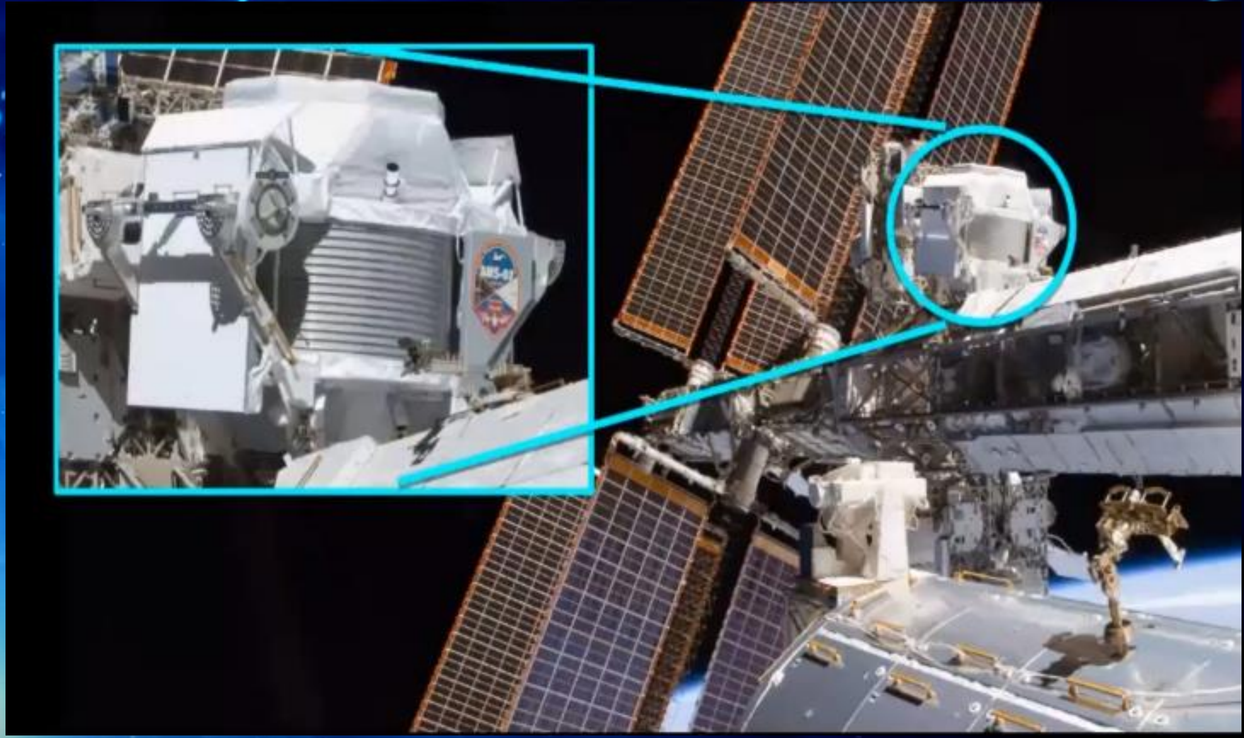
International Astronautical Conference 2021



