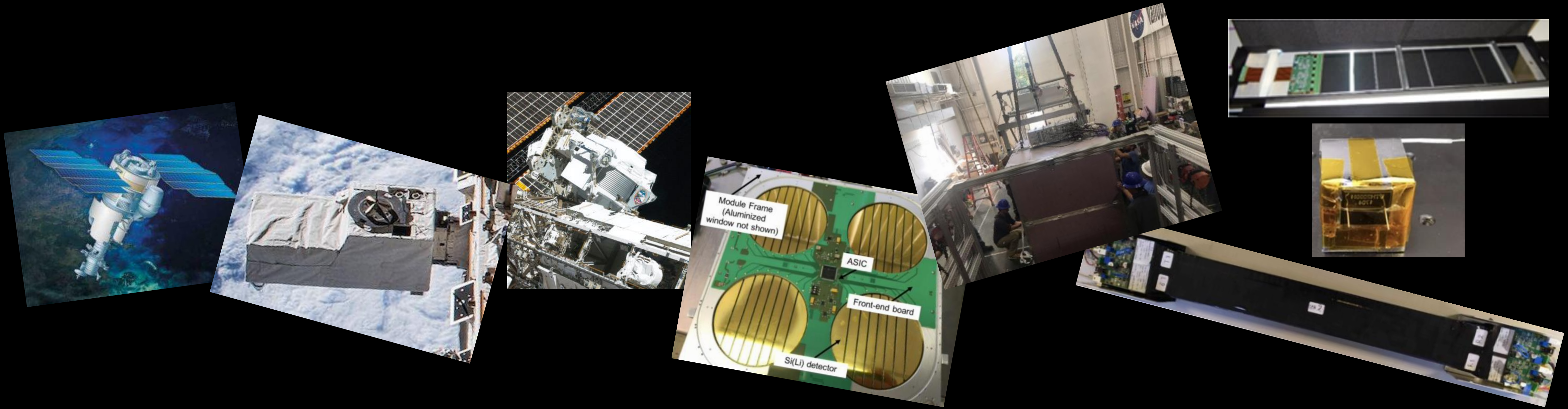
16TH TOPICAL SEMINAR ON INNOVATIVE PARTICLE AND RADIATION DETECTORS (IPRD23)
Siena, 25 - 29 September 2023

Agenzia Spaziale Italiana

ASI research programs in particle and radiation measurements in space

Valerio Vagelli

Italian Space Agency, Science and Research Directorate



ASI space activity sectors

Measurement of cosmic rays in space

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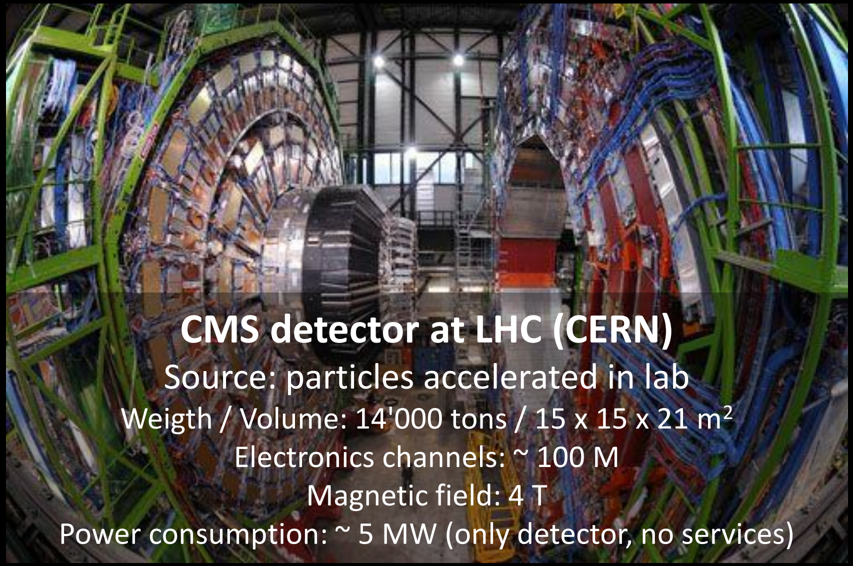
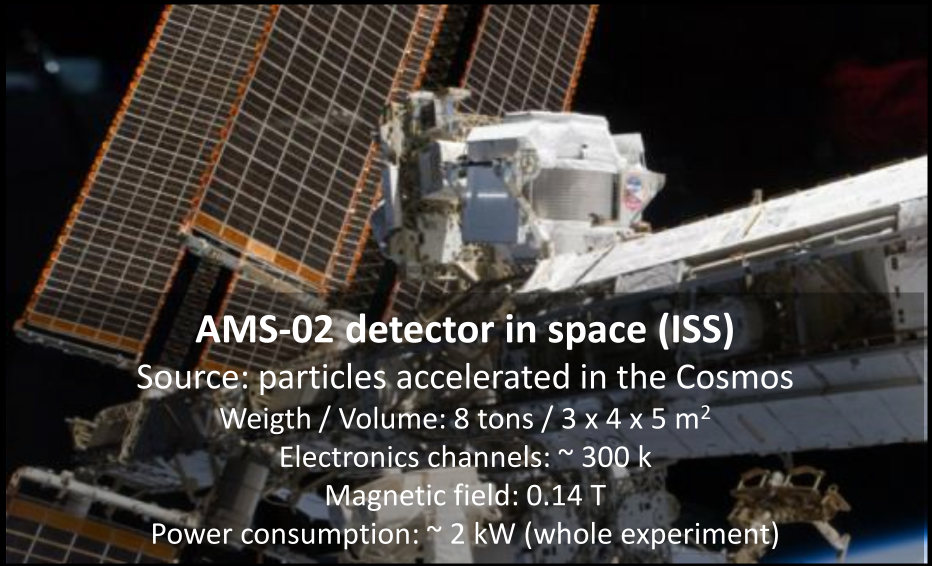
Particle physics detectors operated in the "laboratory" of space



CMS detector at LHC (CERN)
Source: particles accelerated in lab
Weigth / Volume: 14'000 tons / 15 x 15 x 21 m^2
Electronics channels: ~ 100 M
Magnetic field: 4 T
Power consumption: ~ 5 MW (only detector, no services)

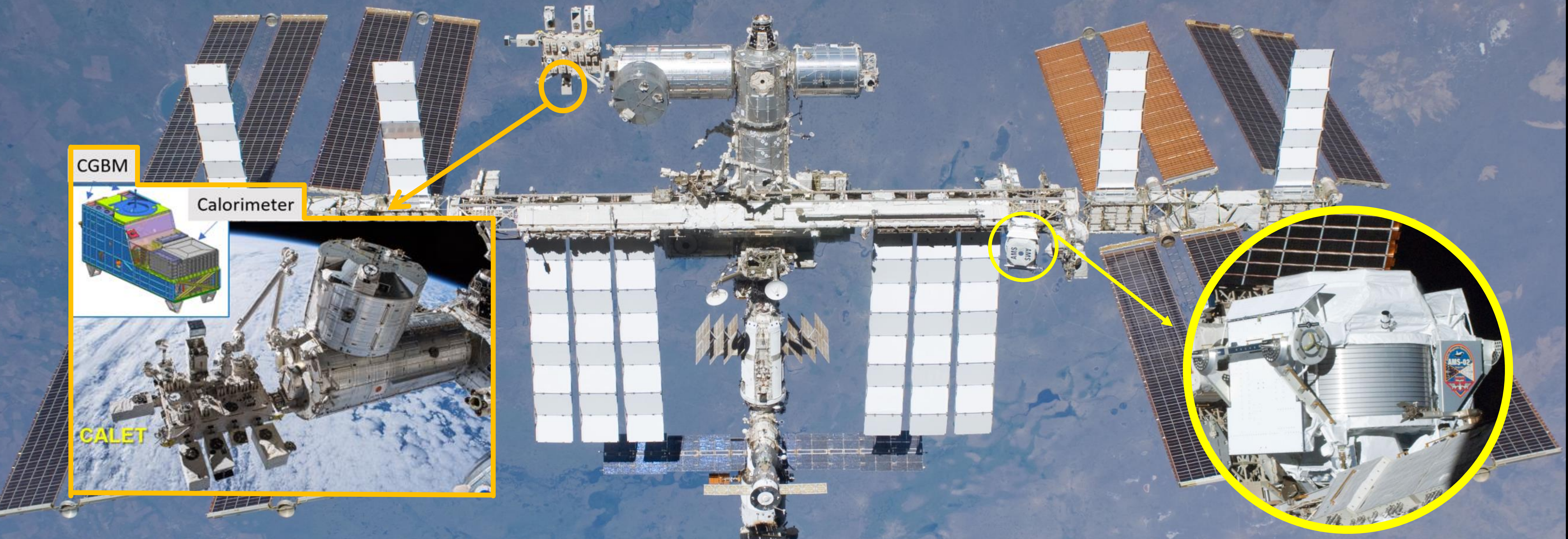


AMS-02 detector in space (ISS)
Source: particles accelerated in the Cosmos
Weigth / Volume: 8 tons / 3 x 4 x 5 m^2
Electronics channels: ~ 300 k
Magnetic field: 0.14 T
Power consumption: ~ 2 kW (whole experiment)

Historical sinergies between collider detectors and space astroparticle detectors in **experimental measurement approaches**, **technological developments**, **facilities**, very long development, design and construction **programs**.

