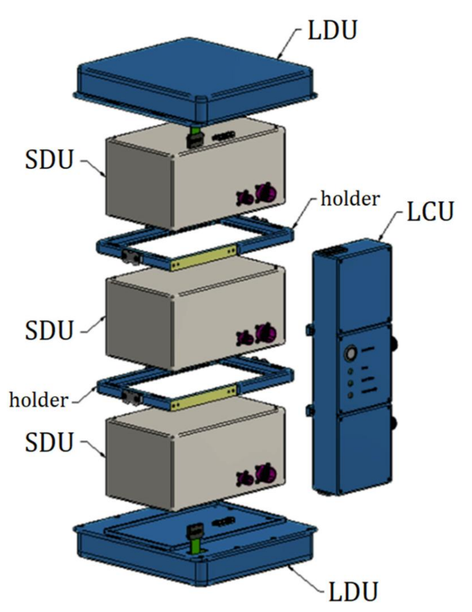
Control, t=0   6 cGy, t=0

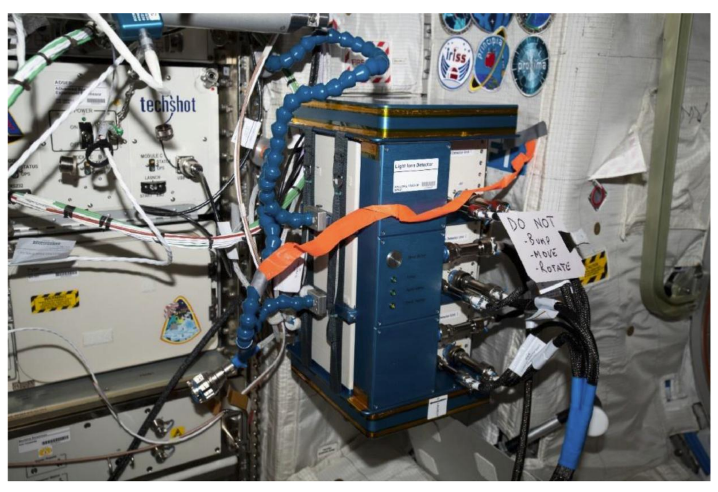
2 The One Board Payloads (*OBP*) project
Light Ions Detector for ALTEA (LIDAL)
a Time-of-Flight Radiation Detector for the International Space Station

EXPERIMENTAL FRAMEWORK

- **Purpose**: Measure flux, energy spectra, and Time of Flight (ToF→ β = v/c) of ions in a space habitat
- **1st detector combining** :
  - Energy deposition: 3 Silicon Detector Units (SDUs) from ALTEA, measuring **LET (Linear Energy Transfer)** → gives Z if particle speed is known
  - **Time-of-Flight (ToF) measurement:** 2 LIDAL Detector Units (LDUs) → gives **β (v/c)**
  - Ion discrimination based on **Z^2/β^2** → an important quantity for **radiation risk models**

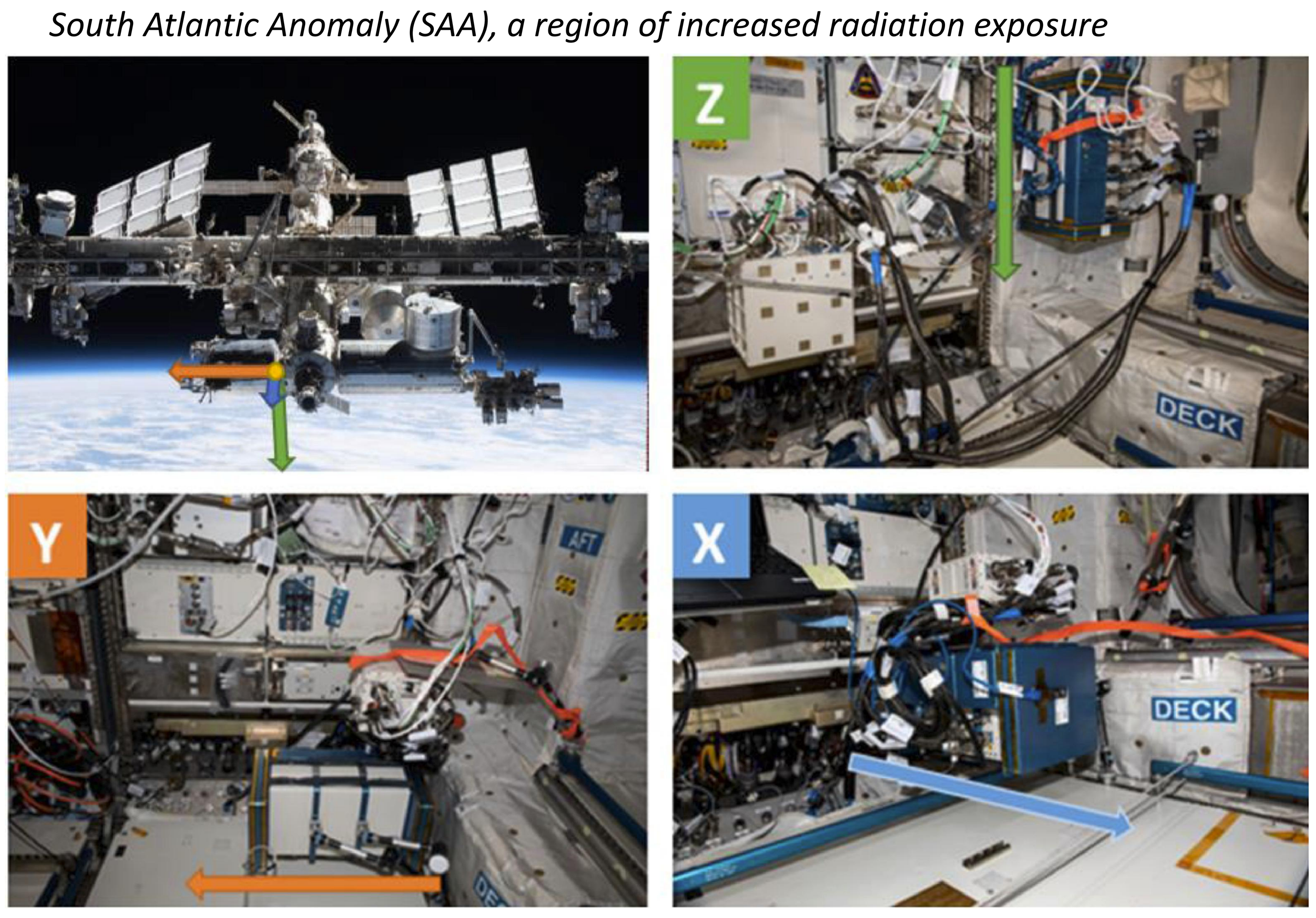
Sketch of the LIDAL detector





ISS operation

- *Uploaded Nov 2019, operational since Jan 2020 in Columbus module*
- *Measures 3 directions across geomagnetic regions: High latitude, low latitude, and South Atlantic Anomaly (SAA), a region of increased radiation exposure*



CONCLUSION

- Detector measurements (particle type, energy, direction) and radiobiological data provide complementary information
- Linking physical radiation quality to biological response is essential for realistic **astronaut risk evaluation**
- The combined approach supports improved space radiation protection strategies for long-duration missions

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