ASTROPARTICLE EXPERIMENTS 4 SPACE RADIOBIOLOGY :

THE RESEARCH TOPIC INITIATIVE

Alessandro Bartoloni
INFN Roma Sapienza

We gratefully acknowledge the strong support from the AMS collaboration
and from the Italian Space Agency (ASI) within the agreement *ASI-INFN n. 2019-19-HH.0.*

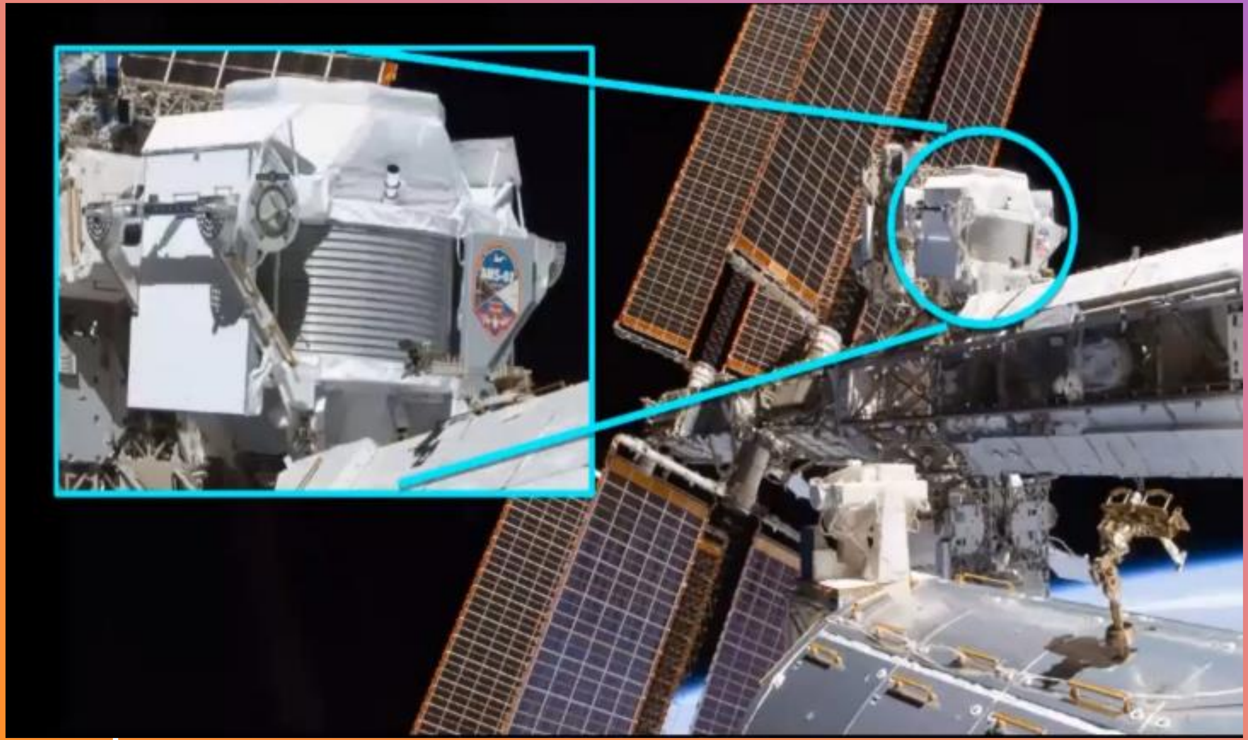
OUTLINE

AMS INFN Roma Sapienza Group

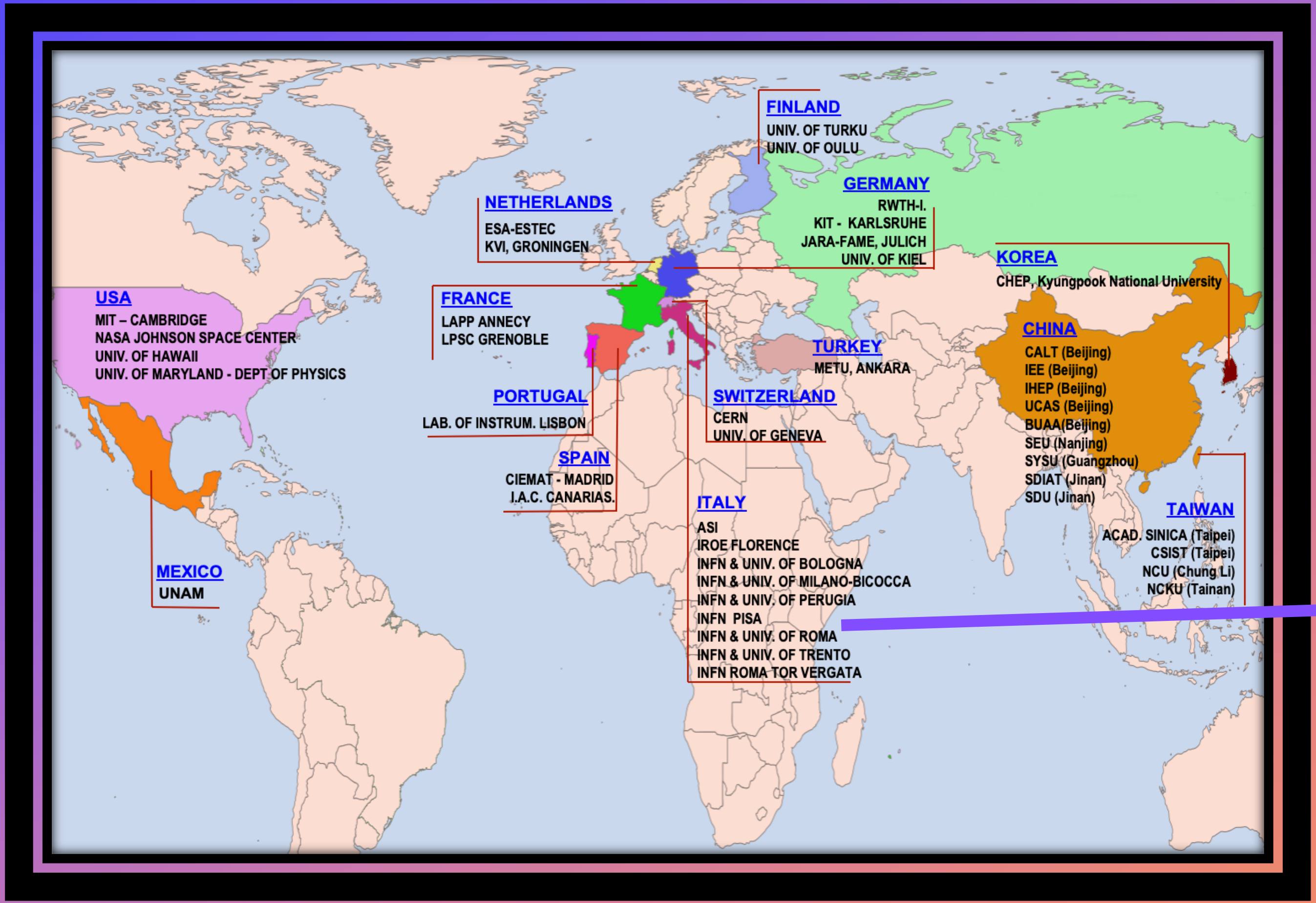
The Research Topic Initiative

AstroParticle Experiments

Space Radiation & Astronaut Safety



AMS INFN ROMA SAPIENZA GROUP



Aboma Negasa Guracho

Alessandro Bartoloni

- Giuseppe Della Gala

Silvia Strolin

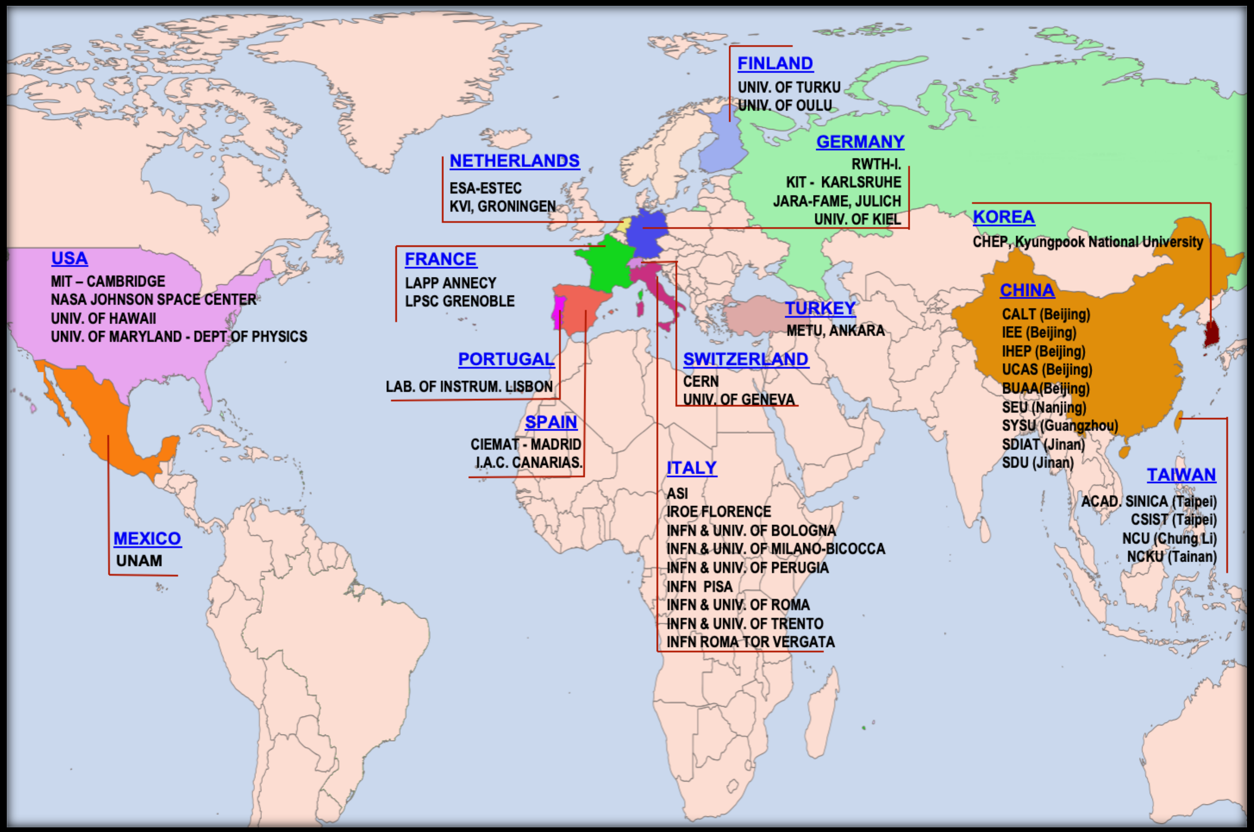
Giulia Paolani

Miriam Santoro

Lidia Strigari

Alpha Magnetic Spectrometer AMS02

AMS is a particle detector measuring Galactic Cosmic Ray fluxes.
It was installed on the International Space Station (ISS) on May 19, 2011



The AMS collaboration

(http://ams02.space)

An international collaboration made of 44 Institutes from America, Asia and Europe

Presents in 7 INFN departments (BO,MIB,PI,PG,RM1,RM2,TN)

It uses the unique environment of space to study the universe and its origin by searching for antimatter, dark matter while performing precision measurements of cosmic rays' composition and flux.

The AMS Payload Operation Control Center at CERN operates 365 days year h24

The AMS02 detector has collected so far more than **200 billion** Cosmic Rays events.

More Info in the AMS-02 webpage:
https://ams02.space

Part of the AMS02 experiment was built at Rome (INFN & Sapienza)

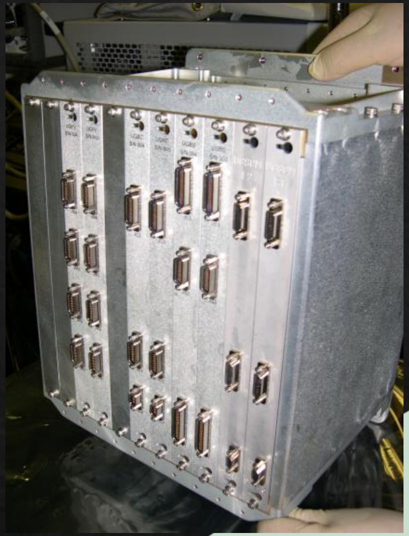
INFN

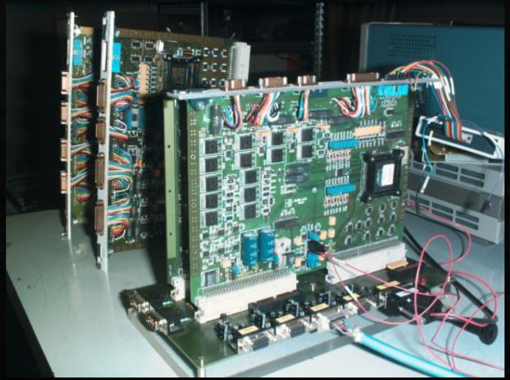
SAPIENZA UNIVERSITÀ DI ROMA

The INFN Roma and the Sapienza university joined the AMS collaboration in 2001.

The group has taken part to the construction of the Transition Radiation Detector (TRD), having as main task the responsibility to develop the slow control electronics of the GAS System of the TRD (UG-Crate).

The UG-CRATE was part of a safety-critical system and the group took care of all the phases of the development (Design–Test-Integrate-Fly) following the NASA requirements.