CALET is a large-acceptance high-energy **calorimeter** in the **GeV-TeV** energy range.
Since **2015** CALET has been operating on the ISS.

AMS-02 is a large-acceptance high-energy **magnetic spectrometer** in the **GeV-TeV** energy range.
Since **2011** AMS-02 has been operating on the ISS.



ASI - italian universities + CNR participation
ASI - JAXA research agreement since 2011
CERN RE25 since 2012

ASI - INFN and italian universities participation
ASI - MIT research agreement since 2003
CERN RE1 since 1997

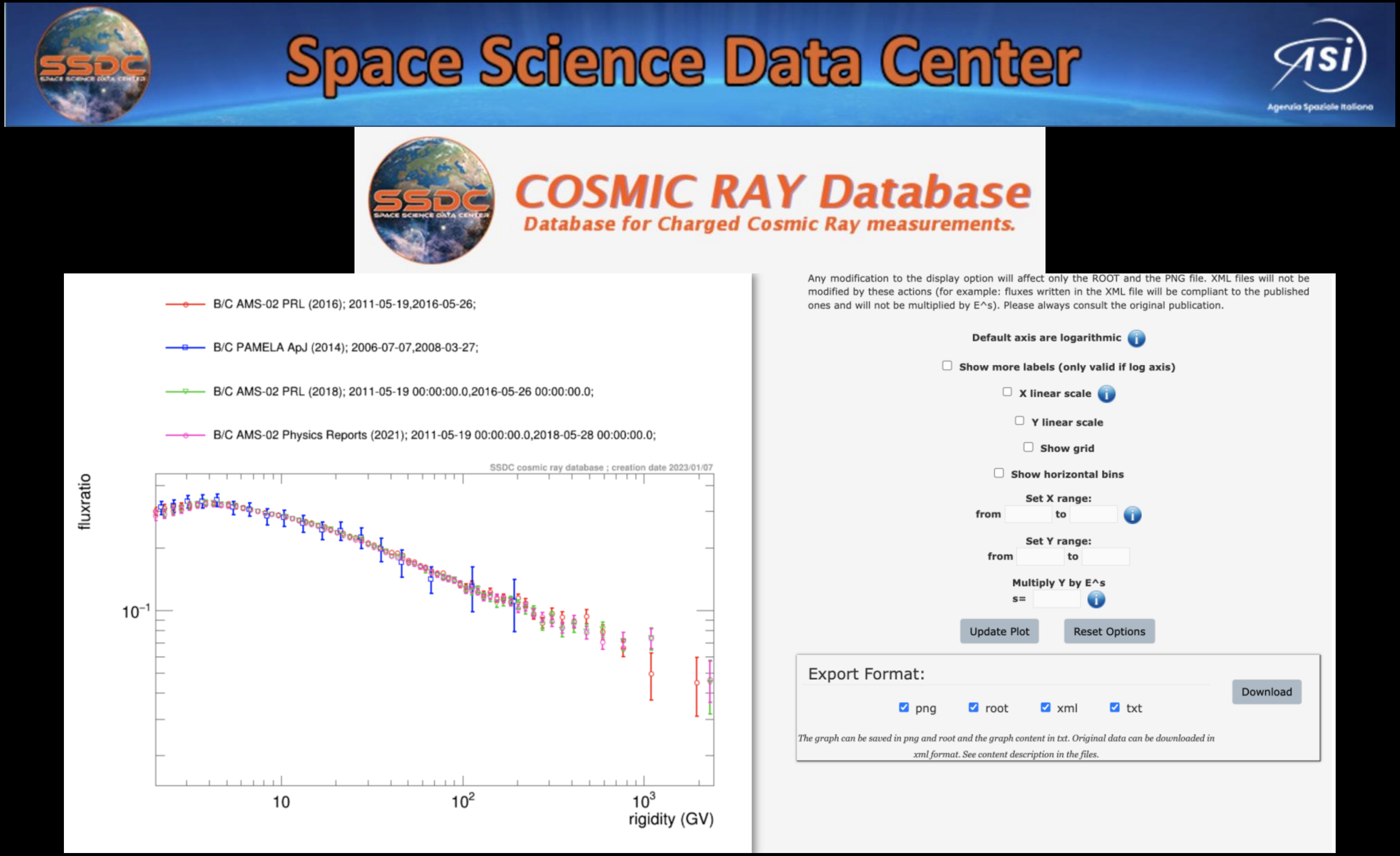
Charged CRs: state of the art

Published results from CR missions are available to the community through the

ASI Space Science Data Center

https://tools.ssdc.asi.it/CosmicRays/

hosted at the ASI Space Science Data Centers

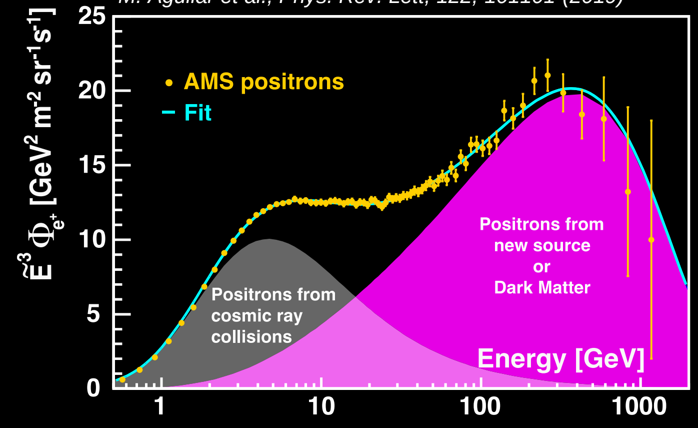


Charged CRs: state of the art

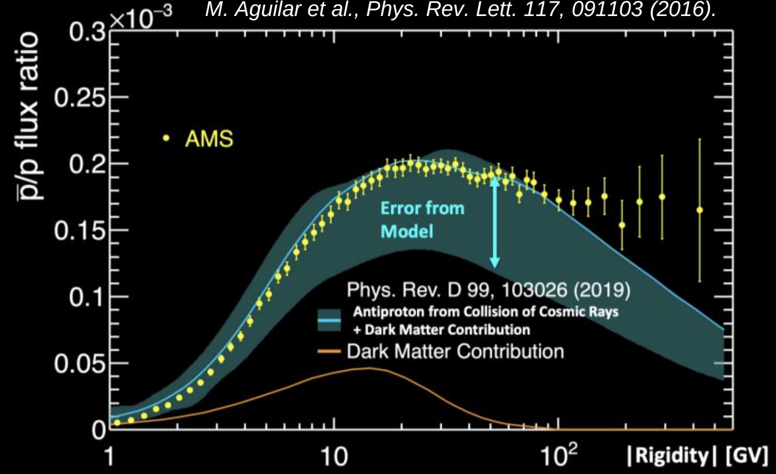
Agenzia Spaziale Italiana

Results on CR spectra in GeV-TeV since 2010 from PAMELA, AMS-02, DAMPE, CALET.... have provided **novel information** and measured **unexpected features** that are forcing to completely **revisit the paradigms behind models of CR origin, acceleration and propagation**

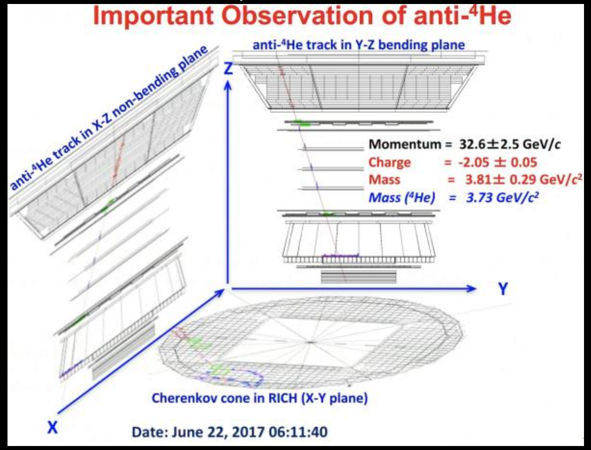
AMS 10 years update. First results in:
M. Aguilar et al., Phys. Rev. Lett. 122, 041102 (2019)
M. Aguilar et al., Phys. Rev. Lett, 122, 101101 (2019)