SPACE RADIATION FIELD CHARACTERIZATION USING THE ASTROPARTICLE OPERATING DETECTORS

A. Bartoloni[a] , L.Strigari[a,b]

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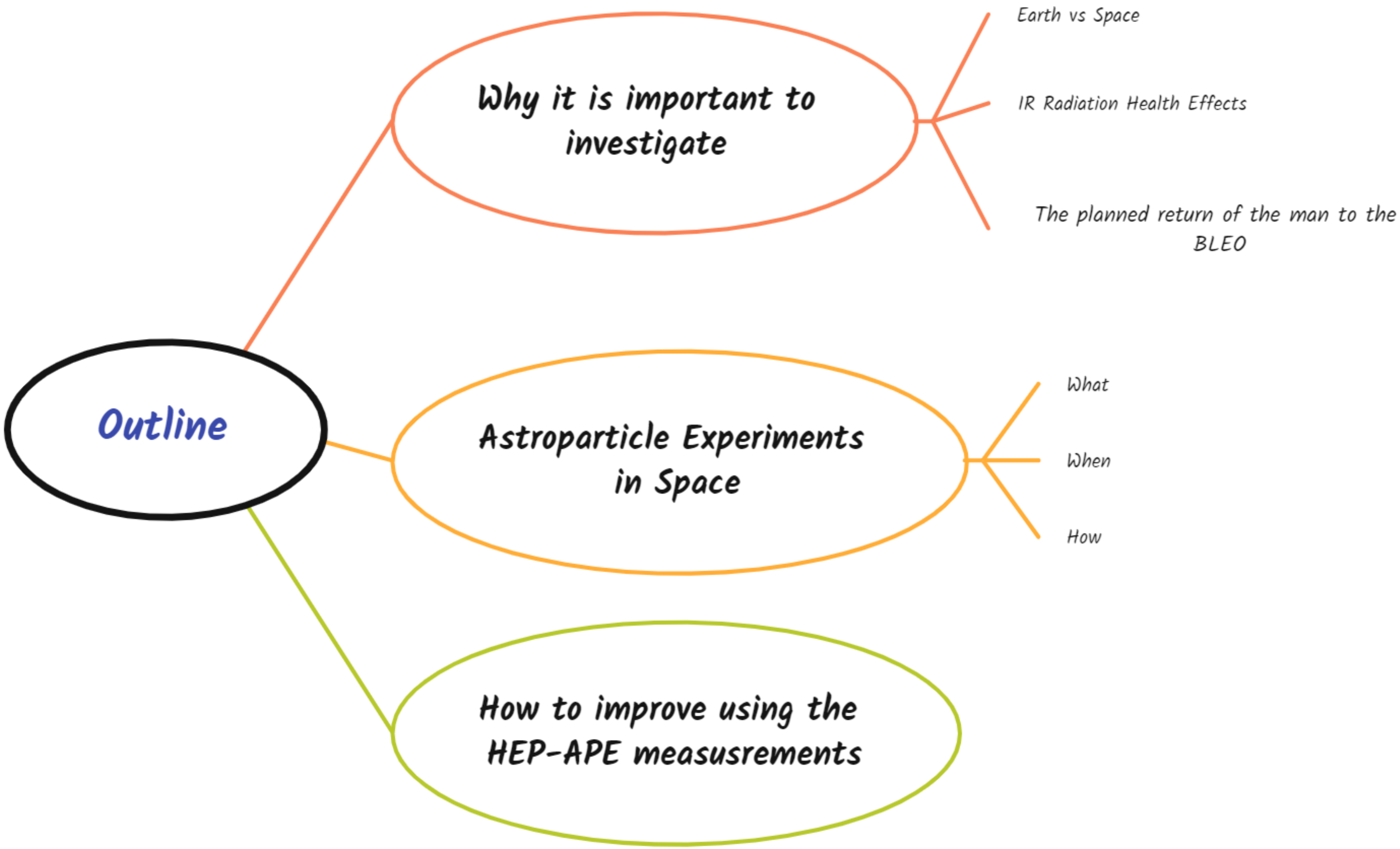
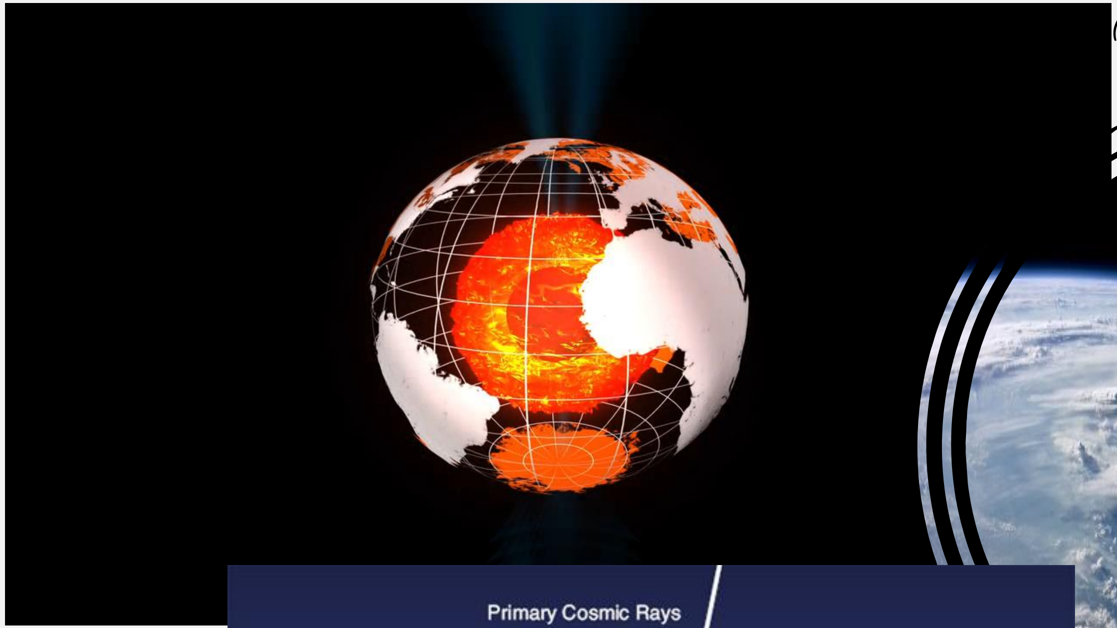
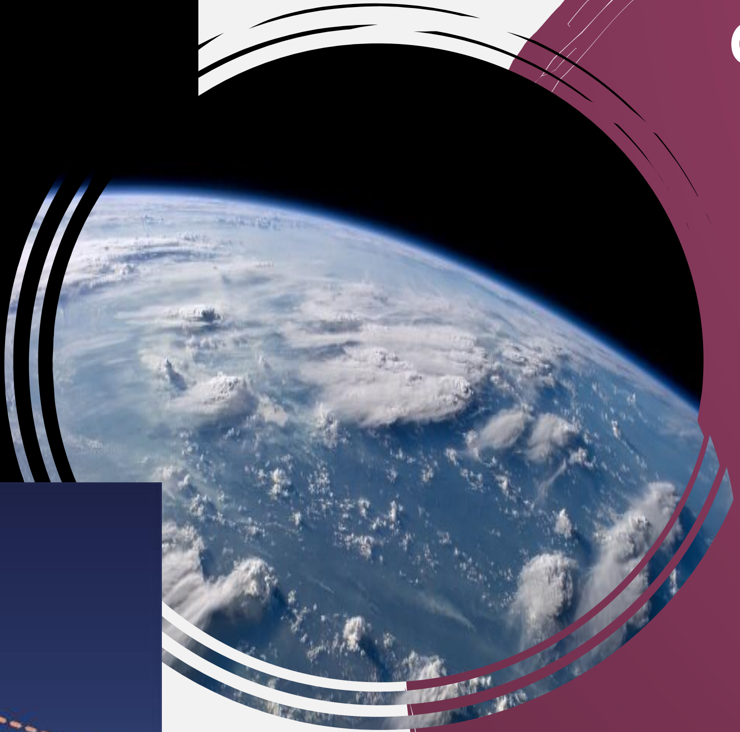
We gratefully acknowledge the strong support from the AMS collaboration
and from the Italian Space Agency (ASI) within the agreement *ASI-INFN n. 2019-19-HH.0*.