Design – Test – Integrate – Fly

2001-2003
- Engineering Modules to test system functionalities

2004-2005
- Qualification Modules to space qualify (EMC-Thermo/Vacuum-Vibration Test)

2006-2008
- Flight & Spare Modules Production and qualification of electronics now installed on the ISS

2009-2011
- UGPD-Crate Assembly in AMS02 and Space Qualification at ESA-ESTEC
- Launch ops at NASA-MSFC

Lidia Strigari,

Dept. of Medical Physics

IRCCS Azienda Ospedaliero-Universitaria di Bologna, Italy

Available Thesis

Strategies for preventing radiobiological effects in space
Galactic Cosmic Rays induced Target and Non Target Effects in space
AMS02 Charged Particle characterization for Space Radiobiology investigations

INFN Roma AMS-02 wiki:
https://wiki.infn.it/strutture/roma1/experiments/ams2/home

At INFN Roma AMS group, led by **Alessandro Bartoloni**, the primary activity is the use of the AMS measurements of cosmic rays to improve the space radiobiology knowledge with a primary emphasis on ***the space radiation relevance and risk for human space exploration***.

In this topic, there is a strong collaboration and participation to the Roma group of the Medical Physics department of the IRCCS University Hospital of Bologna, led by **Lidia Strigari.**

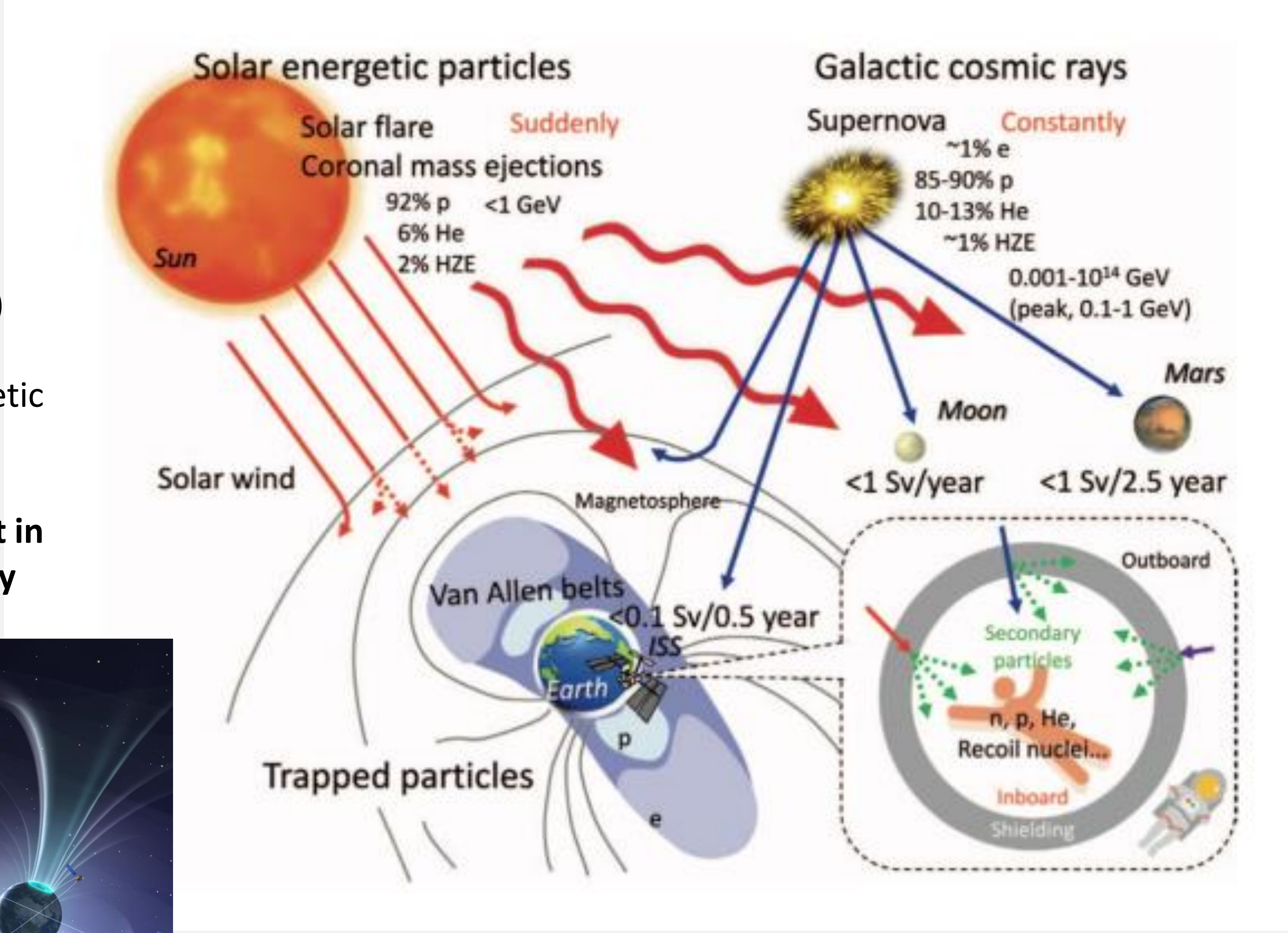
Space Radiation Environment

Human Space activities must cope with the high radiation environment of outer space.

Space Radiation composition

- Galactic Cosmic Rays **(GCR)**
- Particle emitted by the Sun **(SEP)** during isolated events
- Particle trapped in Earth's magnetic field **(Radiation Belt)**

None of the 3 components is constant in time, mainly due to the solar activity



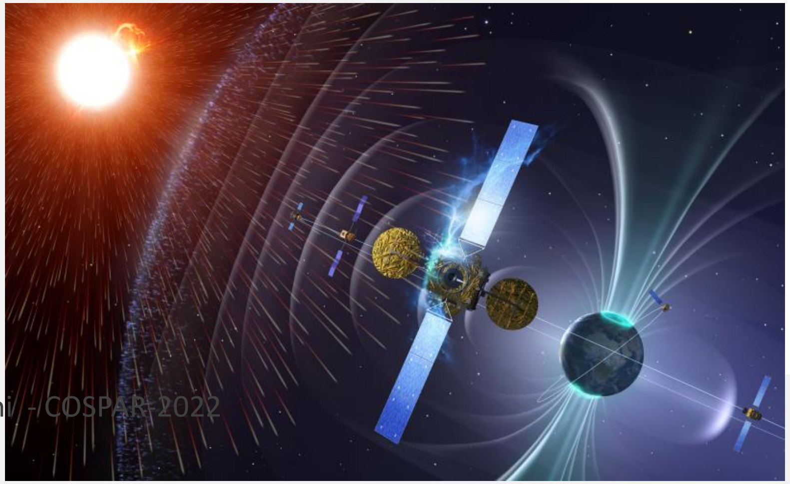
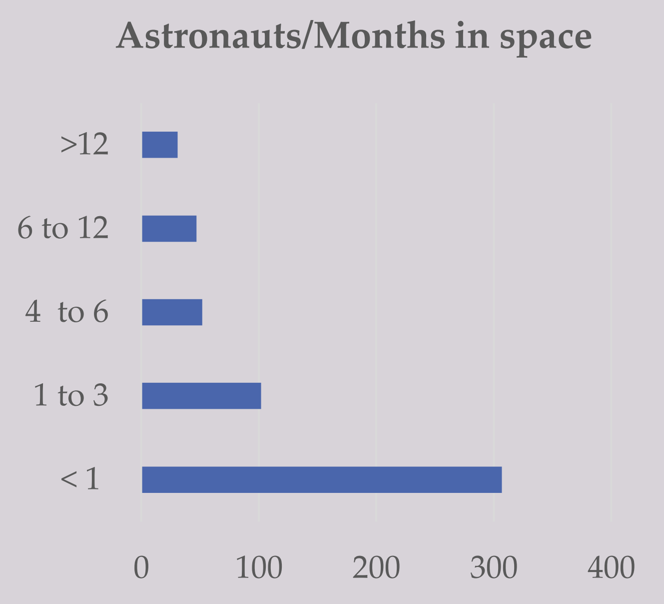


Image courtesy of European Space Agency (ESA)

Dose-Effects Relationship

The known dose-effect relationships are based on a limited number of astronauts

(hundreds)



Total Space Radiation Dose (mGy)	<0.2	0.2–1.99	2–3.99	4–10.99	≥11	Total
# Astronauts	14	19	11	15	14	73
# Cancer Deaths	2	2	1	0	2	7
# Cardiovascular Disease Deaths	1	4	1	1	0	7
# Accident Deaths	6	5	0	0	1	12
# Other Deaths	1	0	1	0	1	3
# Unknown Deaths	1	0	0	3	1	5
Mean Medical Dose (SD)	2.4 (6.4)	27.7 (13.6)	34.4 (20.8)	29.1 (15.6)	32.5 (21.7)	25.1 (19.4)
Mean Year at Birth (SD)	1932.6 (4.1)	1931.7 (5.2)	1931.6 (2.5)	1932.2 (4.4)	1931.5 (3.3)	1931.9 (4.1)
Mean Age at Entry into Astronaut Corps (SD)	31.6 (2.7)	32.2 (3.4)	33.0 (2.5)	31.8 (2.8)	32.5 (2.2)	32.2 (2.8)
Mean Follow up Time (SD)	29.3 (23.6)	40.3 (15.0)	46.4 (12.9)	50.7 (7.8)	48.1 (7.5)	42.8 (16.1)
Total Group Person Years	409.9	766.5	510.1	760.8	673.4	3120.8
Mean Age at Death (SD)	57.7 (23.8)	65.7 (15.9)	64.5 (14.9)	78.2 (19.9)	74.9 (10.2)	65.2 (19.1)
Mean Current Age of Living Astronauts (SD)	79.9 (2.9)	82.1 (3.9)	84.9 (3.1)	83.6 (3.6)	83.8 (2.3)	83.4 (3.4)

Table 1. Early astronaut cohort demographics binned by total space radiation dose category. SD = standard deviation.

Needs of improvements

Radiation Exposure and Mortality from Cardiovascular Disease and Cancer in Early NASA Astronauts S.Robin et Al - 2018

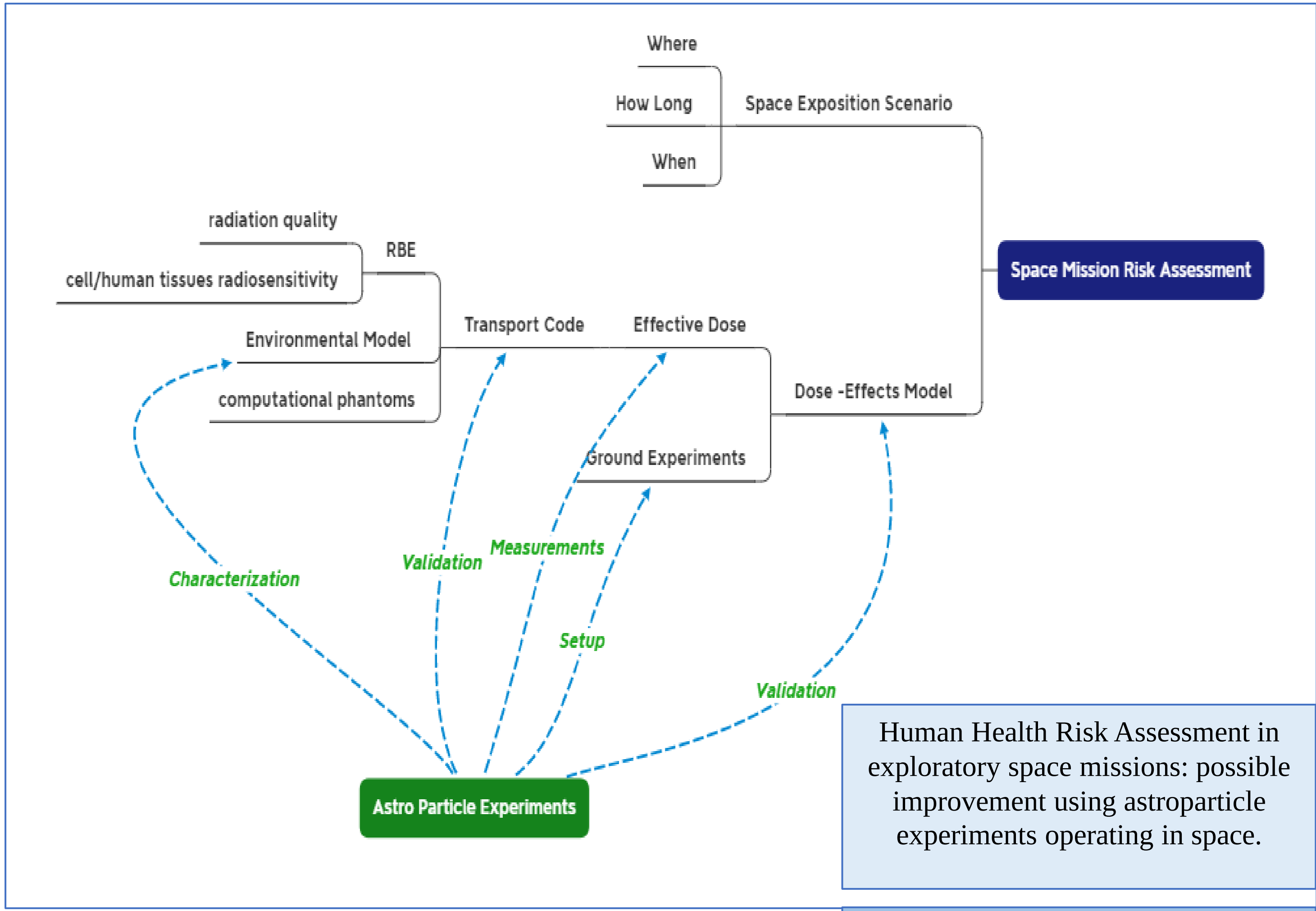
Environmental Model Characterization

2) Effective Dose Measurements

3) Transport Code Validation

4) Space Exposition Scenario Dose Computation

5) Ground or Space-based Experiment setup definition



Human Health Risk Assessment in exploratory space missions: possible improvement using astroparticle experiments operating in space.