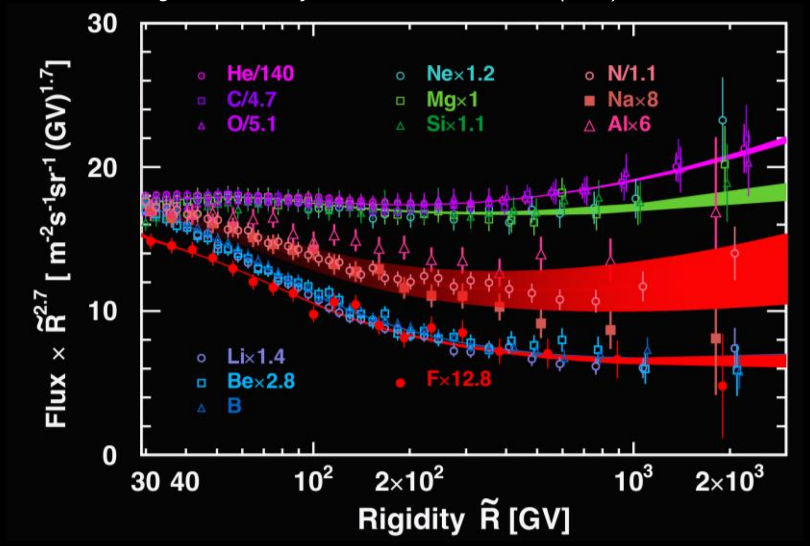
AMS 10 years update. First results in:
M. Aguilar et al., Phys. Rev. Lett. 117, 091103 (2016).



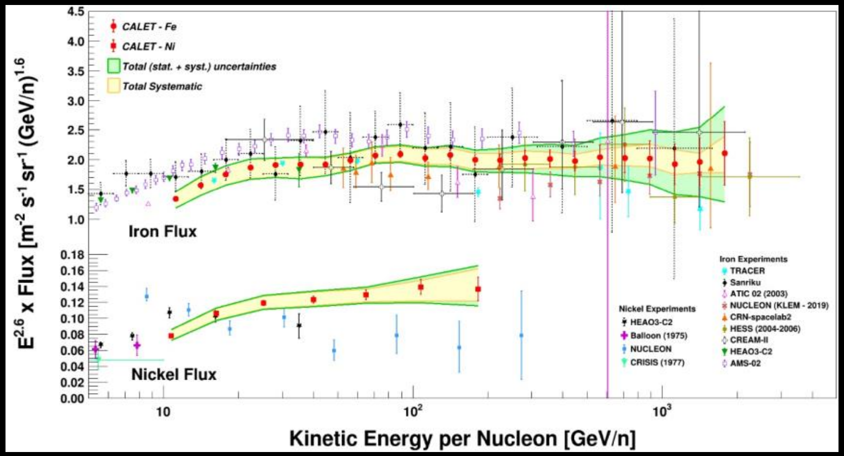
S.Ting, Latest Results from the AMS Experiment on the International Space Station, CERN 2018



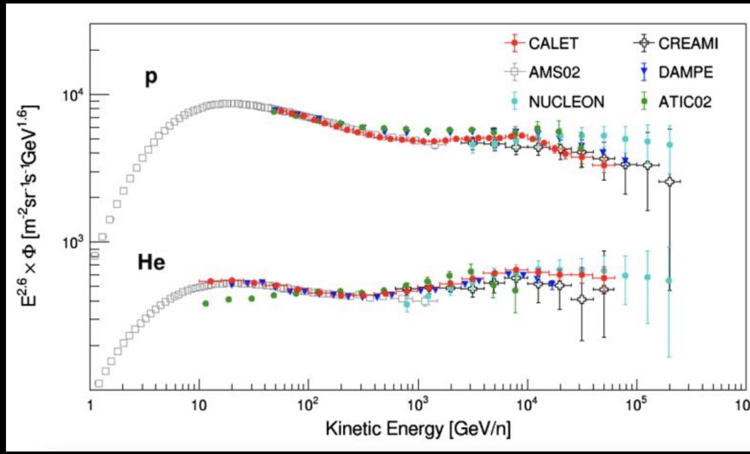
AMS 10 years update. First results in:
M. Aguilar et al., Phys. Rev. Lett. 121, 051103 (2018).
M. Aguilar et al., Phys. Rev. Lett. 127, 021101 (2021).



CALET coll., O. Adriani et al., Phys. Rev. Lett. 128, 131103 (2022)



CALET coll., O. Adriani et al., Phys. Rev. Lett. 130, 171002 (2023).



Charged CRs: open questions

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I. What is the origin of the **hardening observed in the spectra of CR nuclei** at rigidity of 300 GV and ~10 TV?
II. Why is the slope of the spectrum of CR **proton and helium different**?
III. What is the origin of the prominent **break** observed at a particle energy of **1 TeV in the electron spectrum**?
IV. Why do the **proton, positron, and antiproton** spectra have roughly same slopes at particle energies larger than 10 GeV?
V. What is the origin of the **rise in the positron fraction** at particle energies above 10 GeV?
VI. ....

COMPOSITION frontier

ENERGY frontier

ANTIMATTER frontier

NEW paradigm of CR origin, acceleration and propagation

Novel experimental approaches that target all opportunities of space platforms must be addressed, from **cubesats and nanosatellite constellations** up to **large-size space missions** and **Moon**, including **stratospheric balloon flight missions**.

+ synergic activity at ground laboratories and accelerators to tackle **technological challenges**, detector calibrations and investigate particle physics interactions to improve systematic uncertainties

Direct measurements of charged CRs: prospectives

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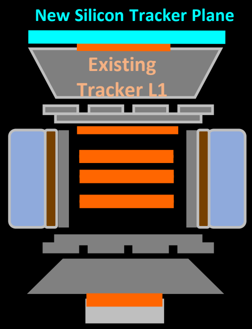
Following up on PAMELA, AMS-02, DAMPE and CALET: calorimeters and spectrometers

Enlarge acceptance and maximum detectable energy to extend statistical limits and explore highest energies

Installation of additional Si-tracker layer (~7 m^2)

Layer 0 (L0)



2011 AMS-02 Installed On ISS

2020 AMS-02.01 Upgrade: UTTPS

2025 AMS-02.02 Upgrade: L0

AMS Tracker Layer 0: acceptance increase by 300%

Expected operations in 2025

AMS-02 is the only magnetic spectrometer planned to be operated in space in the future to pursue investigations on antimatter physics with magnetic spectrometers

Direct measurements of charged CRs: prospectives

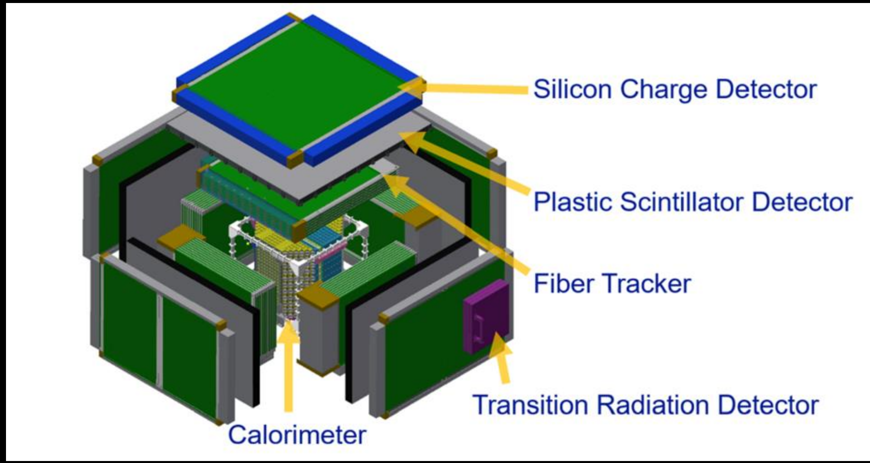
Agenzia Spaziale Italiana

Following up on PAMELA, AMS-02, DAMPE and CALET: calorimeters and spectrometers

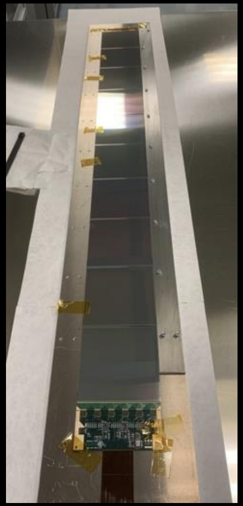
Enlarge acceptance and maximum detectable energy to extend statistical limits and explore highest energies

Z. Wang, PoS ICRC 2023, 181

HERD



PSD prototype



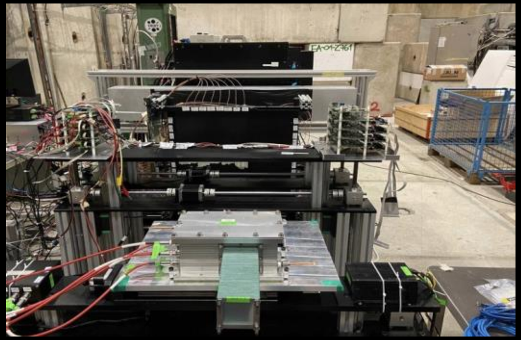
SCD ladder prototype

Small scale CALO prototype

Large acceptance calorimeter planned for operations on the CSS

- CR nuclei up to PeV, $e^{+/-}$ up to 20 TeV
- nearly 4π acceptance based on italian CALOCUBE heritage
- China lead, Italy (INFN) first international partner with responsibilities of 3 out of 5 subdetectors