Outline
Why it is important to investigate
Earth vs Space
IR Radiation Health Effects
The planned return of the man to the BLEO
Astroparticle Experiments in Space
What
When
How
How to improve using the HEP-APE measusrements



(credit : ESA)

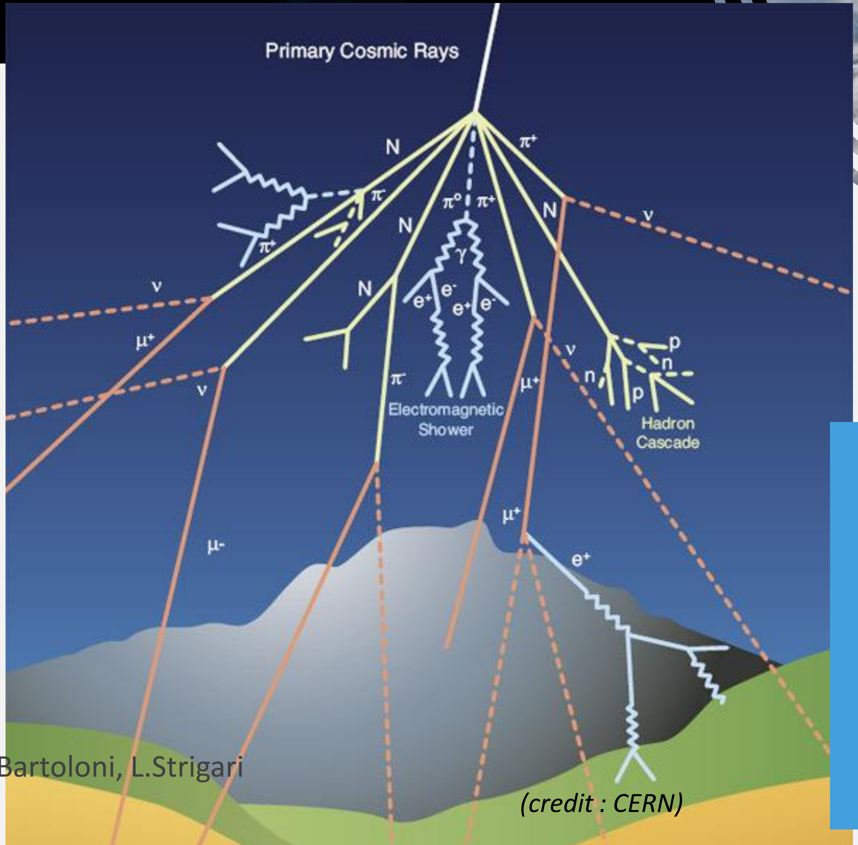


Cosmic Rays Interactions with the geo-magnetosphere

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 about **0.3 mSv**

<10% of “Natural Background Radiation”
(Radon, Soils, Foods, ..)