A. Bartoloni [a]*, L. Strigari[b]
Proceedings of GLEX-21-8.2.5 (ID:62186 2021)

REVIEW article

Front. Public Health, 08 November 2021
Sec.Radiation and Health
https://doi.org/10.3389/fpubh.2021.733337

This article is part of the Research Topic
Medical Application and Radiobiology Research of Particle Radiation
View all 16 Articles

Dose-Effects Models for Space Radiobiology: An Overview on Dose-Effect Relationships

Lidia Strigari[1], Silvia Strolin[1], Alessio Giuseppe Morganti[2] and Alessandro Bartoloni[3*]

We did and publish in 2021 an extensive review of the existent literature

There is a dedicated poster COSPAR2022 TW-233

COSPAR 2022 44th SCIENTIFIC ASSEMBLY
16-24 July 2022, Athens, Greece

Dose-Effects Models for Space Radiobiology:

An Overview on Dose-Effect Relationships

Lidia Strigari[1,2], Silvia Strolin[1,2], Alessio Giuseppe Morganti[3] and Alessandro Bartoloni[2]
[1]Department of Medical Physics, IRCCS Azienda Ospedaliero-Universitaria di Bologna, Bologna, Italy
[2]Istituto Nazionale di Fisica Nucleare (INFN) Sezione di Roma 1, Roma, Italy
[3]Radiation Oncology Center, School of Medicine, Department of Experimental, Diagnostic and Specialty Medicine - DIMES, University of Bologna, Bologna, Italy

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45% Downloads rank
This article has more downloads than 45% of all Frontiers articles.

Space radiobiology is an interdisciplinary science that examines the biological effects of ionizing radiation on humans involved in aerospace missions. The dose-effect models are one of the relevant topics of space radiobiology. Their knowledge is crucial for optimizing radioprotection strategies, the risk assessment of the health hazard related to human space exploration, and reducing damages induced to astronauts from galactic cosmic radiation. Dose-effect relationships describe the observed damages to normal tissues or cancer induction during and after space flights. They are developed for the various dose ranges and radiation qualities characterizing the actual and the forecast space missions.

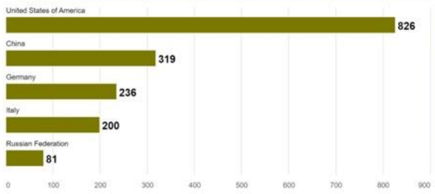
Based on a *PubMed* search including 53 papers reporting the collected **dose-effect relationships after space missions or in ground simulations**, 7 significant dose-effect relationships (e.g., eye flashes, cataract, central nervous systems, cardiovascular disease, cancer, chromosomal aberrations, and biomarkers) have been identified.

For each considered effect, the absorbed dose thresholds and the uncertainties/limitations of the developed relationships are summarized and discussed. The current knowledge on this topic can benefit from further *in vitro* and *in vivo* radiobiological studies, an accurate characterization of the quality of space radiation, and the numerous experimental dose-effects data derived from the experience in the clinical use of ionizing radiation for diagnostic or treatments with doses like those foreseen for the future space missions.

The growing number of pooled studies could improve the prediction ability of dose-effect relationships for space exposure and reduce their uncertainty level. Novel research in the field is of paramount importance to reduce damages to astronauts from cosmic radiation before Beyond Low Earth Orbit exploration in the next future. The study aims at providing an overview of the published dose-effect relationships and illustrates novel perspectives to inspire future research.

Model	Study Type	Dose Range/Threshold or LET	#Papers	Reliability	Priority
Eye Flashes	Spaceflight	LET>5-10 KeV/µm	4	****	*
Cataract	Spaceflight	8 mSv	5	***	***
CNS	Ground/Simulations	100-200 mGy	11	**	*****
CVD	Spaceflight	1000 mGy	4	*	***
	Ground/Simulations	0.1-4,500 mSv	8		
Cancer	Spaceflight	< 100 mGy	2	***	*****
	Ground/Simulations	< 100 mGy	9		
Biomarkers or Chromosomal Aberrations	Spaceflight	<5-150 mGy	11	***	*****
	Ground /Simulations	< 10,000 mGy	4		
Other Risks	Ground/Simulations	2,000 mGy	2	*	***

= Very Low, **=Low, *=Medium, **** = High, ***** = Very High.*



https://doi.org/10.3389/fpubh.2021.733337

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Research Topics are Open Access themed article collections (similar in nature to classical special issues) with:

a dedicated landing page, Continuous publication, Advanced impact metrics, Cross-disciplinarity, Multiple article types, e-book production

Research Topic

Astroparticle Experiments to Improve the Biological Risk Assessment of Exposure to Ionizing Radiation in the Exploratory Space Missions

frontiers in Astronomy and Space Sciences

The actual and next decade will be characterized by an exponential increase in the **exploration of the Beyond Low Earth Orbit space (BLEO)**. Moreover, the firsts tentative to create structures that will enable a permanent human presence in the BLEO are forecast. In this context, a detailed space radiation field characterization will be crucial to optimize radioprotection strategies (e.g., spaceship and lunar space stations shielding, Moon / Mars village design, ...), to assess the risk of the health hazard related to human space exploration and to reduce the damages potentially induced to astronauts from galactic cosmic radiation. On the other side, **since the beginning of the century, many astroparticle experiments** aimed at investigating the unknown universe components (i.e., dark matter, antimatter, dark energy, ...) have been collecting enormous amounts of data regarding the cosmic rays (CR) components of the radiation in space.

Such experiments essentially are actual **cosmic ray observatories, and the collected data (cosmic ray events) cover a significant period and permit to have integrated not only information of CR fluxes but also their variations on time daily**. Further, the energy range is exciting since the detectors operate using instruments that allow measuring CR in a very high energy range, usually starting from the MeV scale up to the TeV, not usually covered by other space radiometric instruments. Last is the possibility of acquiring knowledge in the full range of the CR components and their radiation quality. The collected data contains valuable information that can enhance the space radiation field characterization and, consequently, improve the radiobiology issues concerning one of the most relevant topics of space radiobiology represented by the dose-effect models.

This articles collection accepts original research papers and review papers relating (but not limited to) the following topics:

- The analysis and proposal on how to use these astroparticle experiments data to enhance the space radiation field characterization and, consequently, improve the radiobiology issues in space concerning one of the most relevant topics of space radiobiology represented by the dose-effect models and relationship.

- The proposal of new methods or instruments to use the astroparticle experiments to improve the space radiobiology knowledge (i.e., real-time dosimetry, monitoring of solar activities, ...)

Keywords: Cosmic Ray, Space Radiation, Space Radiobiology, Astro-Particle Experiments, Human Space Exploration

Topic Editors

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National Institute of Nuclear Physics of Rome
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Lidia Strigari
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Bologna, Italy

Participating Journals

Manuscripts can be submitted to this Research Topic via the following journals:

Frontiers in
Astronomy and Space Sciences
Astrobiology

Frontiers in
Physics
Radiation Detectors and Imaging

Frontiers in
Public Health
Radiation and Health

A new scientific language is needed to support the exploratory space missions because of the return of humans outside the Low Earth Orbit. The keywords are *Peacefully, Safely, Transparently*.

In that context, a priority is to keep the space exploration community secure and safe, and a crucial part is a detailed and accurate ionizing radiation health effects characterization.

Participate in creating part of this new language joining this interdisciplinary Frontiers Research Topic!

Research Topics are Open Access themed article collections (similar in nature to classical special issues) with:
a dedicated landing page, Continuous publication, Advanced impact metrics, Cross-disciplinarity, Multiple article types, e-book production

Improve the Radiation Health Risk Assessment for Humans in Space Missions

Since 2018, the INFN Roma Sapienza AMS group has collaborate with researchers and scientists to investigate the possibilities of using the CRD to improve the radiation health risk assessment for humans in space missions.

Collaborations were mainly focused on creating synergy within different scientific communities (radiobiology, medical physics, radiotherapy, and nuclear medicine) and institutions (Research, Universities, Space Agencies and Industry).

In 2019 we organize at INFN Roma Sapienza a thematic meeting with participants from ESA and Thales Alenia Space

The Research Topic Initiative

- While progressing in the research activity raised the awareness that to make progress in such a field it was required a new scientific language able to connect and create **synergy** between different scientific communities.

- Firstly, cause to **understand the relationship between ionizing radiation and biology** and to solve problems in this field, researchers incorporate fundamentals of biology, physics, astrophysics, planetary science, and engineering.

- Further **space exploration and colonization** collects the worldwide hopes of a new era characterized by transparency and peacefully development. In that sense, these expectations coincide with the primary scientific interest, and science could play a breakthrough role in such direction.

- Among the many possibilities thus, we decided, supported and asked by the Frontiers Editorial team, to launch this research topic named "**Astroparticle Experiments to Improve the Biological Risk Assessment of Exposure to Ionizing Radiation in the Exploratory Space Missions**".

-

TOPIC EDITORS

Alessandro Bartoloni

INFN Istituto Nazionale di Fisica Nucleare
Sezione di Roma

Cristina Consolandi

University of Hawai'i

Lidia Strigari

POLICLINICO DI SANT'ORSOLA
SERVIZIO SANITARIO REGIONALE EMILIA-ROMAGNA
Azienda Ospedaliero - Universitaria di Bologna
ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA

Nan Ding

IMP

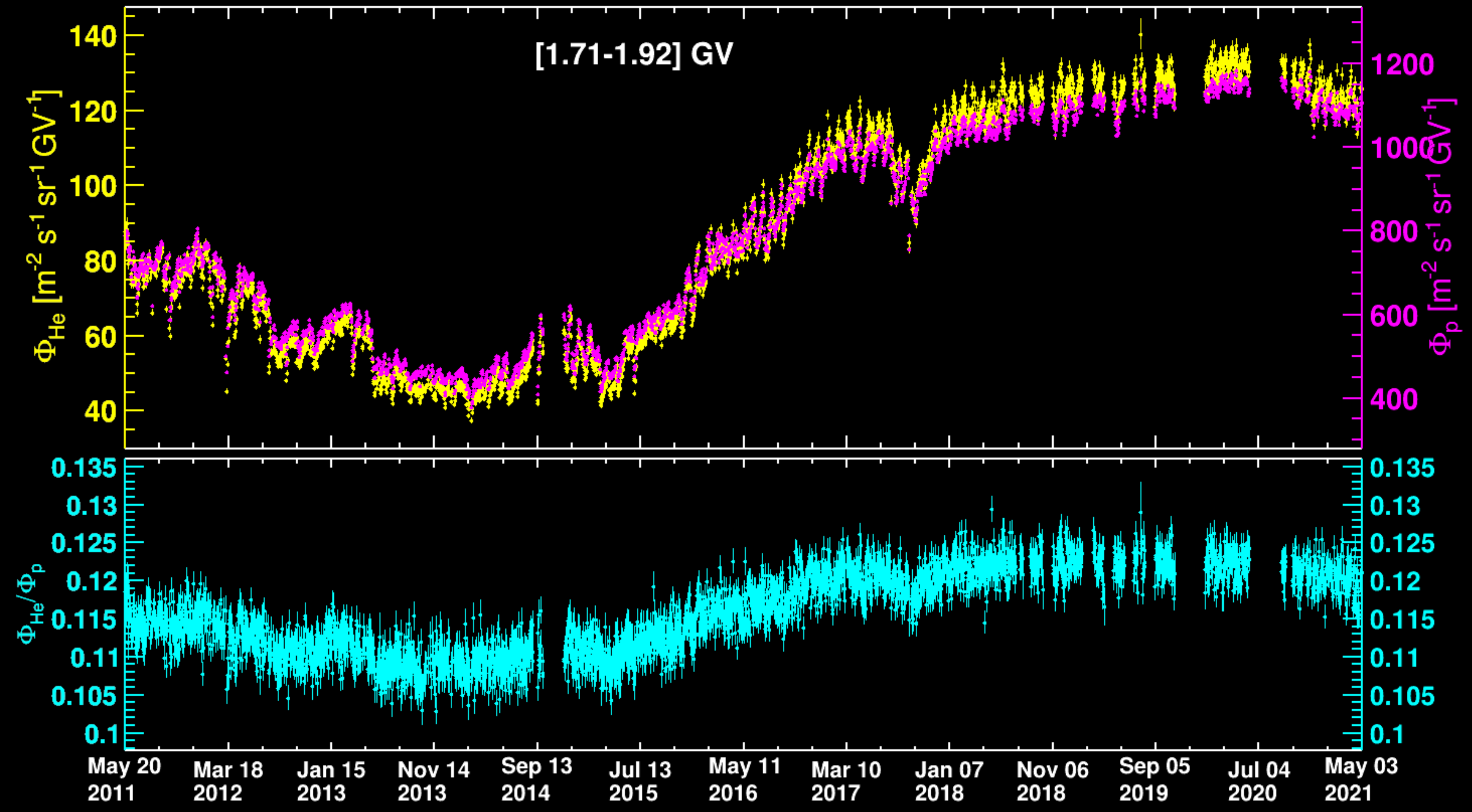
Gianluca Cavoto

SAPIENZA UNIVERSITÀ DI ROMA

We created a research topic **editorial board** that was representative of **different scientific cultures** and **geographic areas** and invited many researchers and scientists from many different research areas due to the strong interdisciplinarity of the topic.