ASI – INFN and italian university participation to phase B for italian subdetector responsibilities (SDC, PSD, CALO-PD)



Many BT campaigns at CERN PS/SPS and INFN BTF to consolidate the technology

(INFN activity before ASI support, that just started in May 2023)

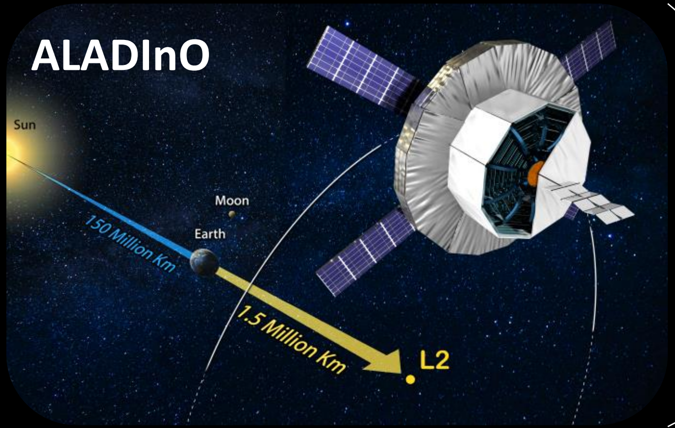
See also G. Silvestre, this conf. Wednesday
L. Silveri, this conf. Wednesday

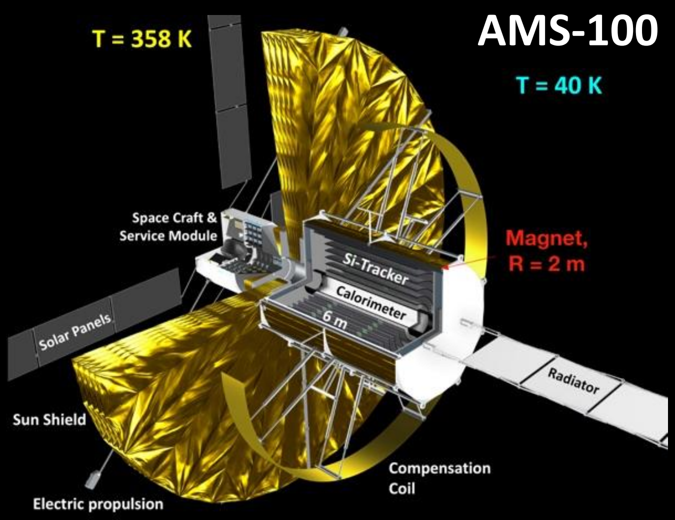
Direct measurements of charged CRs: prospectives

Following up on PAMELA, AMS-02, DAMPE and CALET: calorimeters and spectrometers

Enlarge acceptance and maximum detectable energy to extend statistical limits and explore highest energies

O.Adriani et al., *Instruments* 2022, 6(2), 19





S. Schael et al., *NIM-A* 944 (2019) 162561

Large acceptance HTSM spectrometer planned for operations in L2

- Extends 10x AMS-02 acceptance
- HERD physics + TeV e^+ and p-bar + GeV D-bar and He-bar
- Mission concept Italy-driven
- **LAMP: Balloon-borne pathfinder required to fill the TRL gaps**

ASI participates in R&D activity to enanche TRL for next-generation HTSM spectrometers in space

HTSM spectrometers: R&D

HTSM is the one the most critical technologies to be enabled to develop next-generation spectrometer missions in space

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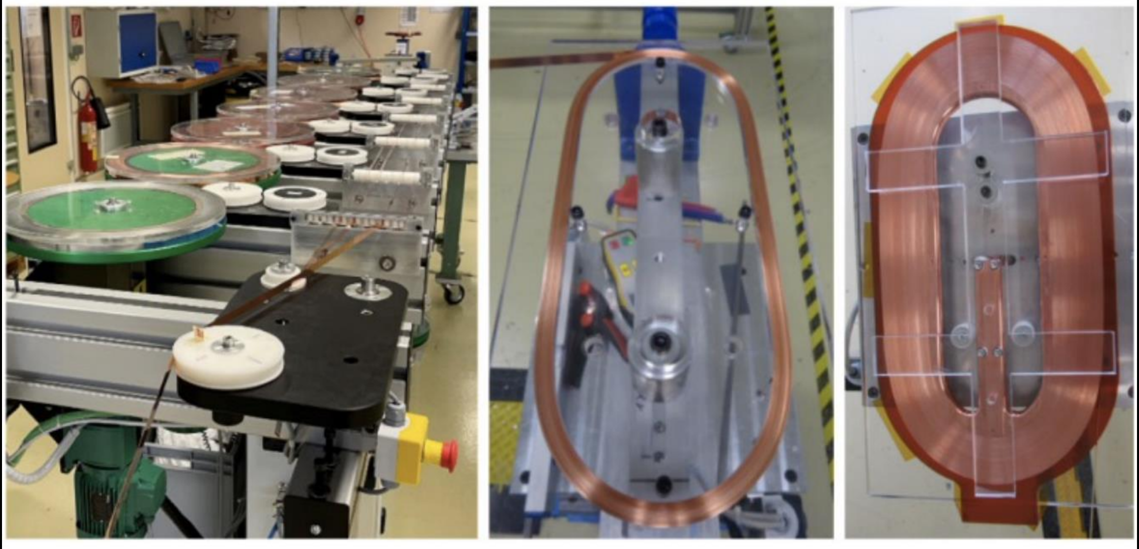
Design, manufacturing and testing of a compact high-field HTS Demonstrator Magnet for Space applications (HDMS)

increase to TRL=6 of the technology required for integration of a HTS coil (REBCO)

Winding of the HDMS coils at CERN

H. Reymond et al., JACoW iCALEPCS2021 (2022) 473-477



HDMS demonstrator (@ ASI, Jan 2023)

ASI - INFN - CERN and italian university participation
scientific follow-up activities just starting

Project successfully completed 2018-2022. The HDMS team constructed and successfully tested an HTS demonstrator magnet for space with space-compliant and immediately scalable solutions

- No-insulation winding technique
- Self-protection against quenches
- Copper-bands to transfer current

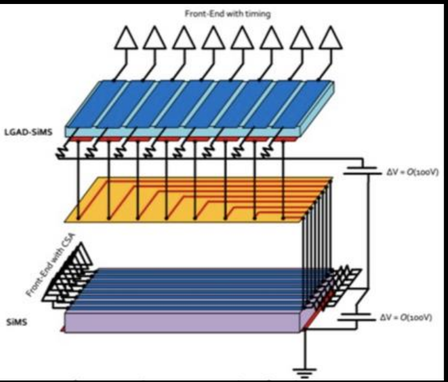
Novel technologies for particle measurements in space

ASI-INFN-FBK research program just funded by italian MUR

PTSD – Pentadimensional Tracking Space Detector

R&D activity to increase LGAD Si-μstrip TRL for space from TRL=2 to TRL=5

Target: breadboard laboratory model for verification of requirements, functionalities and space qualification



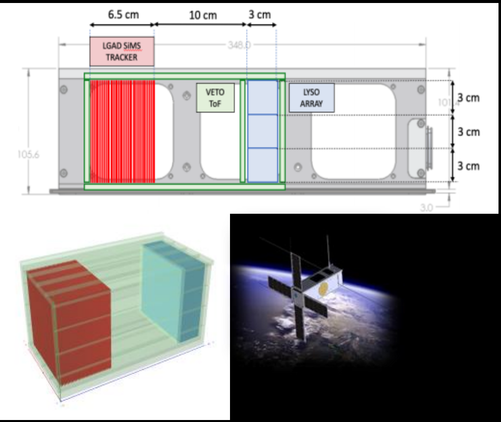
Possible connections for a 5D detector made of a thin LGAD SiMS sensor for timing and moderate resolution coordinate measurement coupled with a thicker standard SiMS sensor for charge and high resolution coordinate measurement.