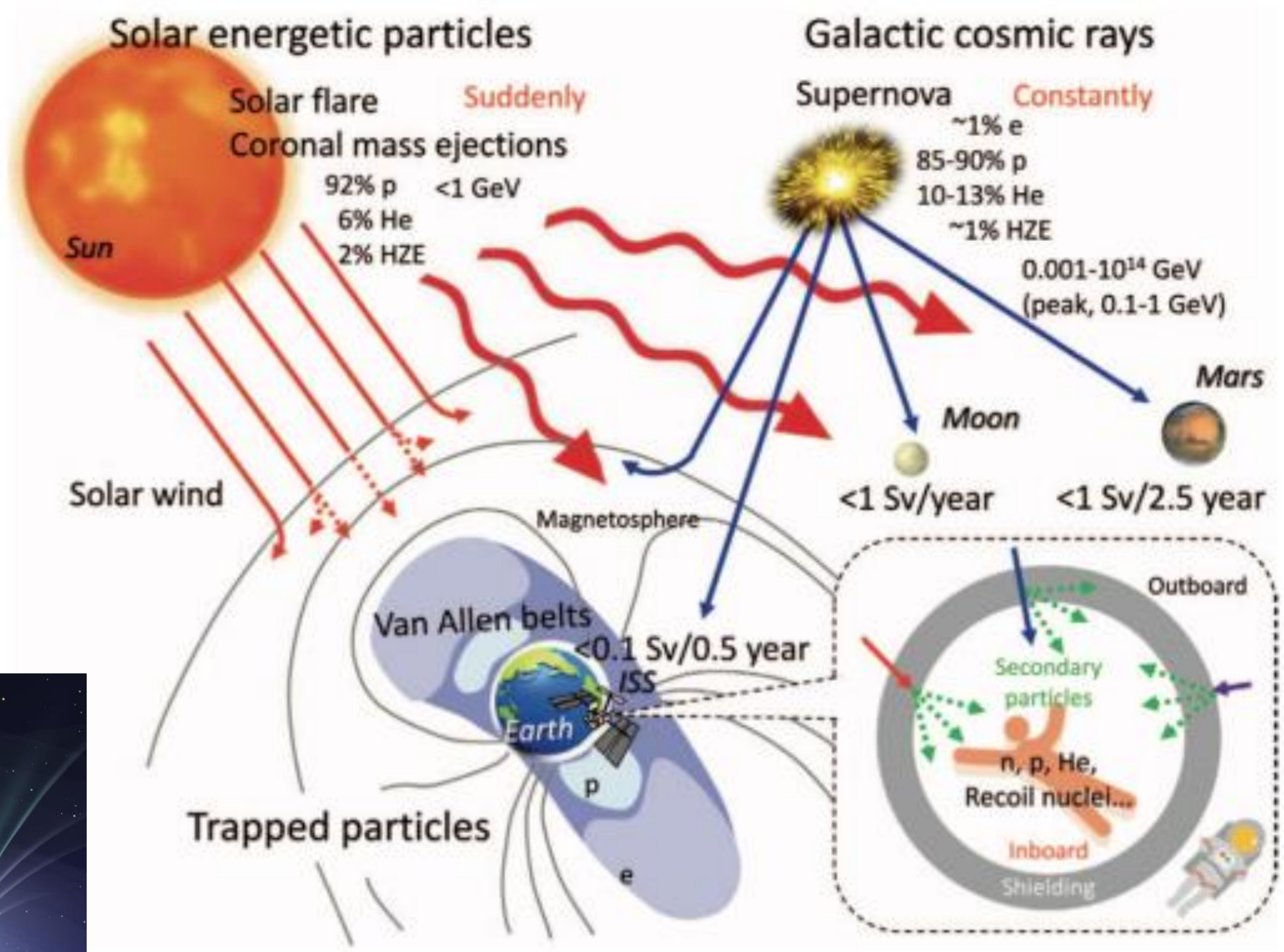
Space Radiation Environment

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



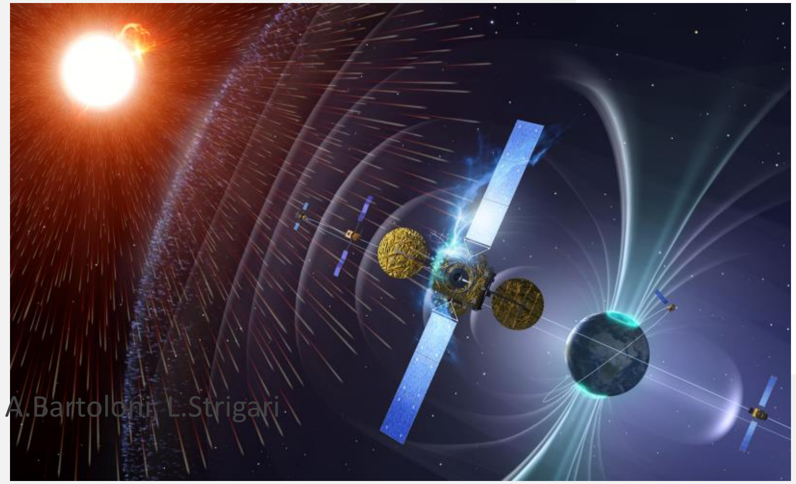


Image courtesy of European Space Agency (ESA)

A new era in human space exploration is coming …

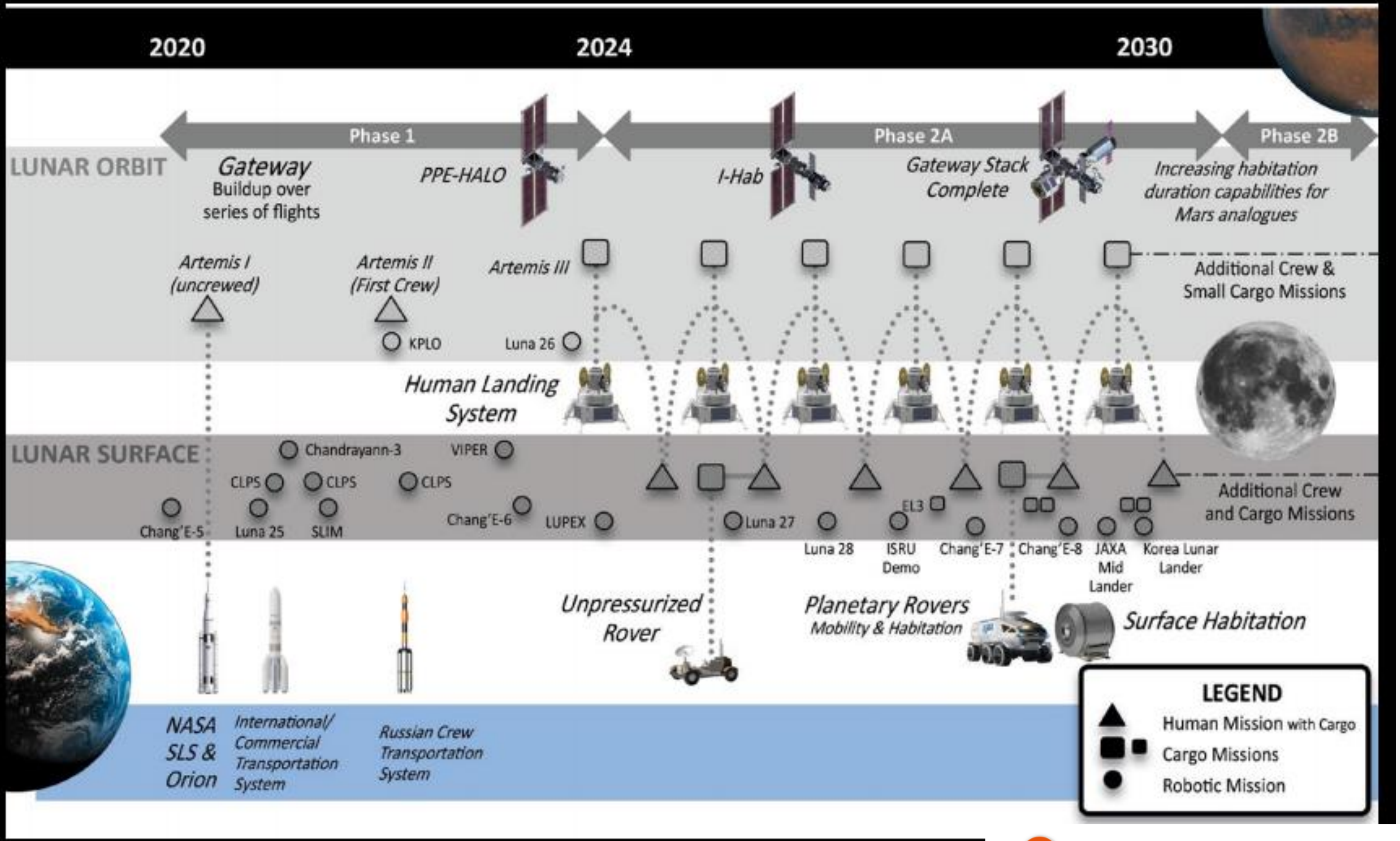


Figure 1. Updated ISECG Lunar Surface Exploration Scenario.

«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

Projected Exploration Missions (2020-2030)

BRYCE space and technology

Data include announced missions, with dates as announced, and projected missions (likely missions such as typical supply missions to space stations), with estimated dates.

International Space Station

Mission	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
SpaceX Cargo	3	3	1								
Northrop Grumman Cargo	2	1	2								
Sierra Nevada Corp.		1	1								
Cargo TBD			1	4	4	4	4	4	4	4	4
Demo-2 *Endeavour*	1										
Boe-OFT 2	1										
Boe-CFT		1									
Commercial Crew	1	2	2	2	2	2	2	2	2	2	2
Soyuz Crew	4	2	2	2	2						
Orel Crew						2	2	2	2	2	2
Progress	2	2	2	2	2	2	2	2	2	2	2
HTV	1		1		1		1		1		1
Axiom 1					1		1		1		

Chinese Space Station

Mission	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Shenzhou		1	1	1	1						
NG Shenzhou	1		1			1	1	1	1	1	1
Tianhe 1		1									
Wentian			1								
Mengtian			1								
Xuntian				1							
Tianzhou		1	1	1	1	1	1	1	1	1	1