Short term Solar Modulation of GCR

Daily Proton and Helium Fluxes and Helium to Proton flux ratio



PHYSICAL REVIEW LETTERS 127, 271102 (2021)
PHYSICAL REVIEW LETTERS 128, 231102 (2022)

Dr. Cristina Consolandi
University of Hawaii, United States

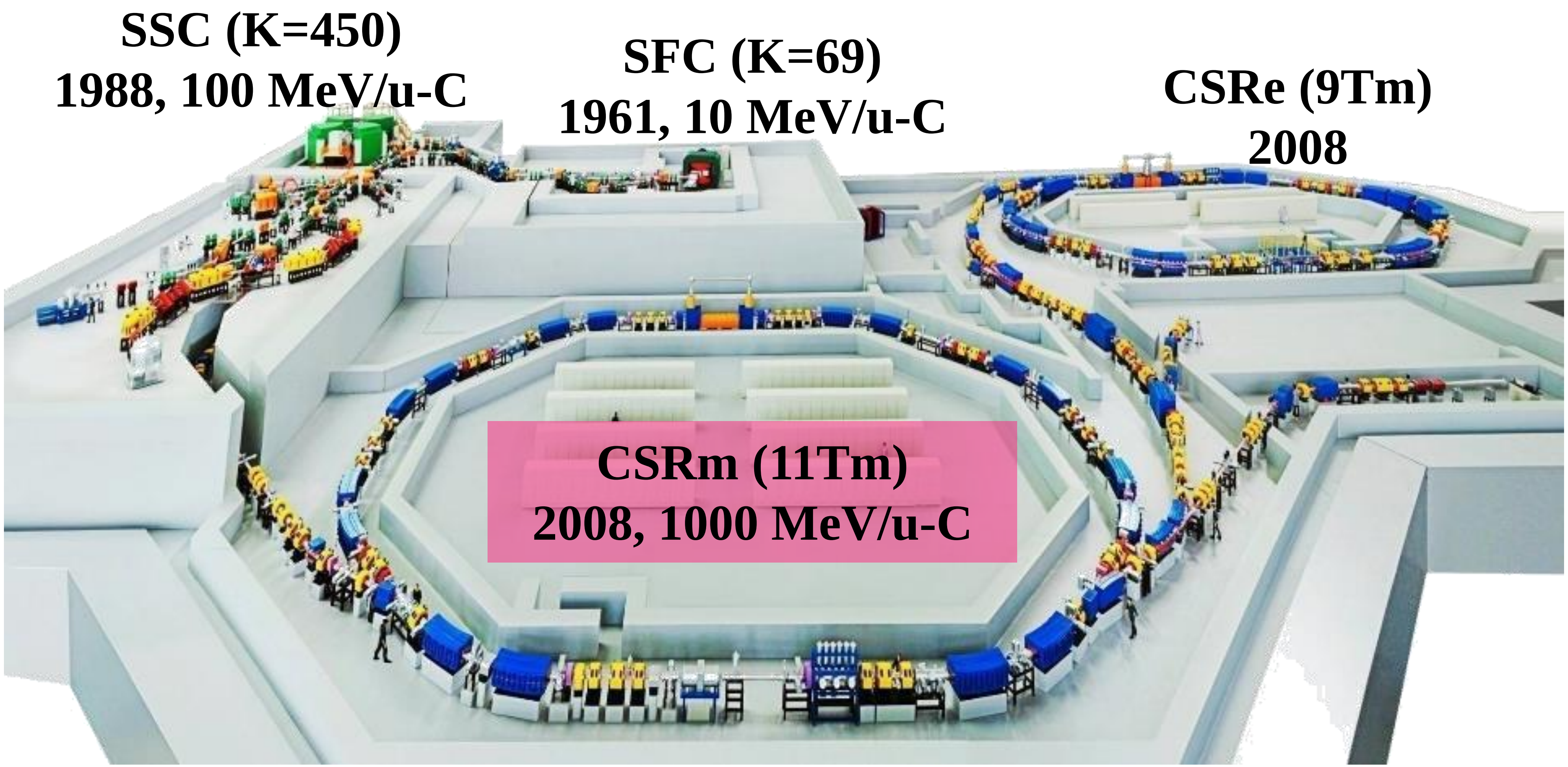
member of the Alpha Magnetic Spectrometer (AMS) collaboration since 2010 (INFN MI Bicocca)

Institute of modern physics, Chinese Academy of sciences

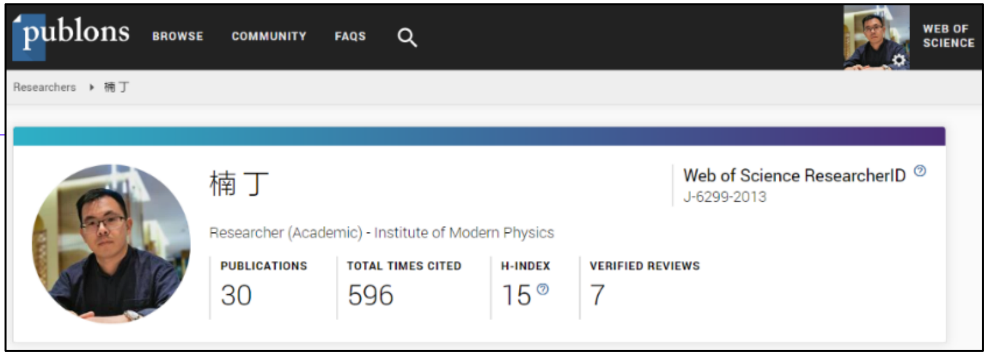
Institute of modern physics (IMP) was established in 1957 in Lanzhou, mainly works on basic and applied research in nuclear physics.

Heavy Ion Research Facility in Lanzhou (HIRFL)

The largest ion-accelerator complex in China



Nan Ding dn@impcas.ac.cn



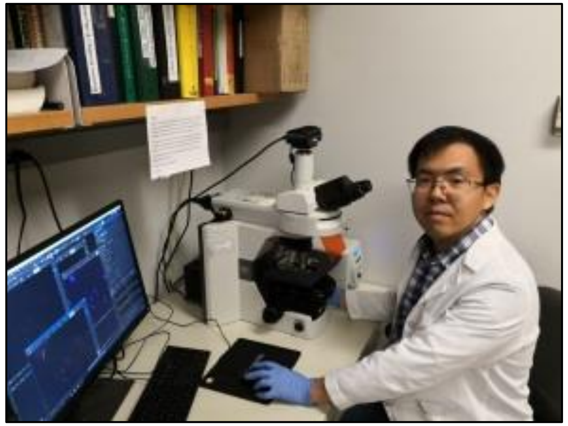
Associate professor, Bio-Medica centra, Institute of modern physics (IMP), CAS

Research Interests

- Biological effects of heavy ion radiation
- Radiation induced bystander effects
- Radiation related ncRNAs

Work Experience

- 2007.7 to date IMP, Lanzhou, CHINA
- 2011.10-2012.4 NIRS, Chiba, Japan
- 2017.8-2018.10 OSU, Columbus, USA



Interdisciplinary Topic

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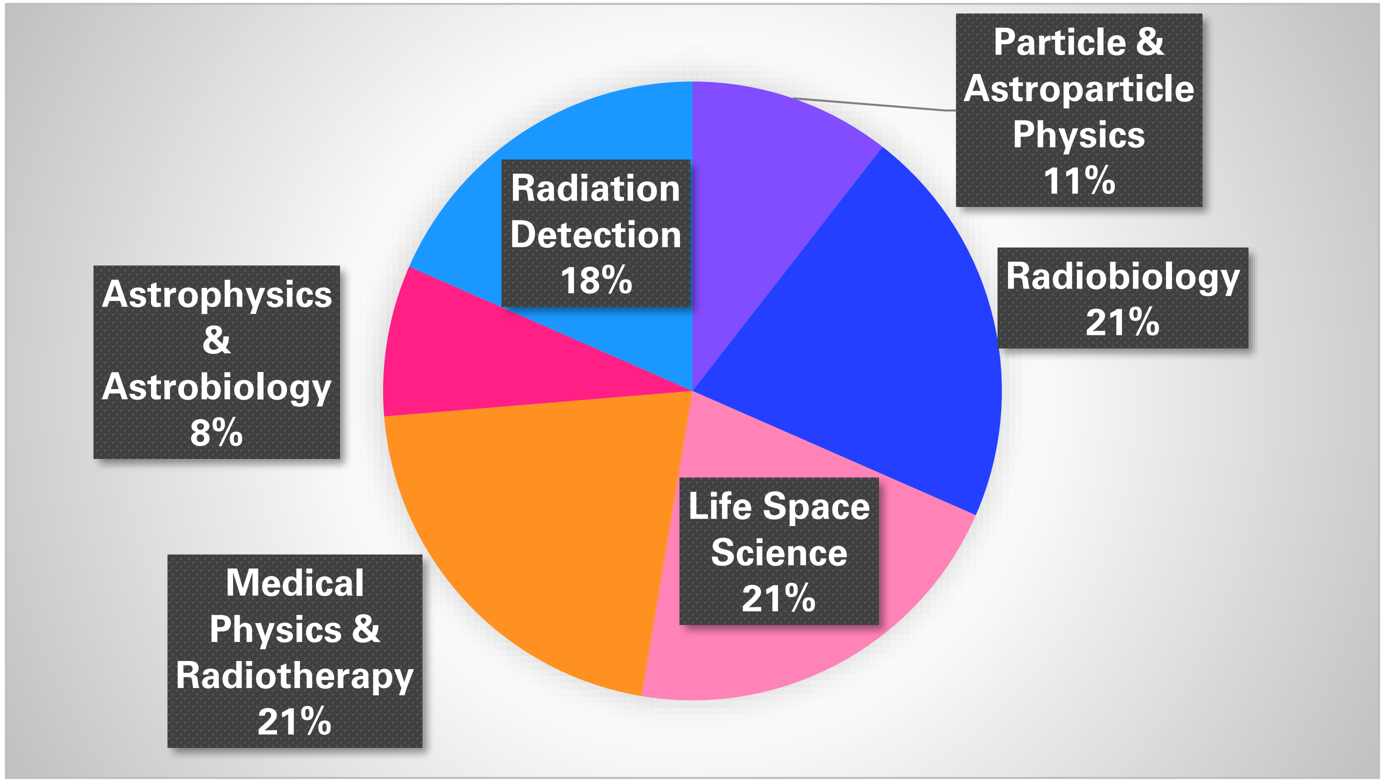
Contributors from different research areas



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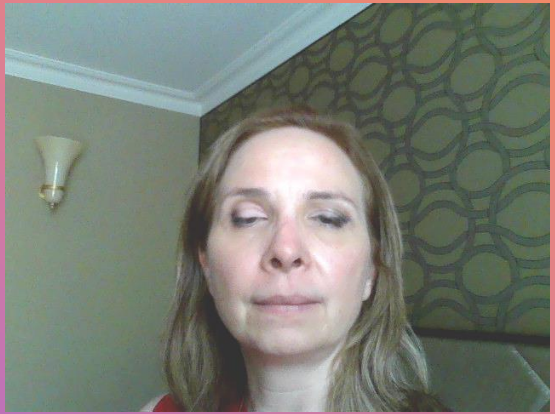
Worldwide interest for the topic

The research topic initiative was launched in

November 2021

- > 1500 views (topic & articles)
- > 20 expected contributions
- > 5 abstracts received
- 1 published manuscript

Open for articles submissions !

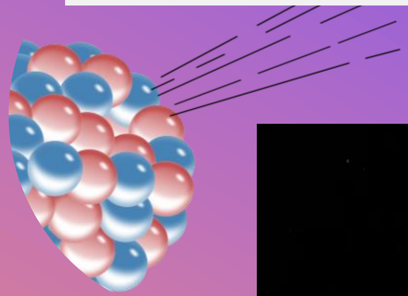


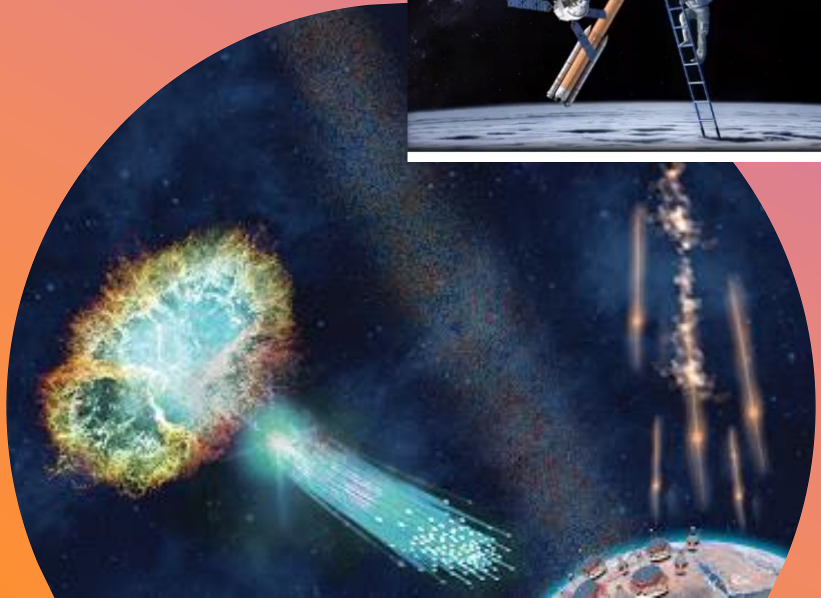
SCAN the QR CODE to participate !

Topic Published	Abstract Deadline	Manuscript Deadline	Extended Deadline
23/11/2021	01/03/2022	**15/10/2022**	**15/11/2022**


Florence, candidate city to host the
COSPAR 2026
46th General Assembly
Florence
1/9 August
Sustainable
space research
for the planet
INAF
ISTITUTO NAZIONALE
DI ASTROFISICA
AIM GROUP INTERNATIONAL
FIRENZE
CONVENTION BUREAU
Firenze fiera
Congress and Exhibition Center

«To fully understand the relationship between ionizing radiation and biology, and to solve problems in this field, researchers incorporate fundamentals of **biology, physics, astrophysics, planetary science, and engineering.»** *(credit : NASA)*





A new scientific language is needed to support the exploratory space missions because of the return of humans outside the Low Earth Orbit. The keywords are *Peacefully, Safely, Transparently*.