FEE power consumption mitigation approaches under investigation

Perspectives to fly a cubesat demonstrator to reach TRL=9

Funding and activities planned to start in Sep. 2023

ASI - INFN - FBK research program



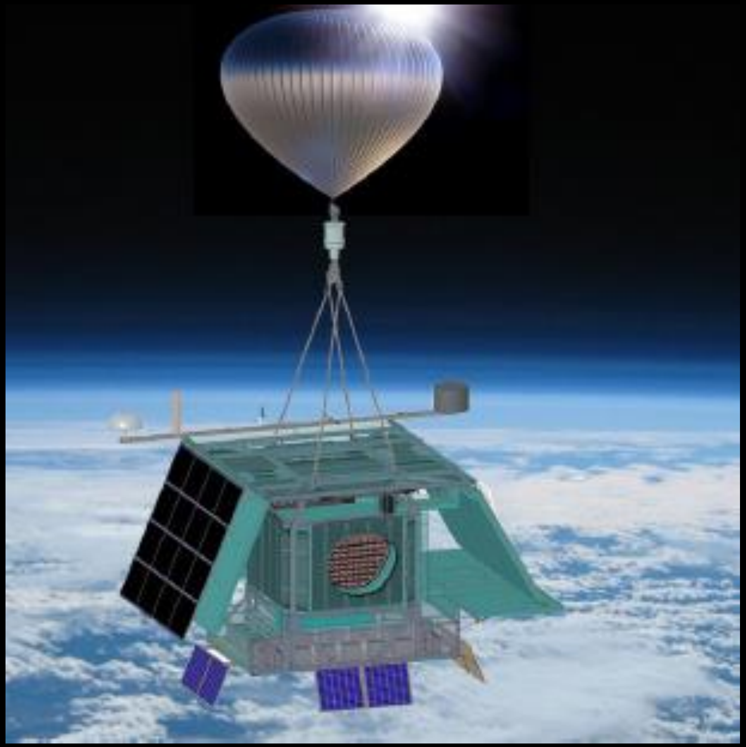
M. Duranti, V. Vagelli et al, *J.Phys.Conf.Ser.* 2374 (2022) 1, 012046

Scientific application: 5D tracking in space

high accuracy position, charge and timing measurement for each hit in the tracking system in a high rate environment

M. Duranti, V. Vagelli et al., *Instruments* 2021, 5(2), 20

Exploring the antimatter frontier with novel approaches



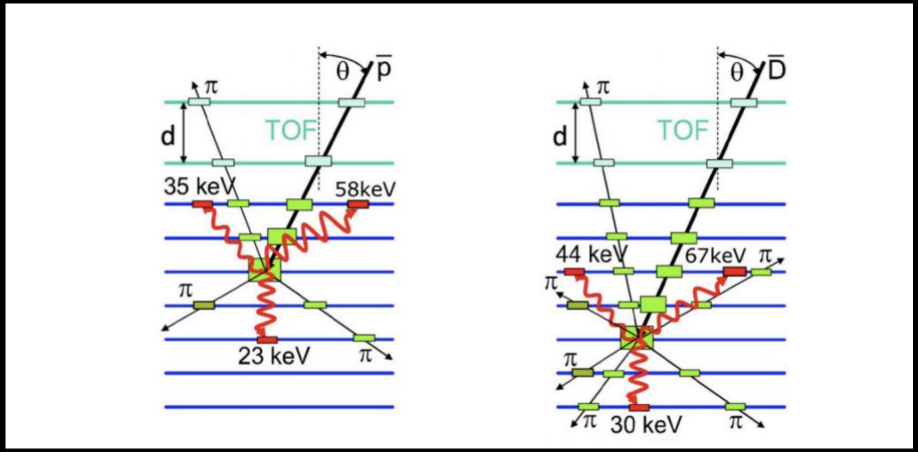
GAPS (General Antiparticle Spectrometer)

see, e.g., R. Munini et al., Astropart.Phys. 133 (2021) 102640

Novel method for detection of nuclear antimatter in CRs by analysis of decay signatures of exotic atoms from interactions of antimatter nuclei with the detector materials

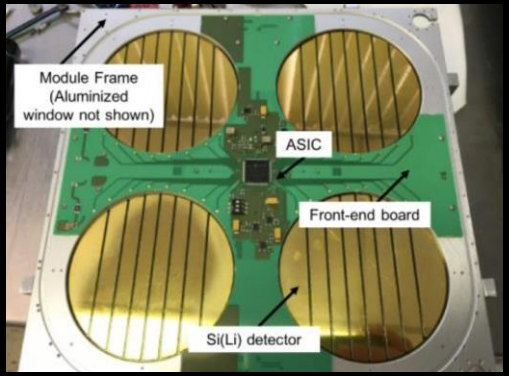
Models predict antideuteron from DM decay or annihilation to be order of magnitude higher than the secondaries. Even a single antideuteron detection with GAPS would point to new physics

Low-energy antimatter detection approach independent from AMS-02 and PAMELA



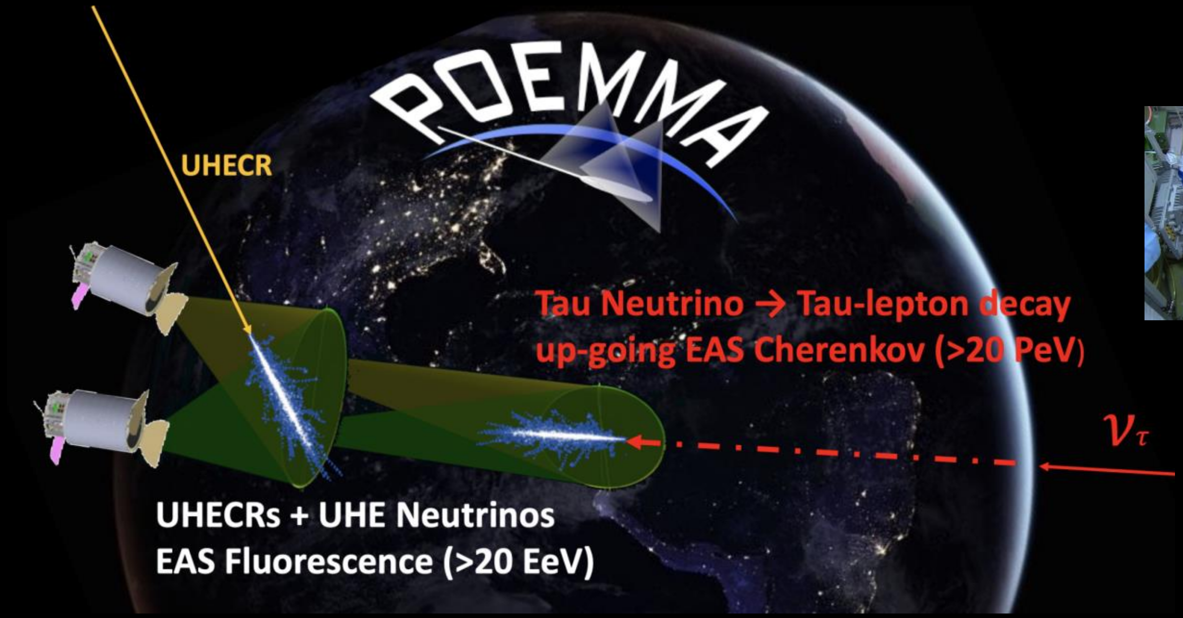
ToF prototype integration

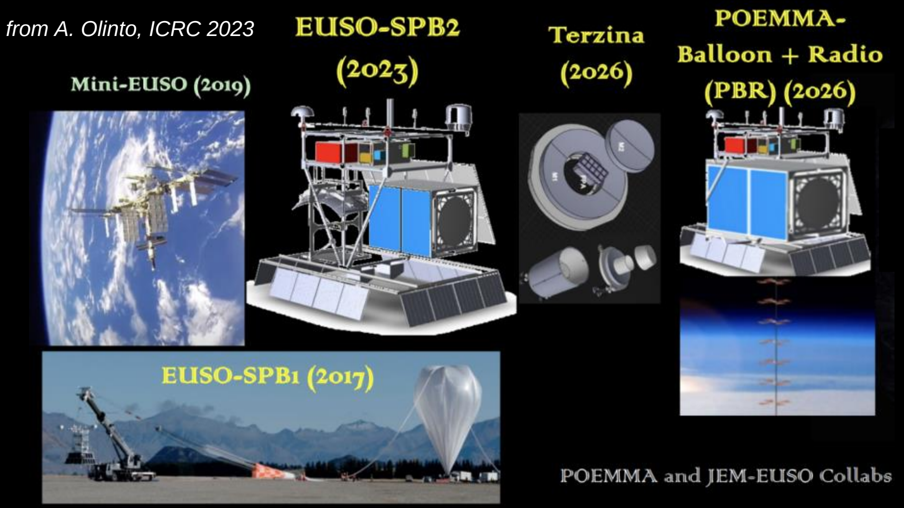
Si(Li) tracker



ASI – INFN and italian university participation
ASI - UniColumbia research agreement since 2021
Planned for 1st flight on NASA balloon from Antartica at Dec 2024

Opening new observation windows from space





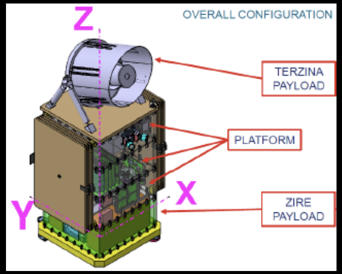
Mini-EUSO

ASI – Uni Rome ToV + INFN participation
ASI - Roscosmos research agreement since 2018
In operation on the ISS since 2019