152 Crew and cargo missions to LEO

95 Missions to the Moon

First crewed landing since 1972

Mission	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Artemis		1		1	1	1	1	1	1	1	1
Human Landing System (HLS)					4	4	4	4	4	4	4
Lunar Gateway PPE and HALO				1							
Lunar Gateway iHab						1					
Lunar Gateway JAXA Logistics Habitat									1		
Lunar Gateway JAXA Pressurized Rover											1
Gateway Logistics Services (GLS)					1	1	1	1	1	1	1
Artemis Base Camp Foundation Habitat									1		
Artemis Base Camp Mobility Habitat										1	
Artemis Base Camp Logistics Mission											1
Commercial Lunar Payload Services (CLPS)		2	2	2	2	2	2	2	2	2	2
CAPSTONE		1									

Mission	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Chang'e 5	1										
Chang'e 6				1							
Chang'e 7					1						
Chang'e 8							1				

Mission	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Luna 25		1									
Luna 26					1						
Luna 27						1					
Luna 28 (sample return)								1			
Luna 29									1		
Orel (uncrewed circumnavigation)					1						
Orel (crewed circumnavigation)							1				
Orel (crewed landing)										1	

Mission	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
HERACLES EL3 (ESA, JAXA, CSA)								1			
Moon Cruiser 1 Logistics Mission (with ESPRIT)						1					
PTScientists ALINA		1									
Spacebit Mission 1		1									
Chandrayaan 3				1							
Hakuto-R Mission 1			1								
Hakuto-R Mission 2				1							
JAXA SLIM			1								
KARI Pathfinder Lunar Orbiter			1								
Lunar Surface Access Service (LSAS)			1								
SpaceX dearMoon Project						1					

11 Missions to Mars

Mission	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Mars 2020	1										
NASA MNG Sample Return Mission							1				
NASA MNG Mission TBD 1									1		
NASA MNG Mission TBD 2											1

Mission	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Tianwen 1 Rover	1										

Mission	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
ExoMars 2022			1								
Mangalyaan-2					1						
JAXA TEREX 1			1								
JAXA TEREX 2					1						
JAXA MMX					1						
UAE Hope	1										

As of August 31, 2020

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Limits and concerns

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

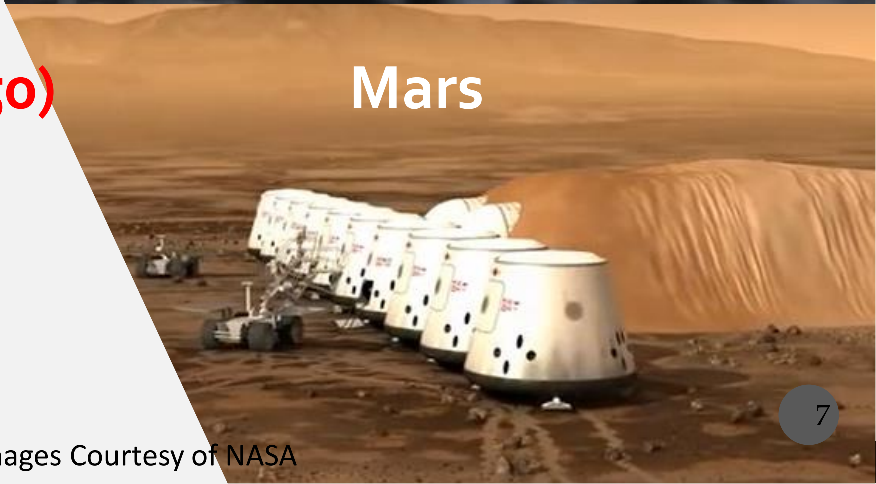
x150-200

x300-400

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

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

x250 (x750)



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

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

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]**

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Edited by:
Yi Xie, Institute of Modern Physics (CAS), China

Reviewed by:
Nan Ding, Institute of Modern Physics (CAS), China
Francis A. Cucinotta, University of Nevada, Las Vegas, United States

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Specialty section:
This article was submitted to Radiation and Health, a section of the journal Frontiers in Public Health

Received: *30 June 2021*
Accepted: *27 September 2021*
Published: *xx October 2021*

Citation:
Strigari L, Strolin S, Morganti AG and Bartoloni A (2021) Dose-Effects Models for Space Radiobiology: An Overview on Dose-Effect Relationships. Front. Public Health 9:733337. doi: 10.3389/fpubh.2021.733337

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 (e.g., spaceship and lunar space station-shielding and lunar/Mars village design), 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 [International Space Station (ISS) and solar system exploration]. 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 similar to 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.

Keywords: human space exploration, galactic cosmic radiation, galactic cosmic radiation effects, space radiobiology, space radiation doses, dose-effect model

Frontiers in Public Health Radiation and Health

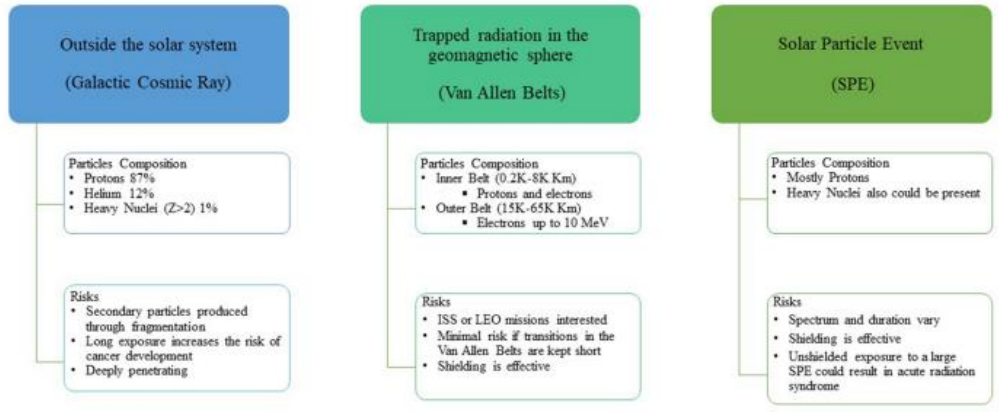


FIGURE 1 | Scheme of the origin of space radiation particles and consequent risk. ISS, International Space Station; LEO, Low Earth Orbit.