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Participate in creating part of this new language joining this interdisciplinary Frontiers Research Topic!

THANKS FOR THE ATTENTION !

Alessandro Bartoloni

Alessandro.Bartoloni@cern.ch

Alessandro Bartoloni

AMS02 INFN ROMA and Sapienza University Web Site

Abstract

The actual and next decade will be characterized by an exponential increase in the **exploration of the Beyond Low Earth Orbit space (BLEO)**. In this context, a detailed space radiation field characterization will be crucial to optimize radioprotection strategies to assess the risk of the health hazard related to human space exploration and to reduce the damages potentially induced to astronauts from galactic cosmic radiation.

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AMS INFN Roma-Sapienza Group

To address such problems a research collaboration on SPace RadioBiology (SPRB) is active since the 2017 between the INFN Roma-Sapienza AMS group and the Medical Physics Department of IRCCS University Hospital of Bologna (Italy)

The aim is to address the topic of space radiobiology by the comparison of possible effects

on the health of astronauts from particles and dangerous charged nuclei with the radiobiology experience in the clinical field where the ionizing radiations are used for therapy and diagnosis

Silvia Strolin

Miriam Santoro

Giuseppe Della Gala

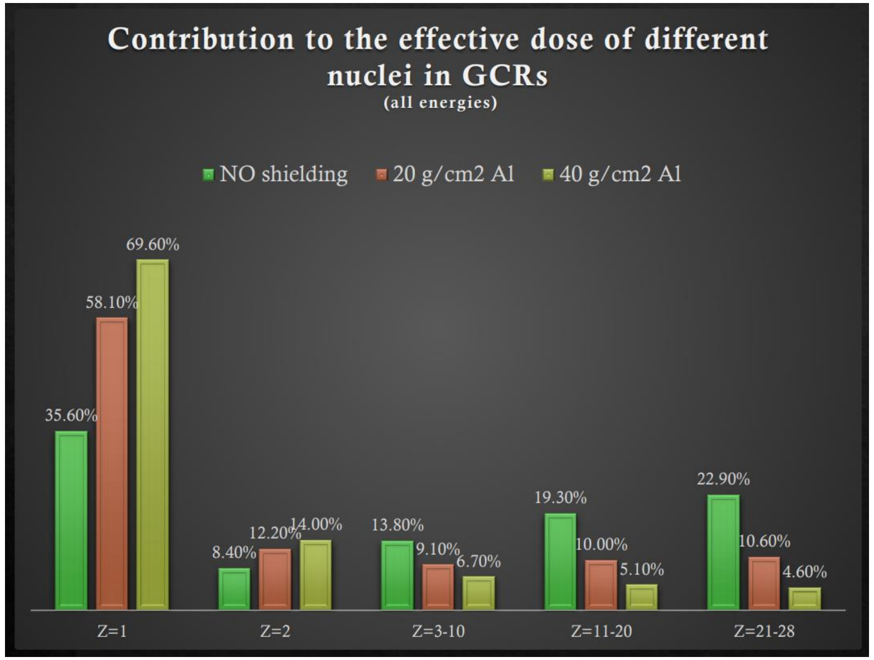
Giulia Paolani

Lidia Strigari

GCR sensitivity analysis

- Identifications of CR components of the CR that are of interest for the computation of possible risks associated with the manned exploratory space missions in LEO and BLEO scenarios.
- Use of space radiation sensitivity studies we also recognised that they correspond with the data taken by the astroparticle experiments

- Environmental GCR model : BON2010 [4]
- ICRP 60 Radiation Quality Factors
- ICRP 103 for Tissue Weights
- "FAX": Female Adult voXel phantom[5]
- Transport Code : HZETRN-π/EM[6]



A. Bartoloni a*, L. Strigari b
SIF 2019

AMS02 Roma Sapienza actual research Targeted Effects vs Non targeted Effects

Target Effects (TE) will regards the IR damage due to the irradiated tissue or organs

Non Target Effects instead will refers to the damage generated in tissue not directly irradiated

Usual linear model used in radioprotection do not take in account the NTE effects

"The scarcity of data with animal models for tissues that dominate human radiation cancer risk, including lung, colon, breast, liver and stomach , suggest that **studies of NTEs in other tissues are urgently needed** prior to long-term space missions outside the protection of the Earth's geomagnetic sphere"

"Non Targeted Effects Models Predict Significantly Higher Mars Mission cancer Risk than Targeted Effects Models" - F.Cucinotta et al. 12/05/2017

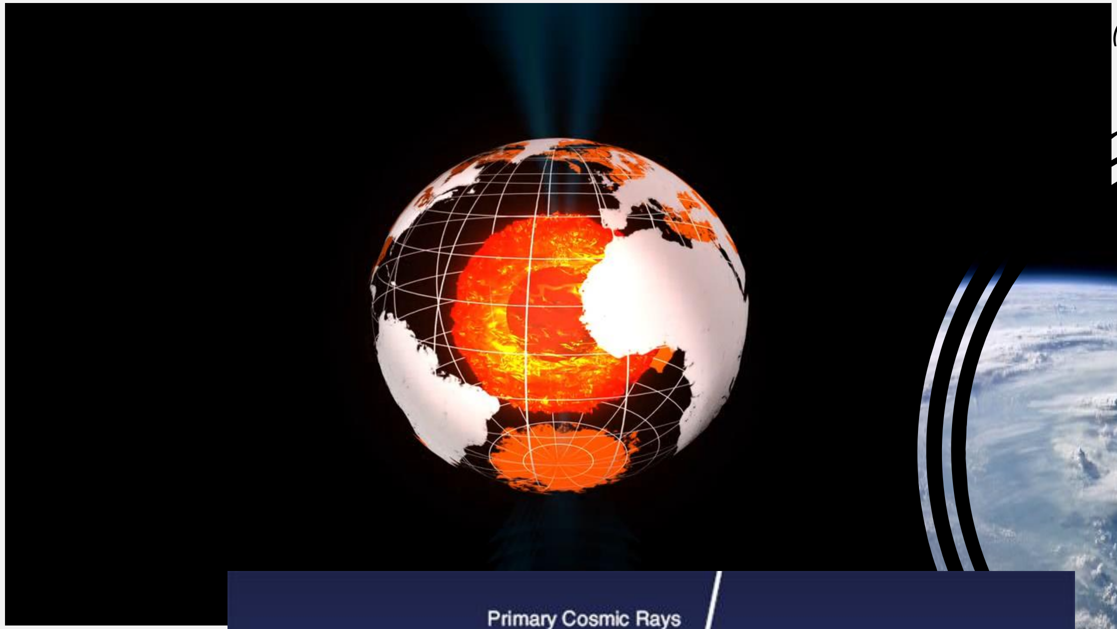
Work in progress with at Roma AMS group (***A.Bartoloni, A.N. Guracho, L.Strigari***) there will be a talk at :

IAC PARIS 2022

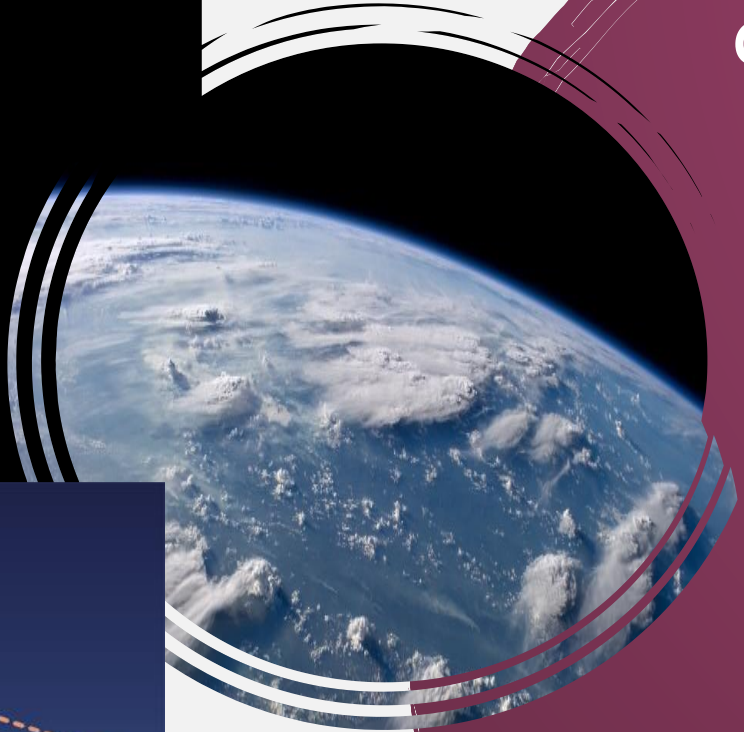
RAD 10th Jubilee Summer Edition
INTERNATIONAL CONFERENCE ON RADIATION IN VARIOUS FIELDS OF RESEARCH
July 25-29, 2022 | Palmon Bay Hotel
Herceg Novi | Montenegro

SPACE RADIATION & ASTRONAUT SAFETY

«To fully understand the relationship between ionizing radiation and biology, and to solve problems in this field, researchers incorporate fundamentals of **biology, physics, astrophysics, planetary science, and engineering.»** *(credit : NASA)*



(credit : ESA)

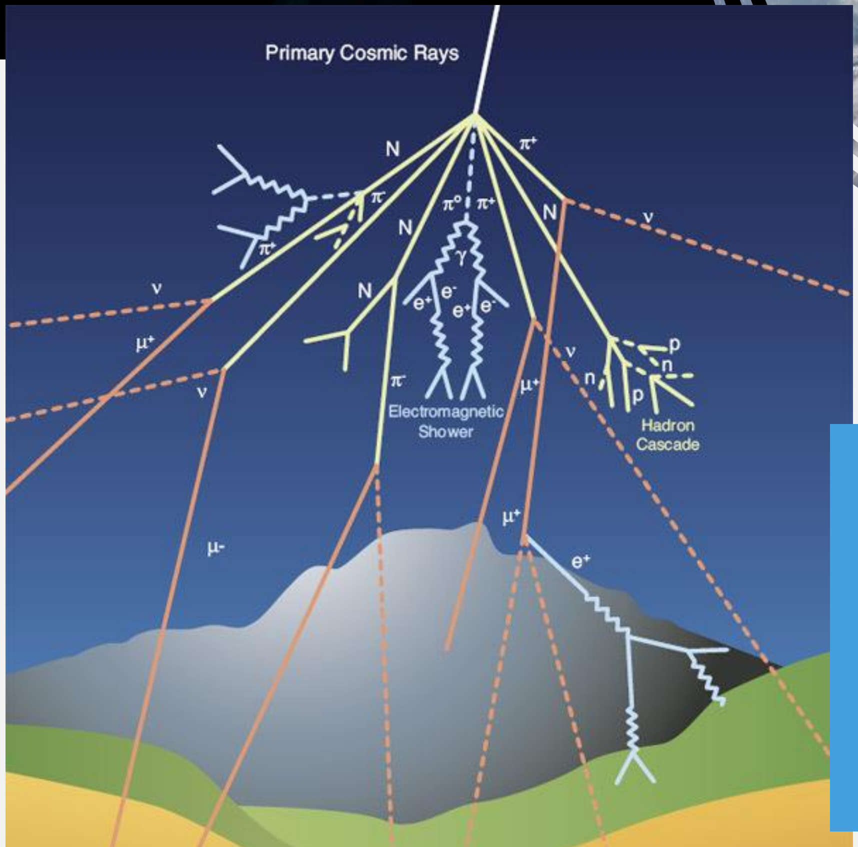


Cosmic Rays Interactions with the geo-magnetosphere

Earth is a cocoon !!!

Magnetosphere stops/deflects 99.9% of charged particles

the Earth Atmosphere is equivalent to a metal shielding 1 meter thick



(credit : CERN)

The annual cosmic ray "dose" at sea level is around **0.27 mSv**

<10% of "background radiation"
(Radon, Soils, Foods, Medical,..)