EUSO-SPB2

ASI – INFN and italian university participation
ASI - UniChicago research agreement since 2022
Launched on NASA SPB from New Zealand in 2023

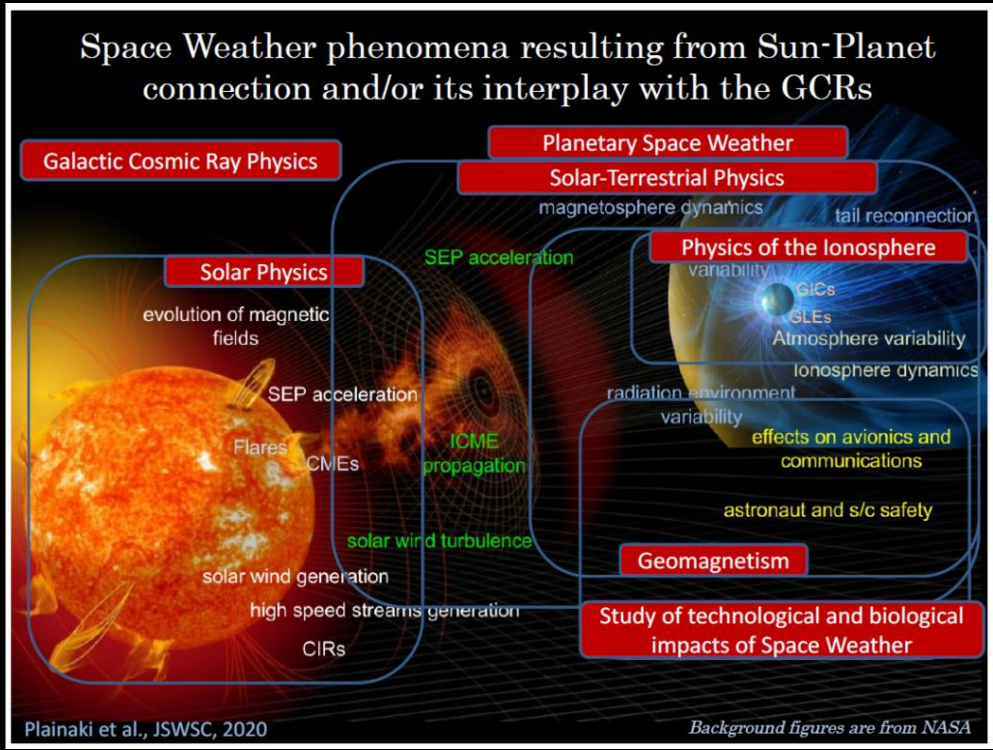
NUSES-Terzina



ASI – GSSI and italian university + INFN participation in consolidation

Cosmic Rays: Space Weather and Earth-Sun system

Agenzia Spaziale Italiana



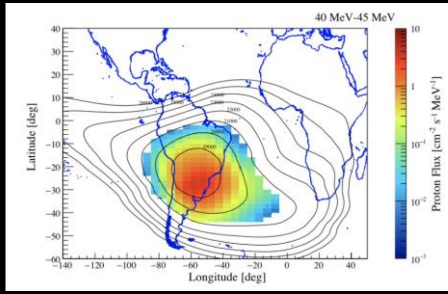
Infrastructure development

- **ASPIS**: a data center hosted at ASI-SSDC for Space Weather data collection, distribution, integration and synergic access for the scientific community

ASI-INAF joint program for a ASPIS prototype (CAESAR)

Space Missions

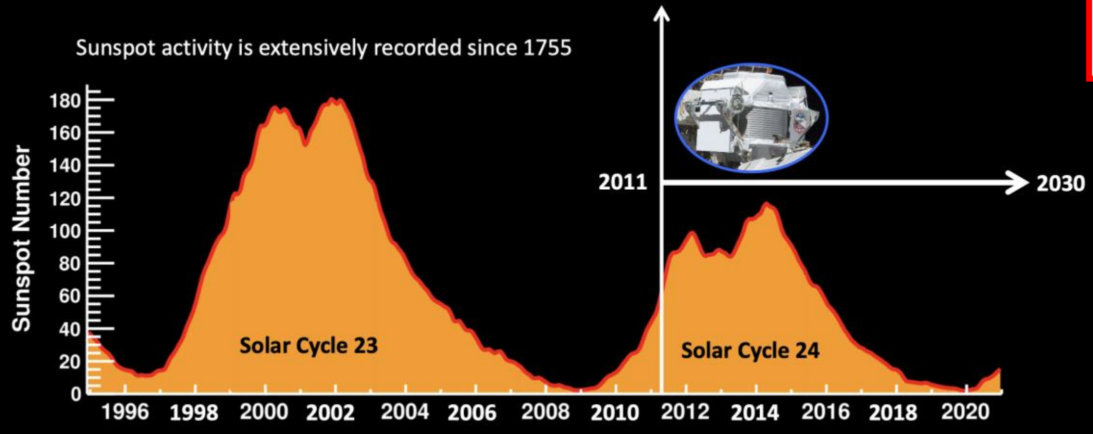
- **HEPD-1** (in space) and **HEPD-02** (to be launched in 2024) onboard CSES satellites



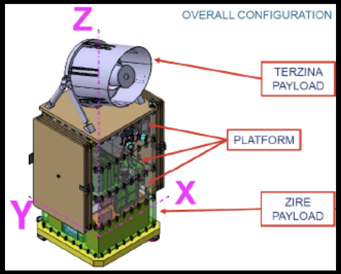
HEPD-2 on CSES satellite

See also E. Ricci, this conf. Monday
V. Scotti, this conf., Tuesday
F. Follega, this conf. Wednesday