TABLE 1 | Dose-effect relationship for space radiation risk assessment.

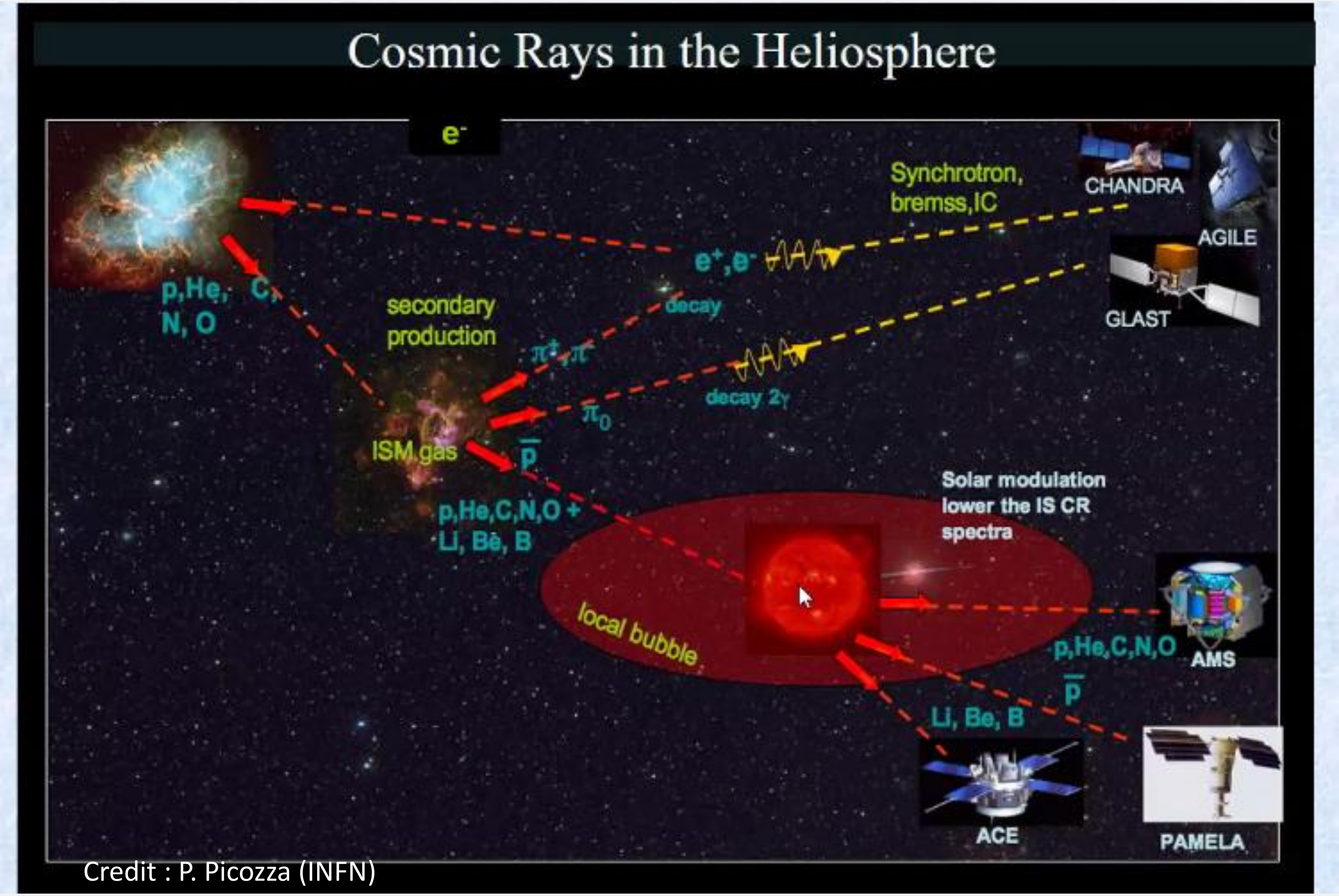
Model	Study type	Dose range/threshold or LET	Reference	Reliability	Priority
Eye flashes	Spaceflight	LET> 5–10 keV/μm	(7–10)	****	*
Cataract	Spaceflight	8 mSv	(11–15)	***	***
CNS	Ground/Simulation	100–200 mGy	(16–27)	**	*****
CVD	Spaceflight	1000 mGy	(28–31)	*	***
	Ground/Simulation	(0.1–4,500) mSv	(32–39)		
Cancer	Spaceflight	<100 mGy	(40, 41)	***	*****
	Ground/Simulation	<100 mGy	(42–50)		
Biomarkers or	Spaceflight	5–150 mGy	(51–61)	***	*****
Chromosomal aberrations	Ground/Simulation	<10,000 mGy	(62–65)		
Other Risks	Ground/Simulation	~2,000 mGy	(66, 67)	*	***

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

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.