A new era in human space exploration is coming …

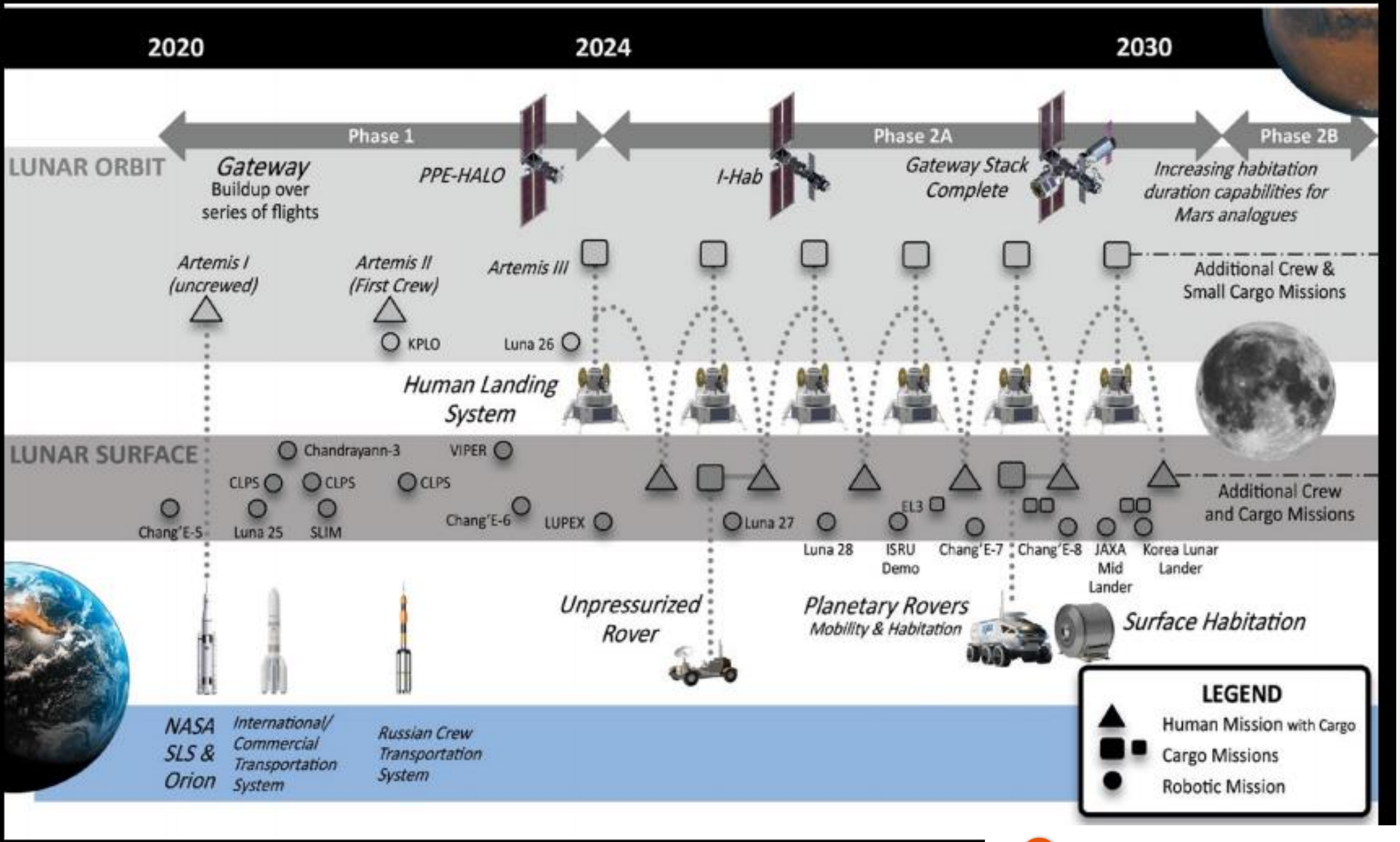


Figure 1. Updated ISECG Lunar Surface Exploration Scenario.

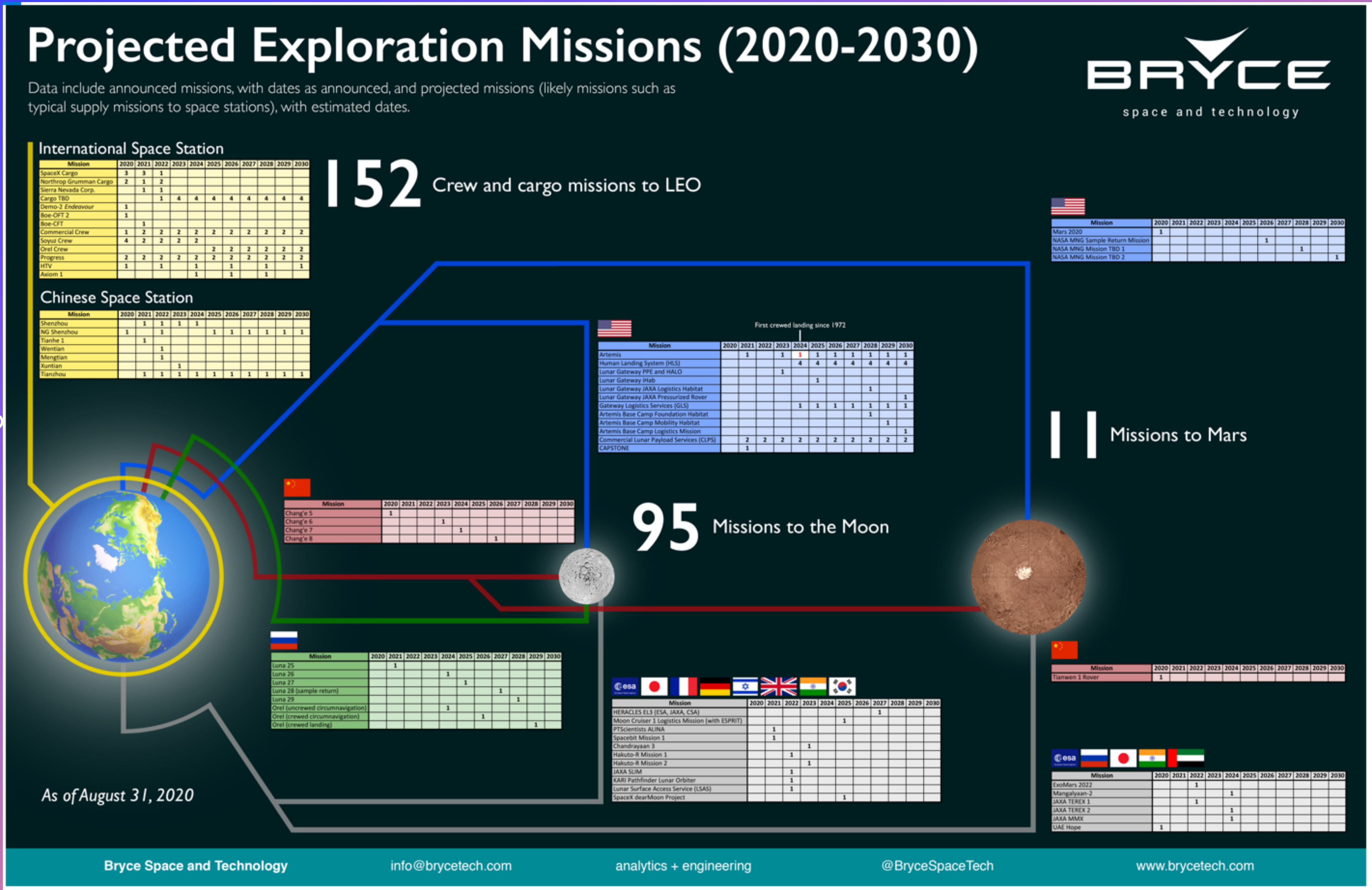
«Global Exploration Roadmap Lunar Surface Exploration Scenario update August 2020»

International Space Exploration Coordination Group (ISECG)

ISECG

The **International Space Exploration Coordination Group** (ISECG) is a forum set up by 14 space agencies to advance the Global Exploration Strategy through coordination of their mutual efforts in space explor

BLEO Space Exploration is restarted ! (IAC2021 . 11/2021)



Limits and concerns

The manned spaceflight especially the one beyond the LEO could represent a concern for the health of astronauts.

The limit in carrying out the missions are due to health effects

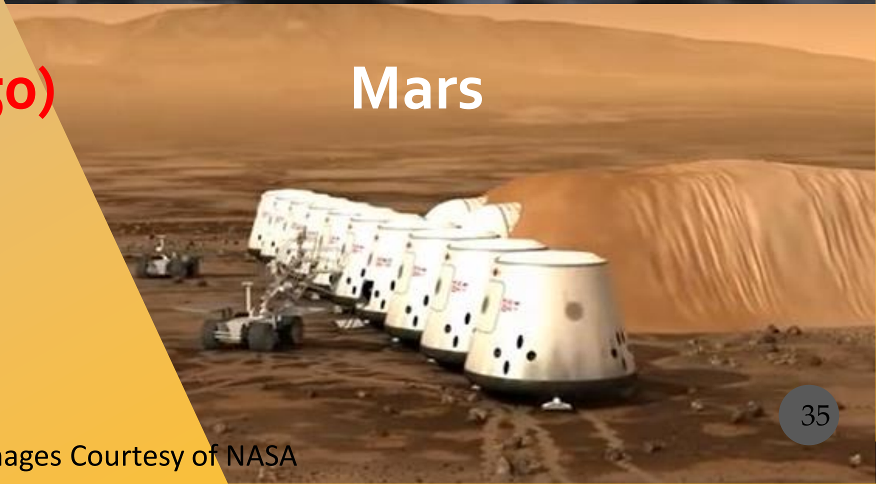
- short-term (<hours)
- acute effects (<months)
- late effects including severe toxicity

Radioprotection in space is a difficult jobs due to the presence of different species of particle and nuclei that present different characteristics in penetrating the barrier and shielding

x150-200

x300-400

x250 (x750)



Images Courtesy of NASA

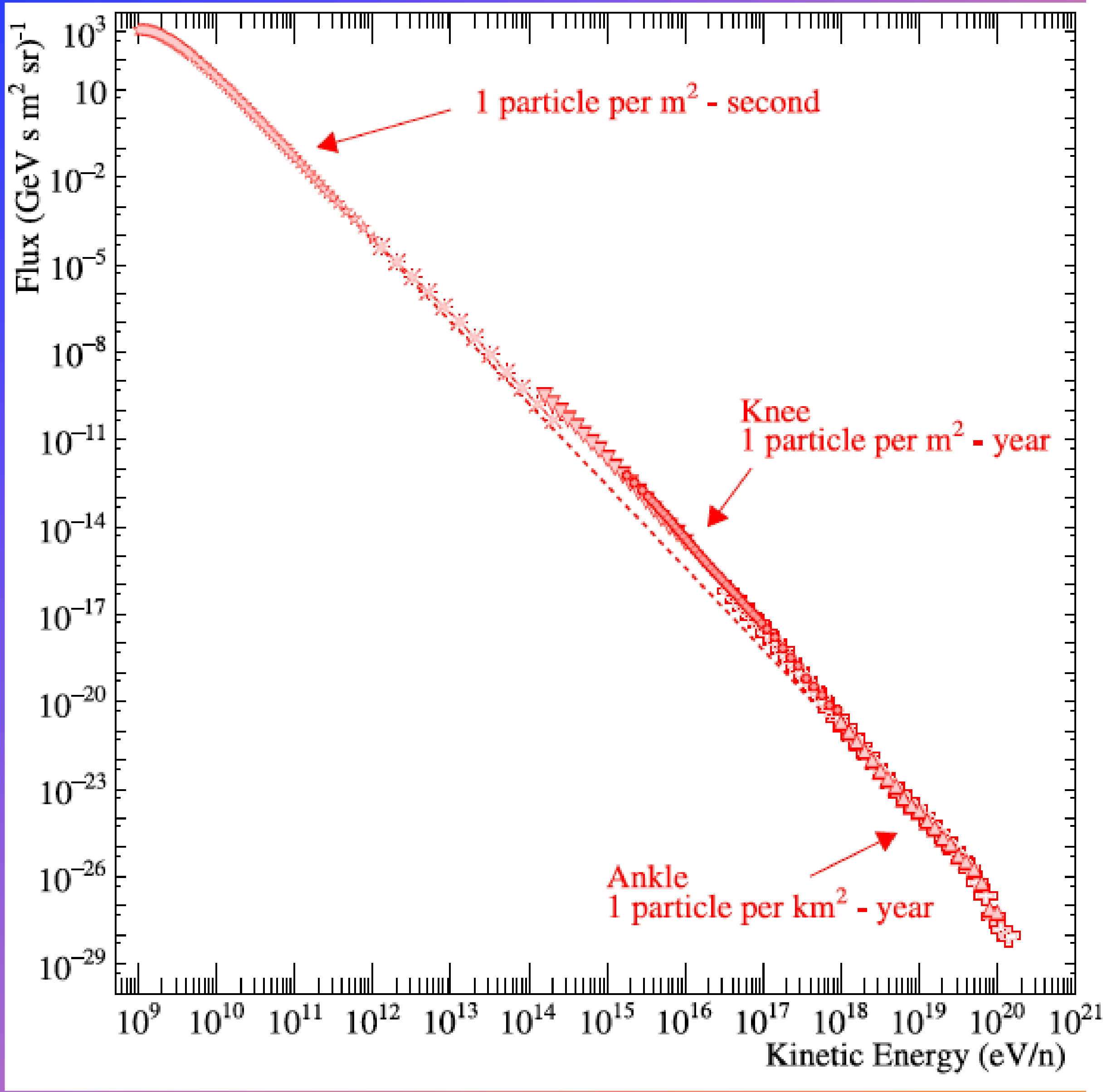
Ionizing radiation exposures is one of the main concern for astronaut's health involved in exploratory missions to the Moon and Mars due to the high doses of radiation expected during the flight and on the surface

The radiation health hazard assessments in exploratory space missions requires the evaluation of the dose effects models in order to quantify the expected damage in the forecast astronaut's exposition scenario.