ASI – INFN and INAF, CNR and italian university participation

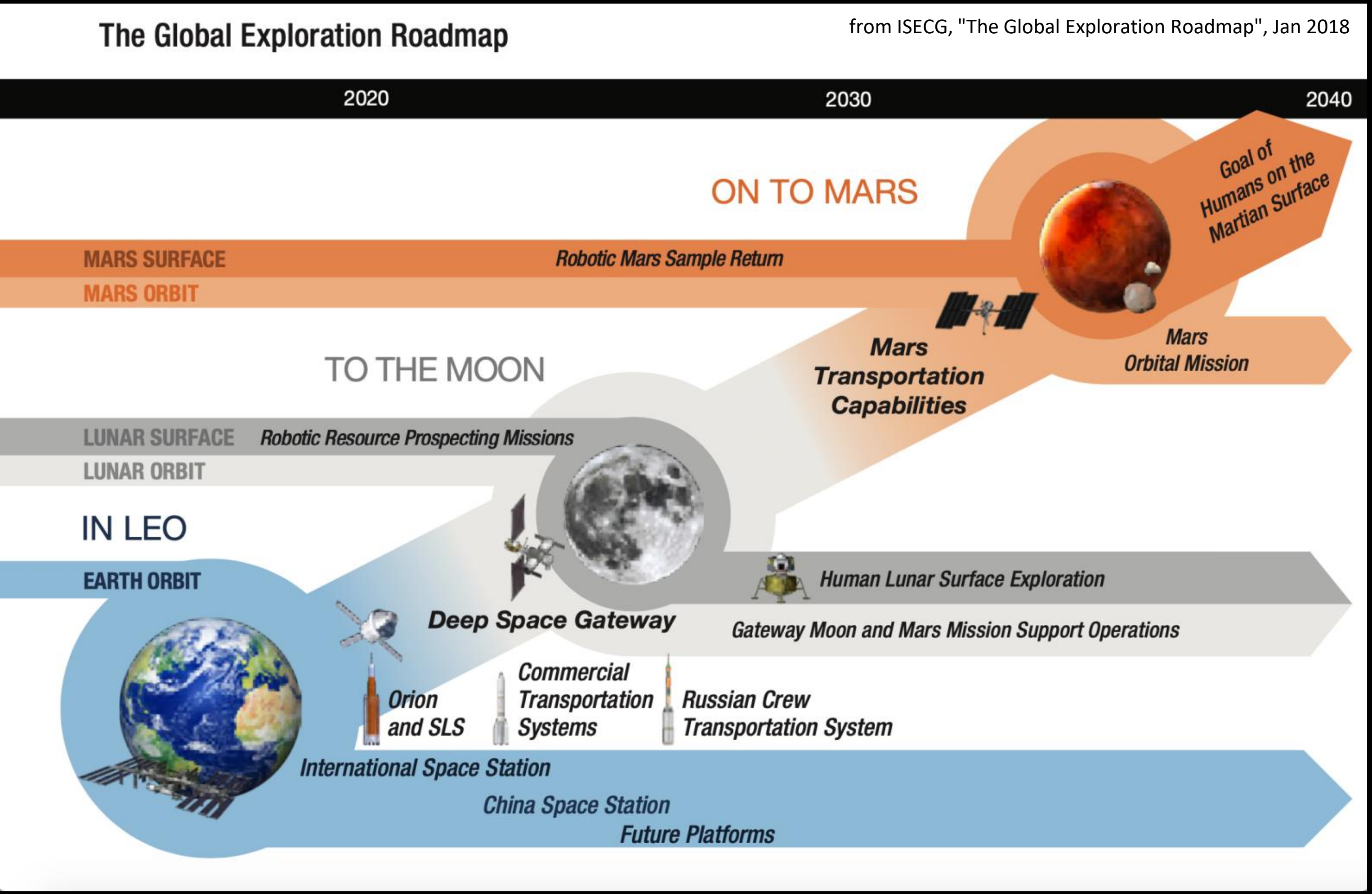


NUSES-Zirè

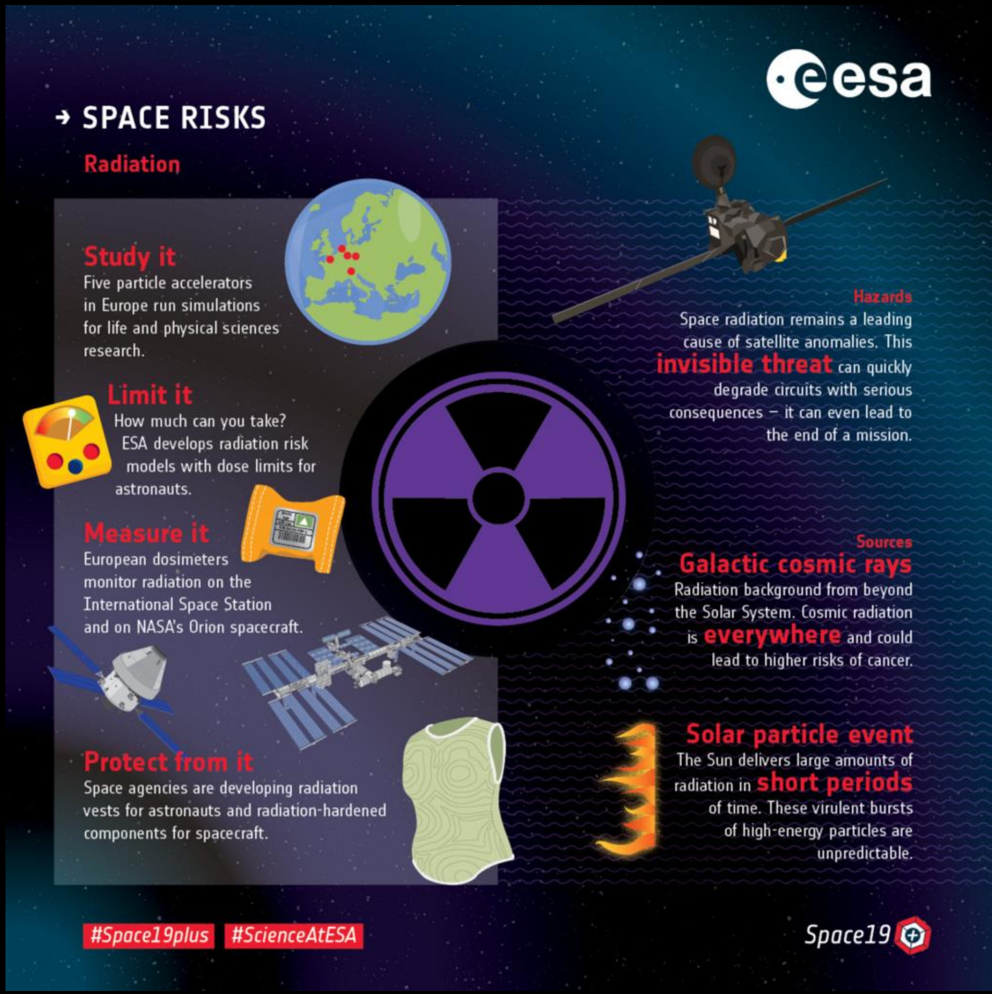


ASI – GSSI and italian university + INFN participation in consolidation

Human space exploration: radiation exposure risks



from ISECG, "The Global Exploration Roadmap", Jan 2018

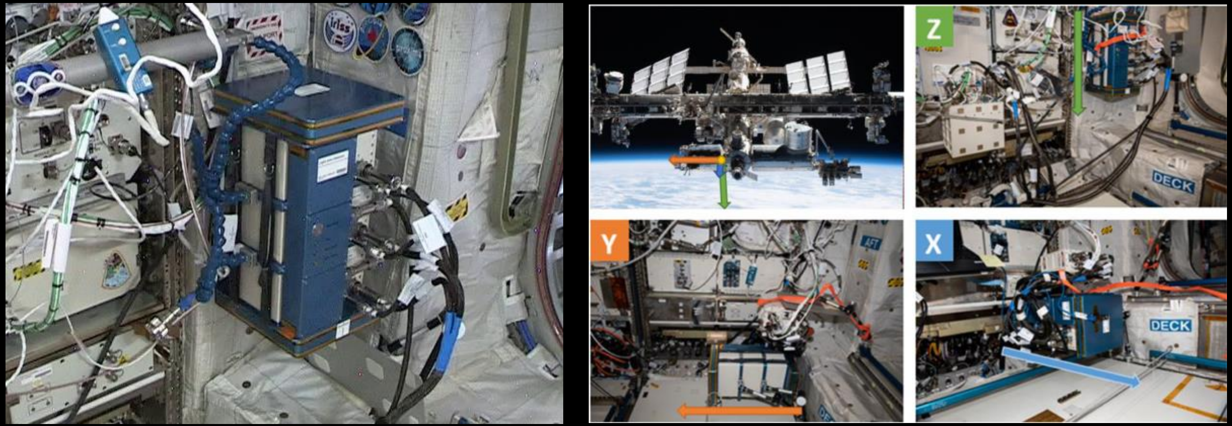


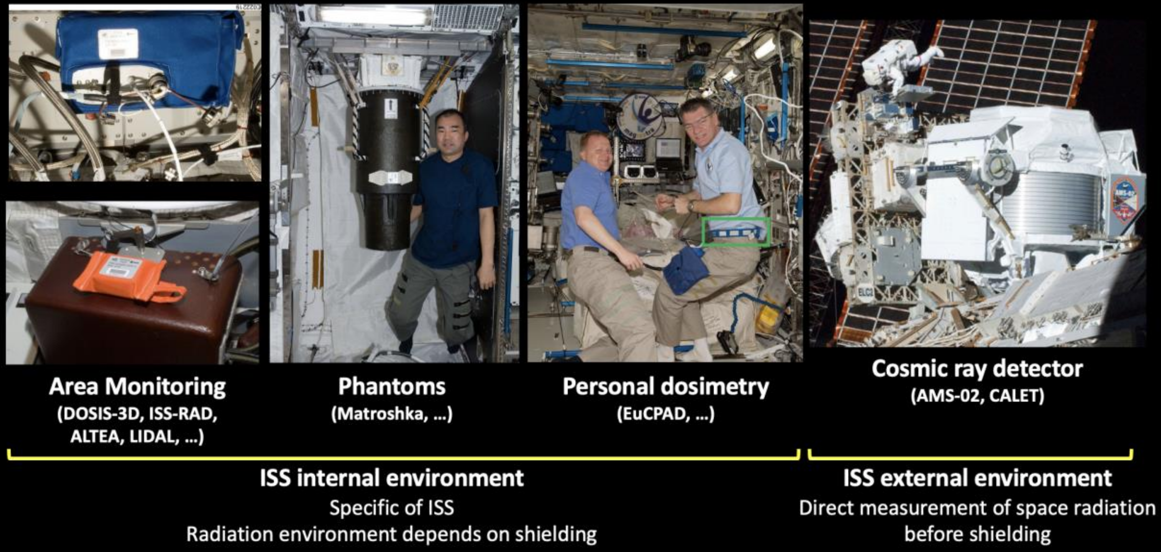
Radiation measurements onboard ISS

Specific missions and programs have been developed with ASI contributions

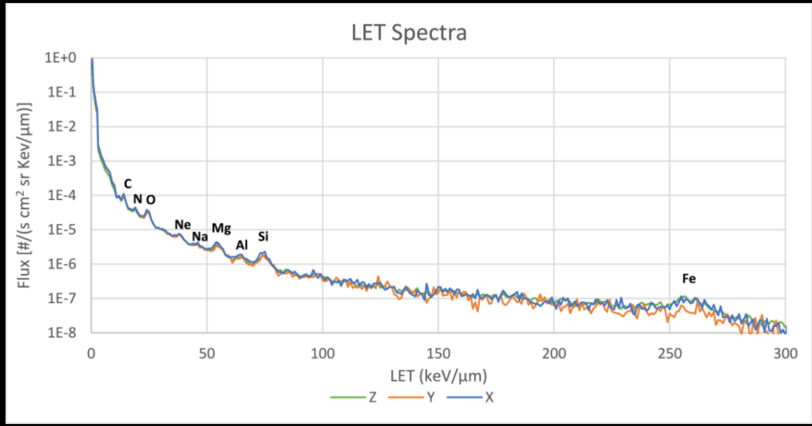
- **ALTEA and ALTEA-LIDAL** onboard ISS (operating since 2020)