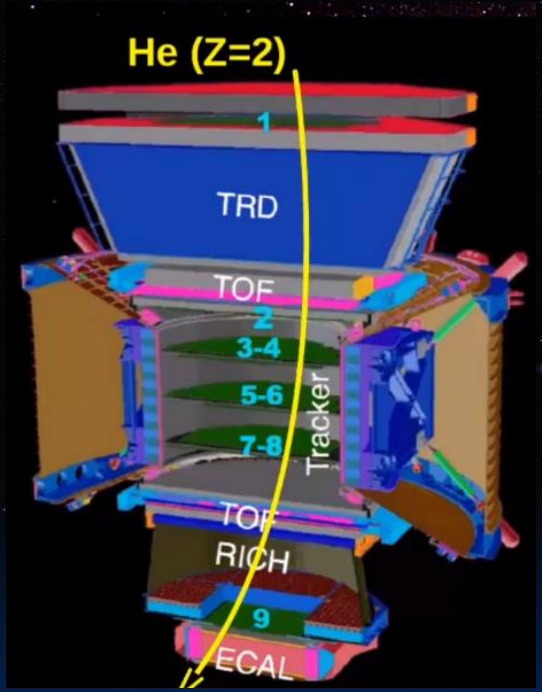


Principal Operating Cosmic Ray Space Detectors

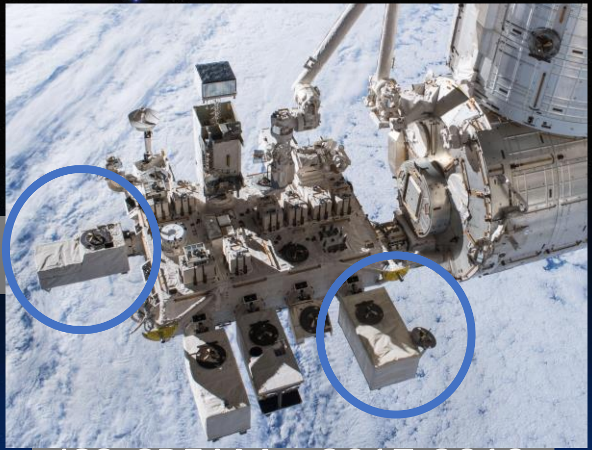
International Space Station based

AMS02 – 2011

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



CALET - 2015

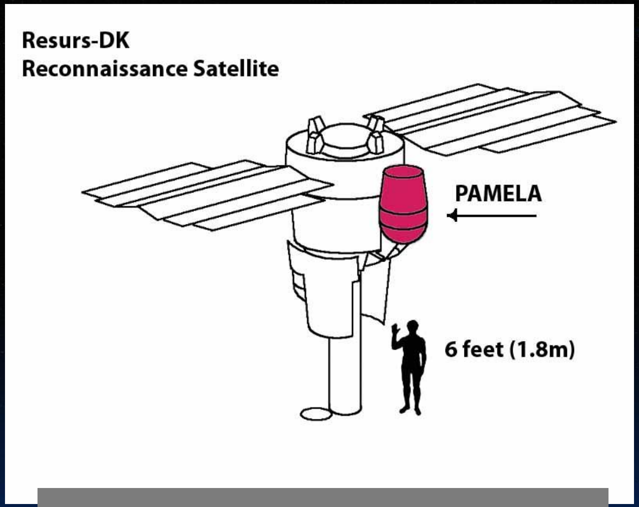