To complete this task the charged particle data taken by the high energy particle experiments can be useful to increase knowledge in many part of the risk assessment phases

ASTROPARTICLE EXPERIMENTS (IN SPACE)

A **cosmic-ray** observatory is a scientific installation built to detect high-energy-particles coming from space called **cosmic rays**



Credit C.Sparvoli

Energetic particles and completely ionized nuclei from outer space

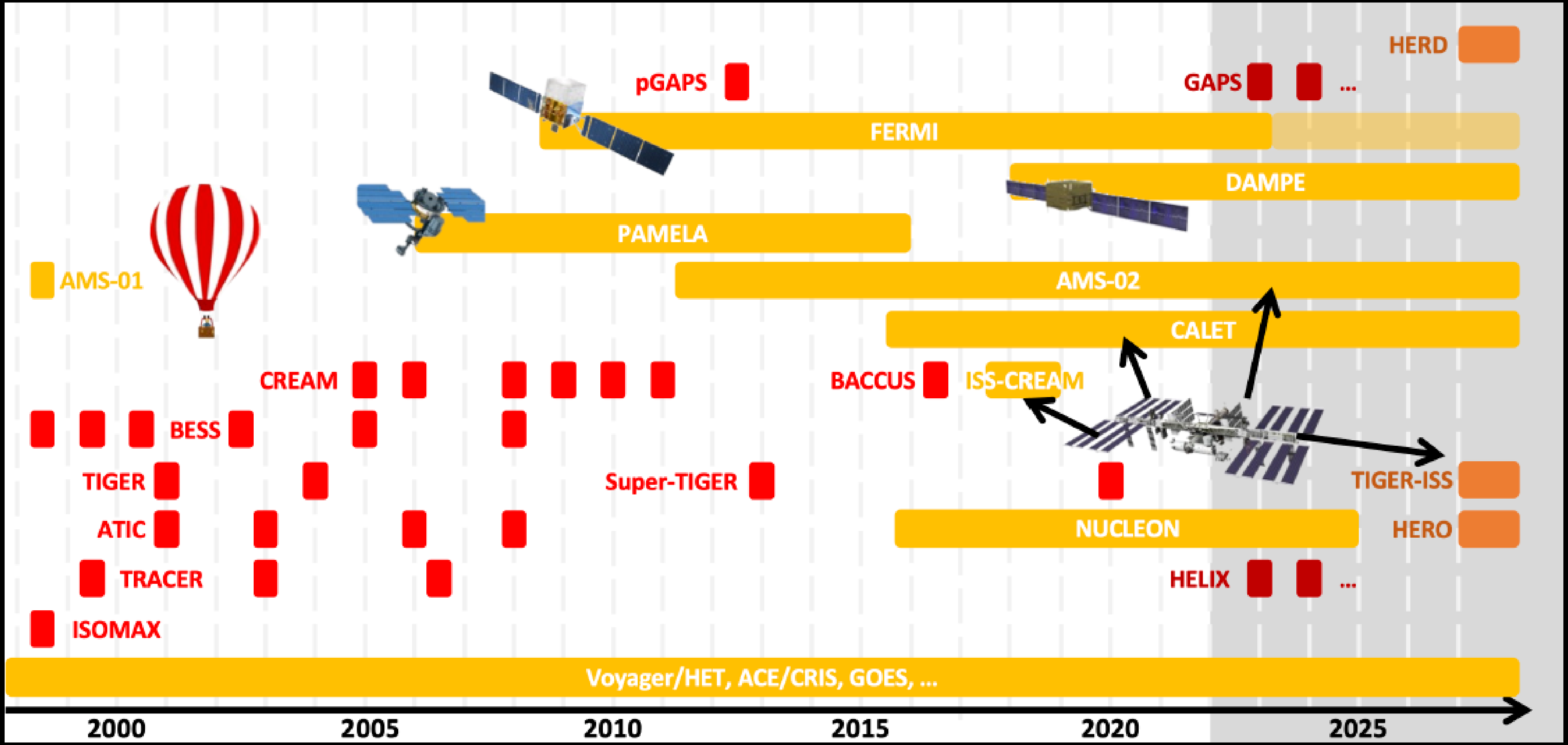
Many orders of magnitude in energy and flux

E < 100 TeV: direct detection
E > 100 TeV: detection of extensive-air-shower

The all-particle spectrum is a "power law" in many orders of magnitude of energy and intensity

with several features (*knee, ankle, …)*
γ = 2,7 for energy <100 TeV
γ = 3,3 for energy >100 TeV

Timeline of Direct Measurement of CRs from 2000

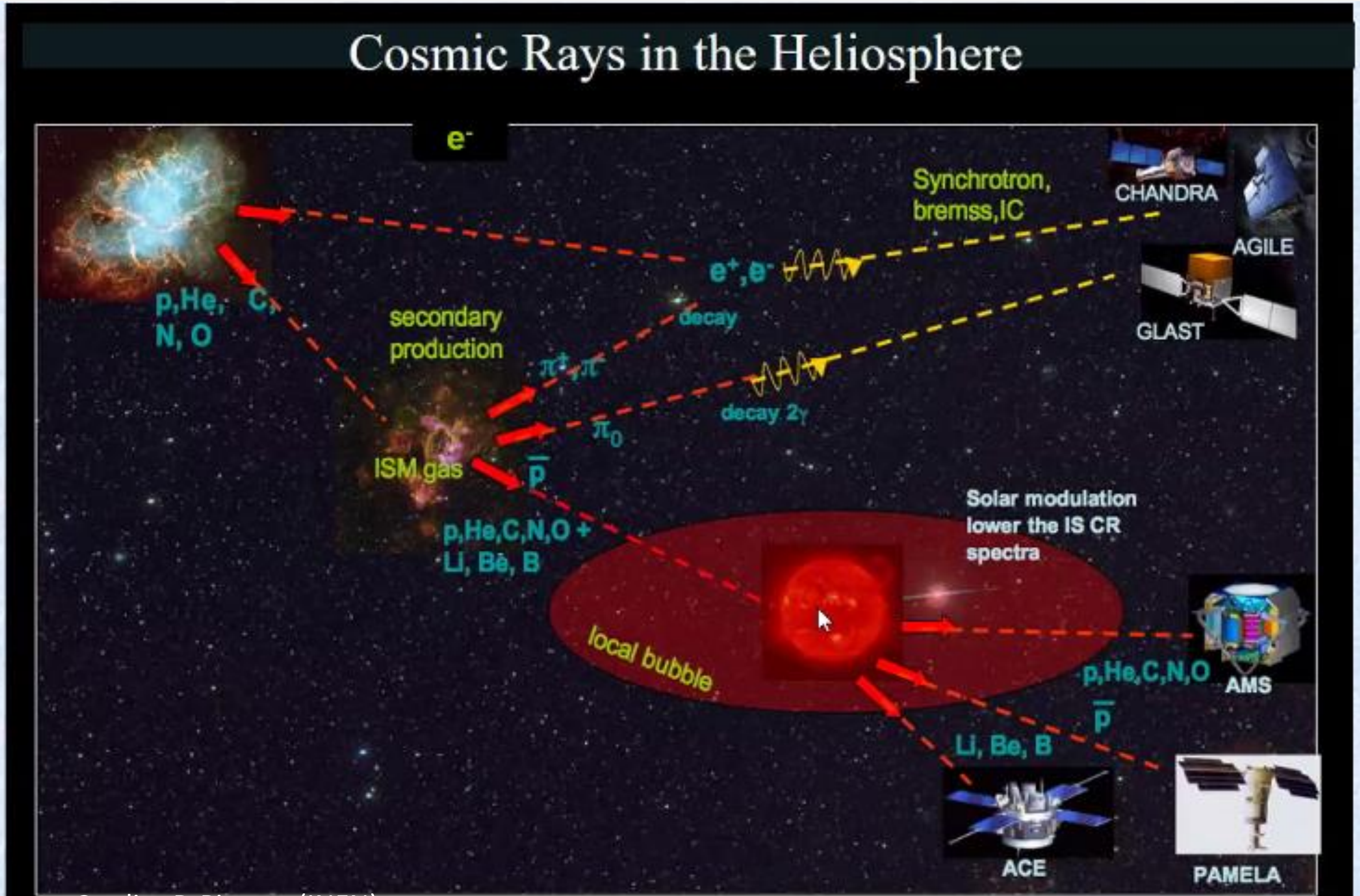


3 possible platform for instruments and detectors
baloons , Satellites , International Space Station

Cosmic Ray Observatory

“A **cosmic**-**ray** observatory is a scientific installation built to detect high-energy-particles coming from space called **cosmic rays**.

This typically includes photons (high-energy light), electrons, protons, and some heavier nuclei, as well as antimatter particles.



Credit : P. Picozza (INFN)

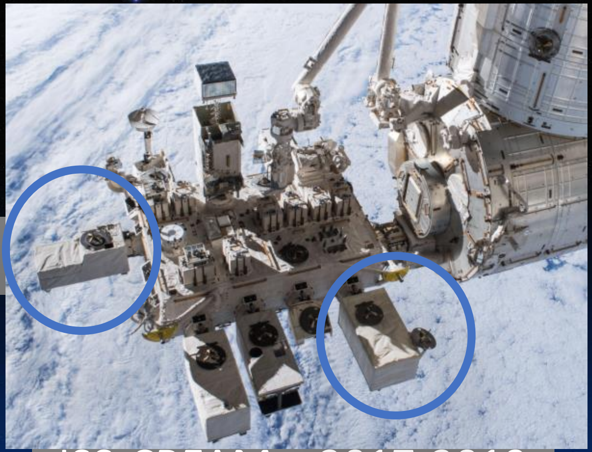
Principal Operating Cosmic Ray Space Detectors

International Space Station based

Satellite Based

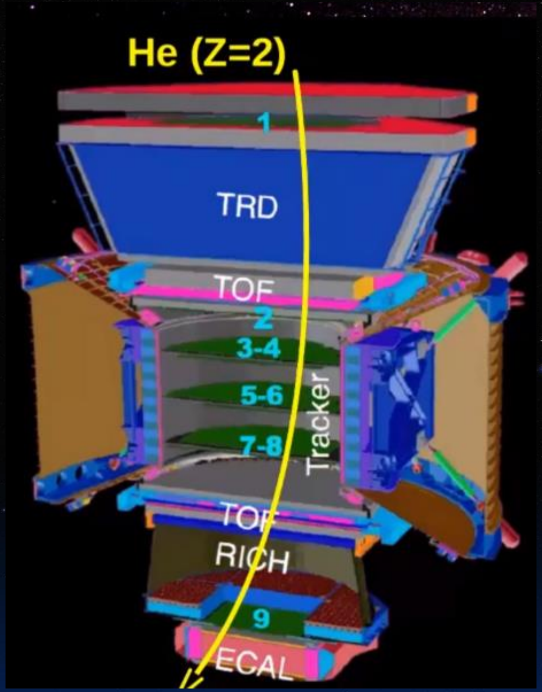
an ensemble of instruments each one designed to capture and measure the cosmic ray particles