ALTEA-LIDAL onboard ISS

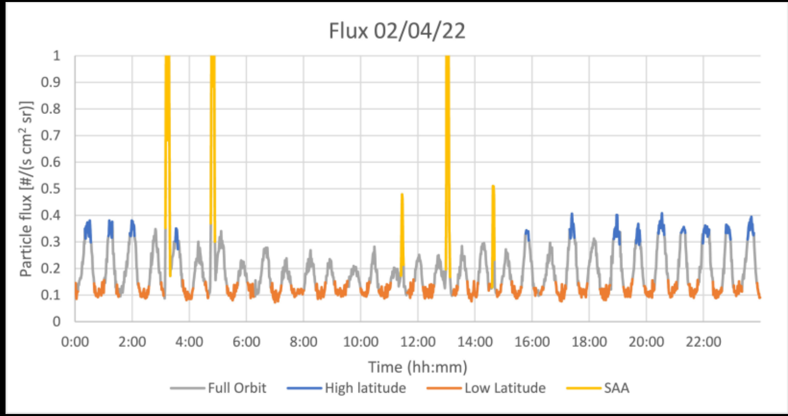




L. Di Fino et al., Life Sciences in Space Research 2023



L. Di Fino et al., Life Sciences in Space Research 2023



ASI – Uni Rome ToV + INFN participation
In operation on the ISS since 2019

Radiation exposure risk mitigation

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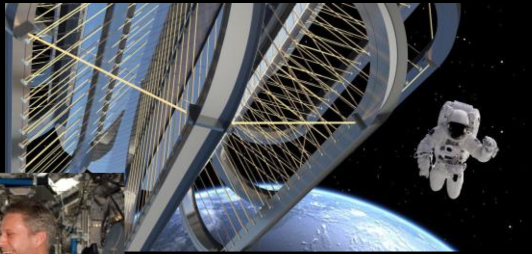



Countermeasures

Minimization of radiation exposures with physical shielding

Minimization of harmful effects through biological and bahevioural countermeasures

Integrated approaches


Space radiation environment

Advances in space radiation environment characterization and modeling

Real-time monitoring and operations

Novel experimental investigation strategies

Radiation Risk Model

Radiobiological effects

Assessment and modeling of radiobiological effects from chronic and abrupt exposures to space radiation

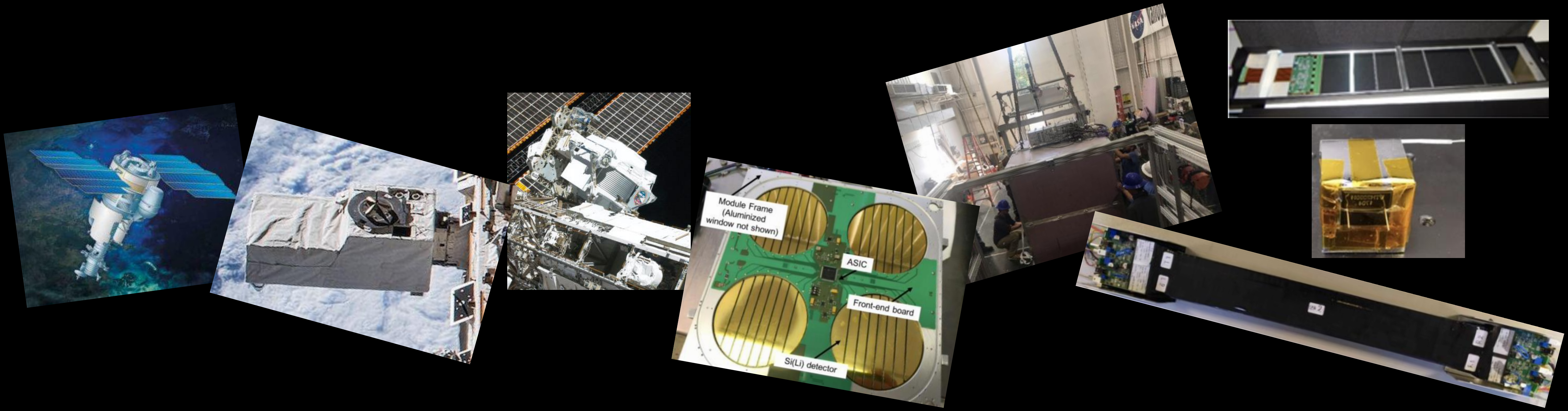
Interdisciplinary approaches in microgravity and radiobiology research

Unified international space radiobiological protection strategy

ASI is contributing since **more than 20 years** to the advances in the field of astroparticle physics, participating with the italian research centers, universities and industries.

Italy is leading/participating in collaboration with **international partners** to the development of **technologies** that are being operated in **current missions**, and which are planned for operations in **future missions**.

New observational approaches from space require a long path of R&D activities, team expertises and visions, which can take advantages from expertises from complementary and sinergic research lines.



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Radiation exposure risk mitigation

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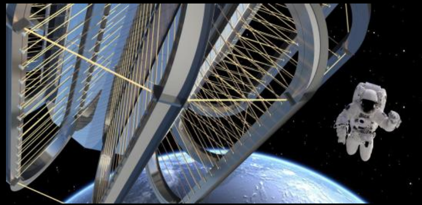
Improve the assessment of space radiation exposure environment

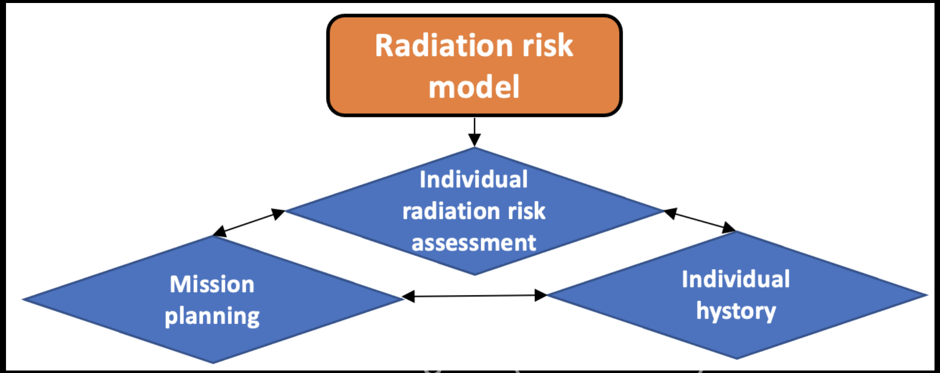
- Develop novel sensor technologies for **model validation** and **real time operation** in space
- ***Re-invent*** radiation measurement approach in space (e.g., distributed net of embedded compact detectors)
- Consolidate SPE **nowcast** alarming and support studies for solar physics SPE **forecasting**
- + (Bio.) improve understanding of **radiobiological effects** in human tissues and biological life support systems
- + (Bio.) ground-based systems for simulating the combined effects of **space radiation and partial gravity**

Decrease human exposure towards space radiation

- Develop integrated strategies to **passive shielding** in operations, sheltering and personal shielding.
- Integration of passive shielding properties with biological, pharmacological, physiological and operational **strategies**.
- Promote further studies in **active shielding countermeasures**.
- + (Bio.) Improve human resilience against radiation
- + (Bio.) Interpreting individual **radio-susceptibility** as a countermeasure



Foster the development of **unique, worldwide Space radiation risk model,** based on transport codes, radiobiological modeling, risk assessment, and uncertainty analysis, to provide both cancer and non-cancer radiation hazard



Slide concept readapted from A. Oliva

Ground/space X-section investigations

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Precision measurement of CRs requires a detailed understanding of the interaction of particles in the detector materials (CRs + C, Si, Al, …):

- total inelastic XS
- spallation XS

Main difference with "astrophysics" are the much heavier targets. In general, these collisions are even less known that the ones with H and He.

A very convincing motivation for such a measurement is the apparent disagreement in the measurement of CRs nuclei spectra between different experiments.

Some attempt to solve this discrepancy has been done comparing survival probabilities from MC codes with direct estimations with CR experiment (Q. Yan et al., Nucl. Phys. A 996 (2020) 121712). However, this work does not translate directly to all other experiments.

Ground investigations of direct X-section measurements for mechanisms of interest for astroparticle detector is required to improve experimental systematic uncertainties currently limiting our understanding in CR phenomenology.

CALET coll., O. Adriani et al., Phys. Rev. Lett. 125, 251102 (2022)