AMS02 – 2011



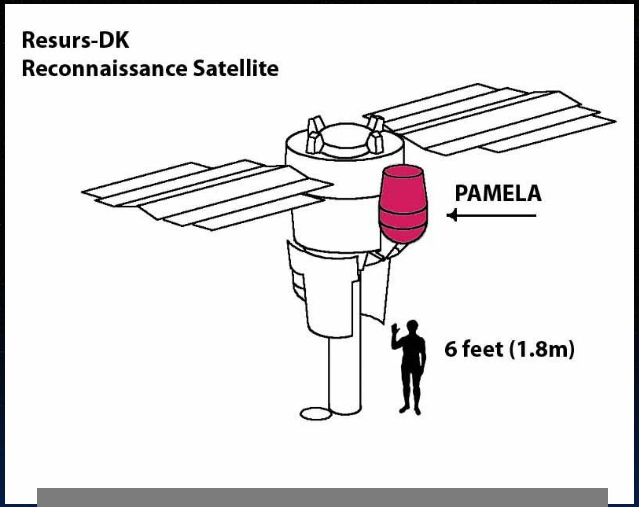
CALET - 2015

ISS-CREAM – 2017-2019



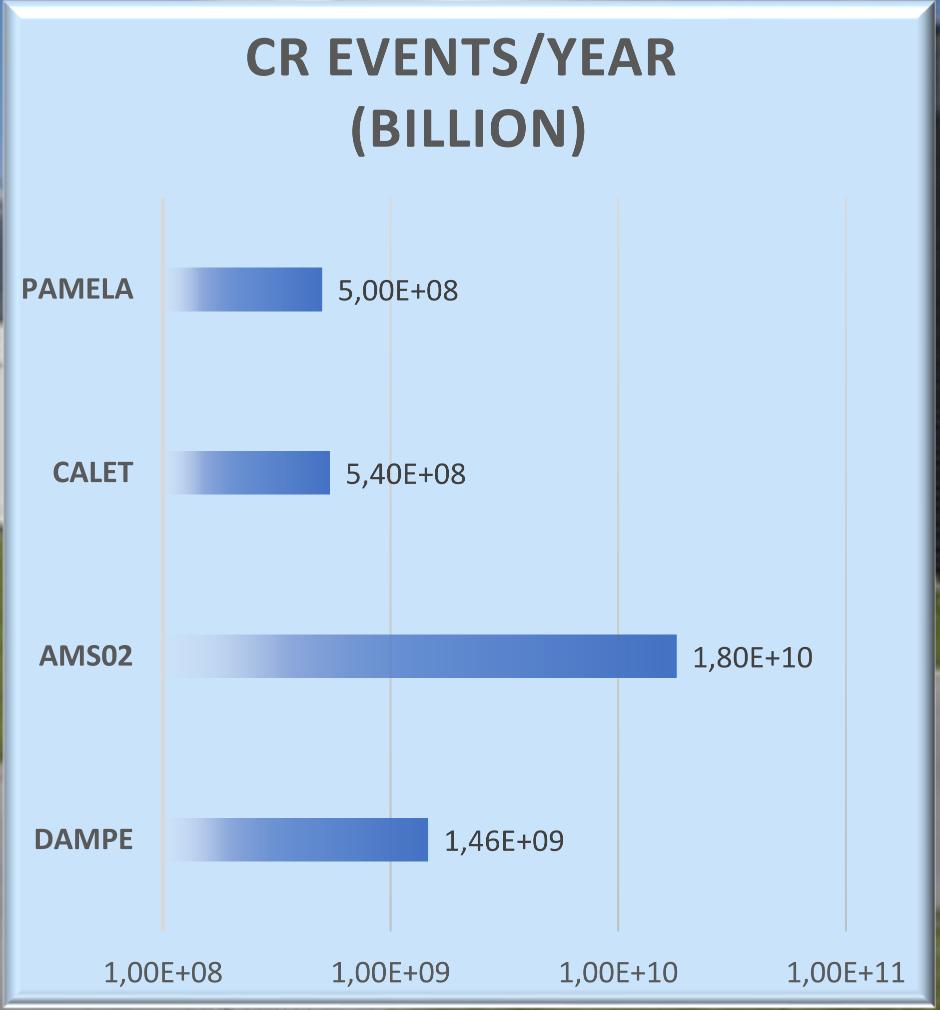
ACE - 1997

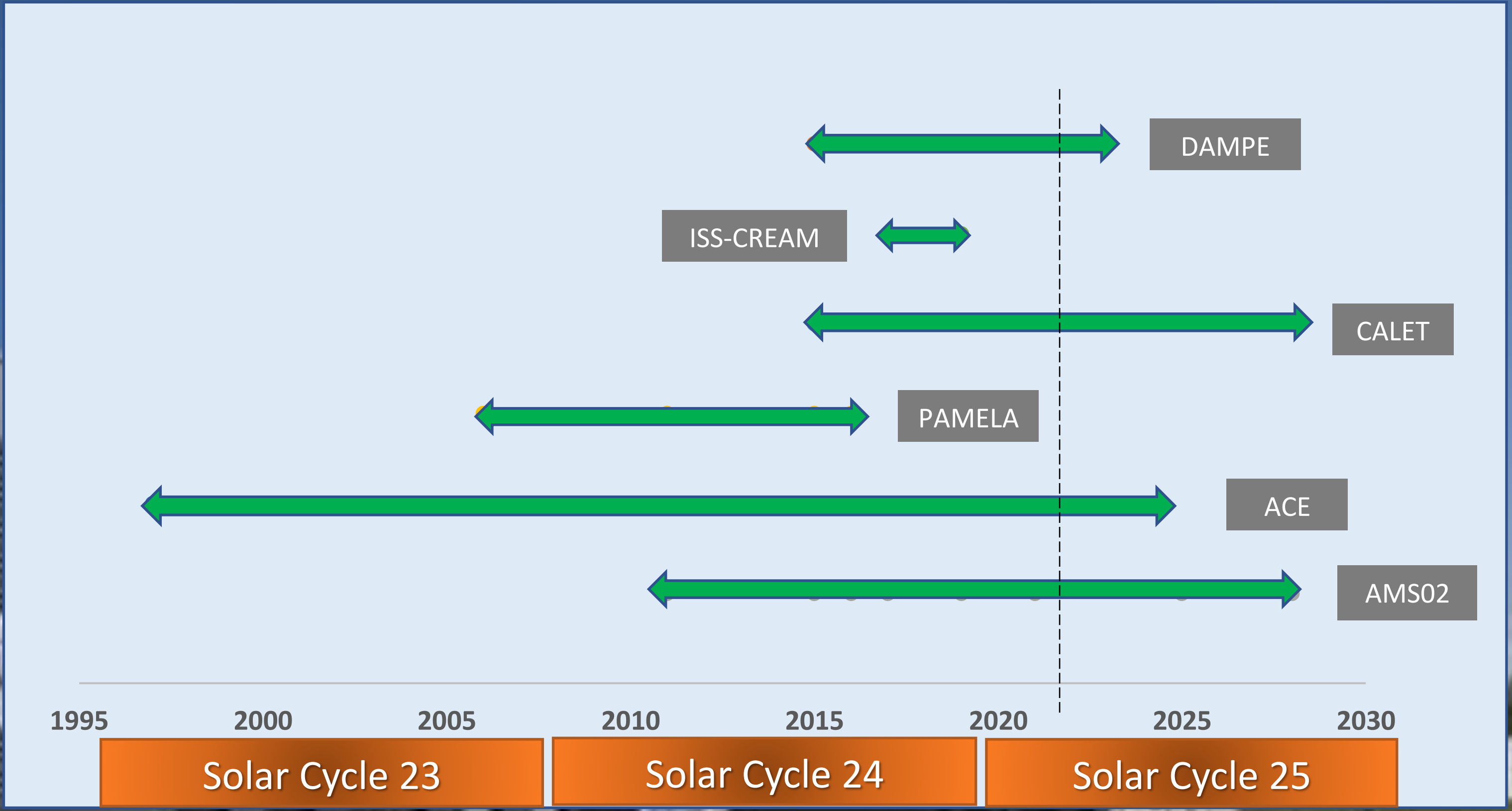
DAMPE - 2017



PAMELA – 2006-2016

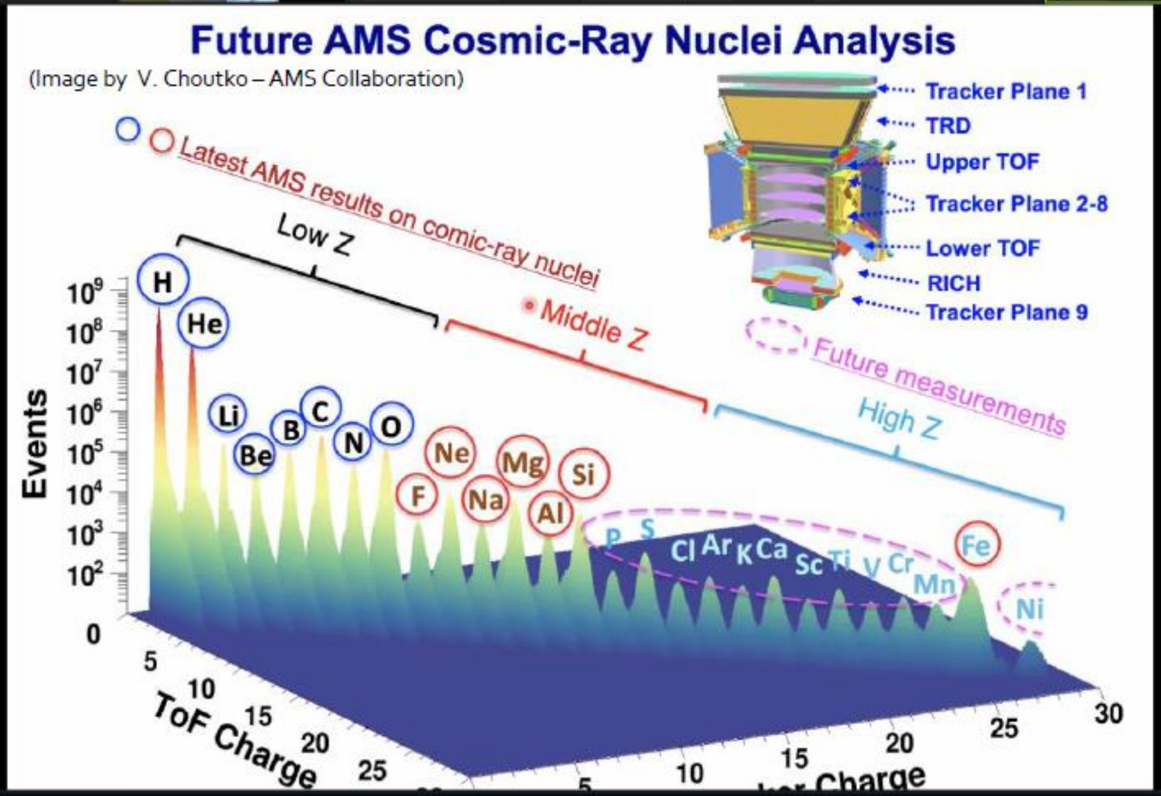
Missions Operations





Cosmic Ray Components Identification

e+,e-	✅ ALL
p+,p-	✅ ALL
D,He	✅ ALL
Low-Z (<=8)	✅ ALL (PAMELA up to Z=6)
Middle-Z	✅ AMS02, CALET, ISS-CREAM, ACE, DAMPE
High-Z (>14)	✅ AMS02, CALET, ISS-CREAM, ACE, DAMPE



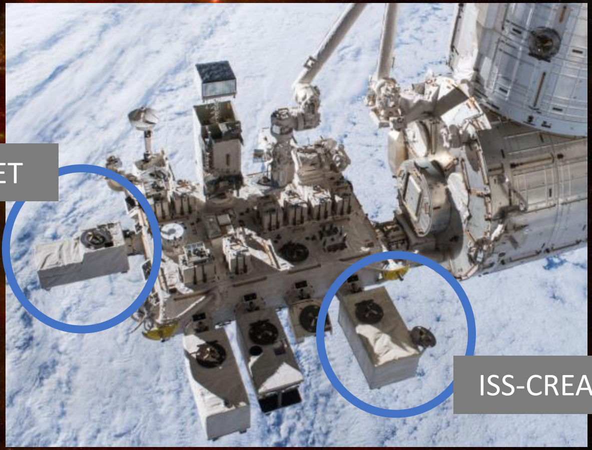
Properties of Iron Primary Cosmic Rays: Results from the Alpha Magnetic Spectrometer
AMS Collaboration • M. Aguilar (Madrid, CIEMAT) et al. (Jan 29, 2021)
Published in: *Phys.Rev.Lett.* 126 (2021) 4, 041104

Properties of Heavy Secondary Fluorine Cosmic Rays: Results from the Alpha Magnetic Spectrometer
AMS Collaboration • M. Aguilar (Madrid, CIEMAT) et al. (Feb 25, 2021)
Published in: *Phys.Rev.Lett.* 126 (2021) 8, 081102

HEP-APE Energy Range


PAMELA

CALET - **1 GeV-10TeV**


CALET

ISS-CREAM

PAMELA - **50 MeV-2TeV**

ISS-CREAM - **1TeV-1PeV**


AMS02

AMS02 - **500 MeV-3TeV**


DAMPE

DAMPE - **5GeV-100TeV**

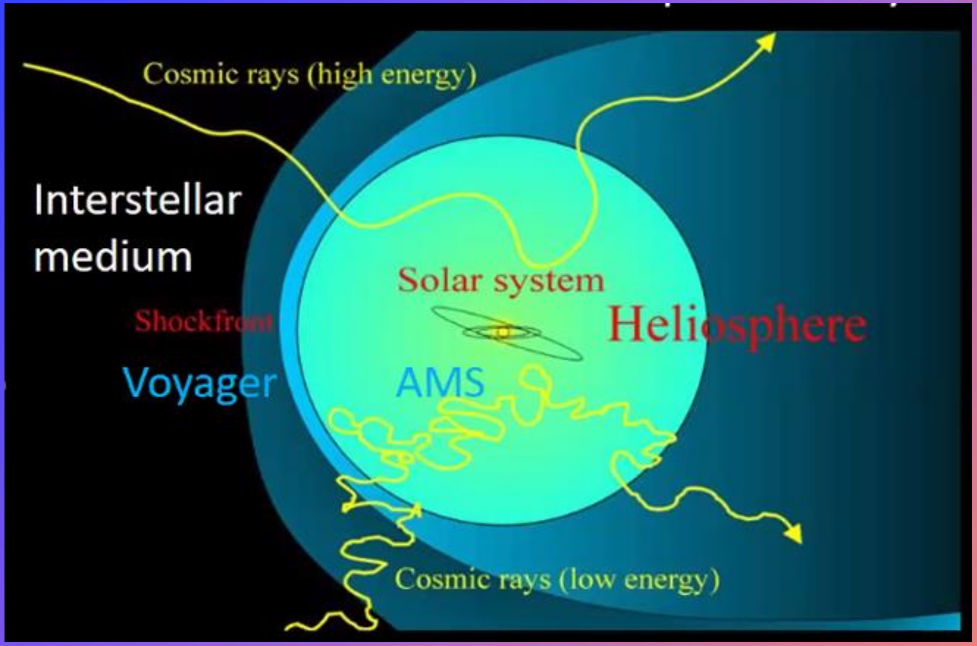

ACE

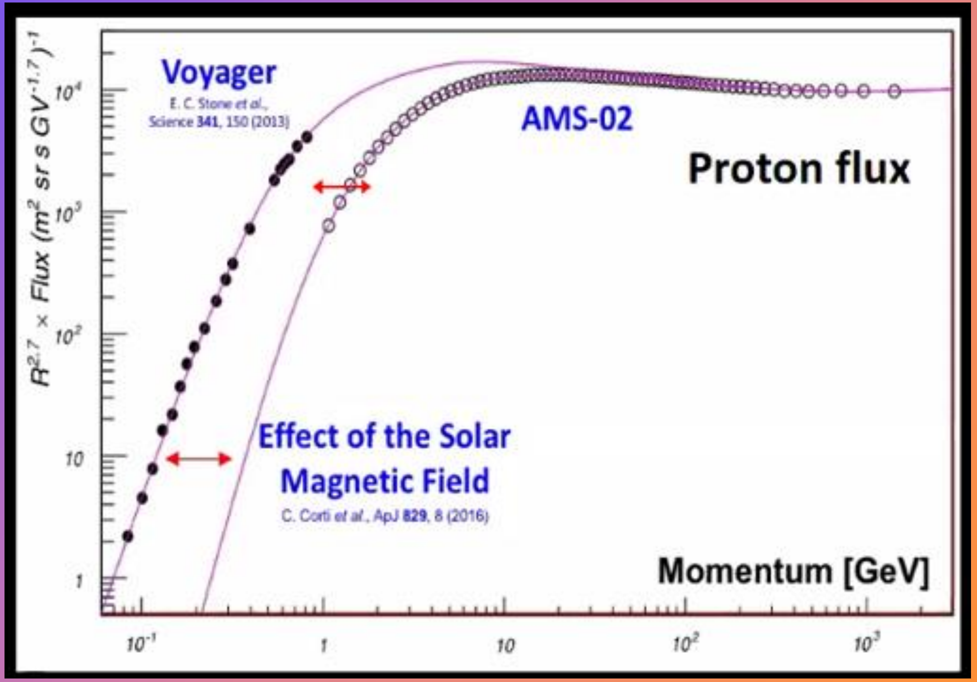
50 – 500 MeV

0.01 | 0.1 | 1 | 10 | 10^2 | 10^3 | 10^4 | 10^5 | 10^6 | 10^7

Energy (GeV)

The biological effects of ionising radiation is a consequence of the energy transfer by ionization and excitation to body cells





Credit S.Ting & AMS Collaboration

Cosmic Rays
Solar modulation

Cosmic rays from interstellar mediaum are «screened» by the Heliosphere.

This effect is particulary visibile at low energies

Measurements of time evolution of cosmic ray fluxes of different particles over an extende period of time is very valuable

A. BARTOLONI - COSPAR-2022