ISS-CREAM – 2017-2019

Satellite Based

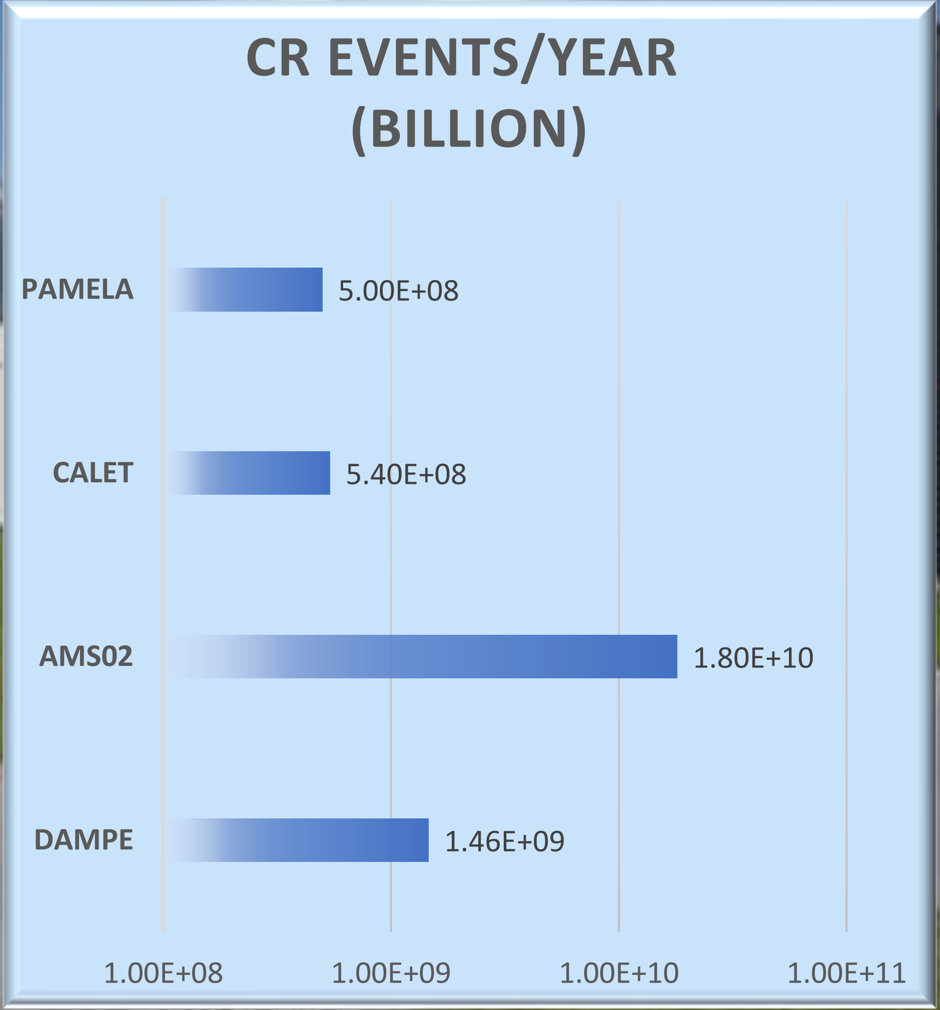
ACE - 1997

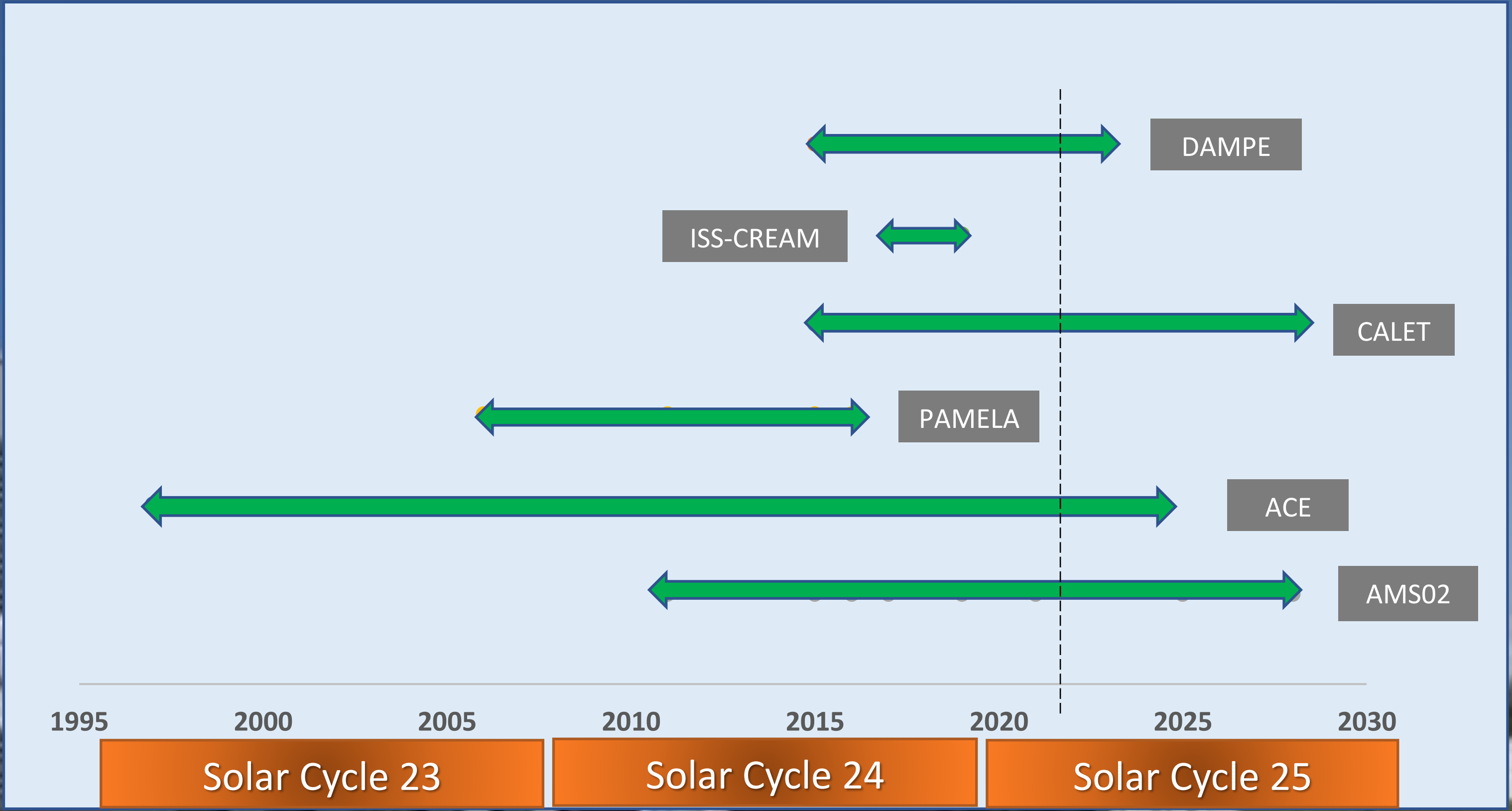
DAMPE - 2017



PAMELA – 2006-2016

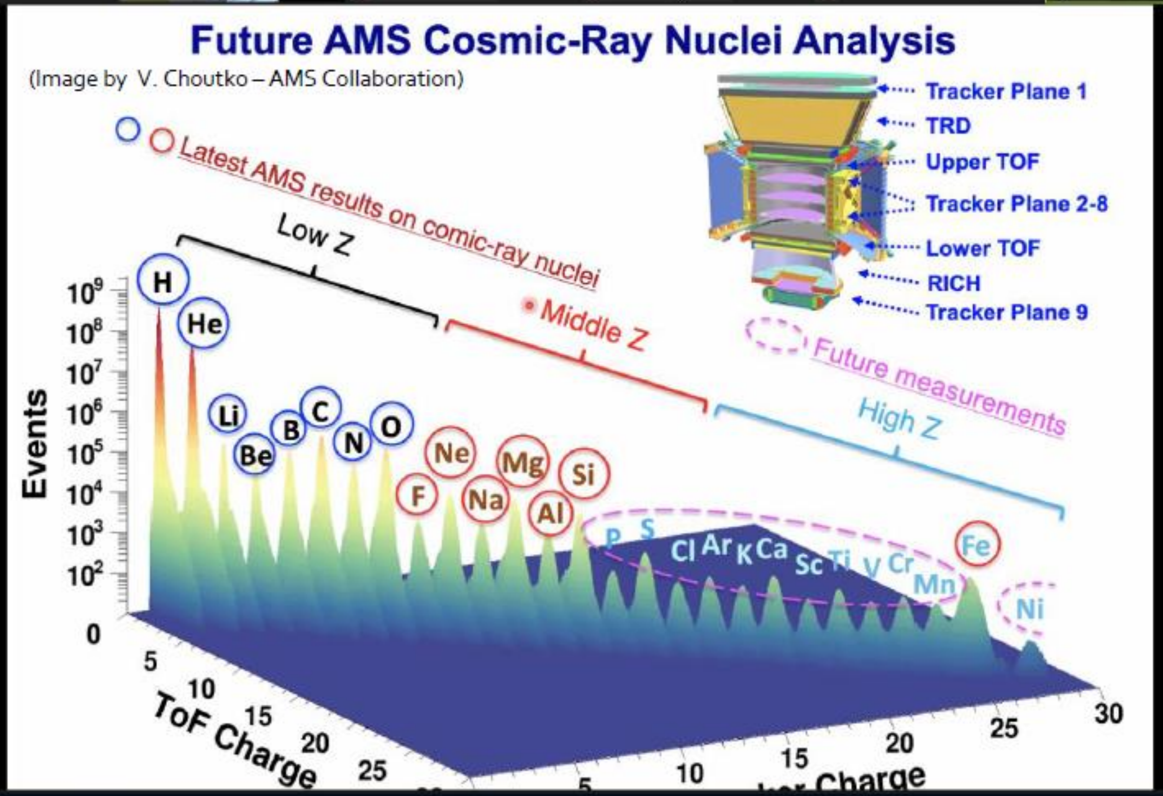
Missions Operations





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)

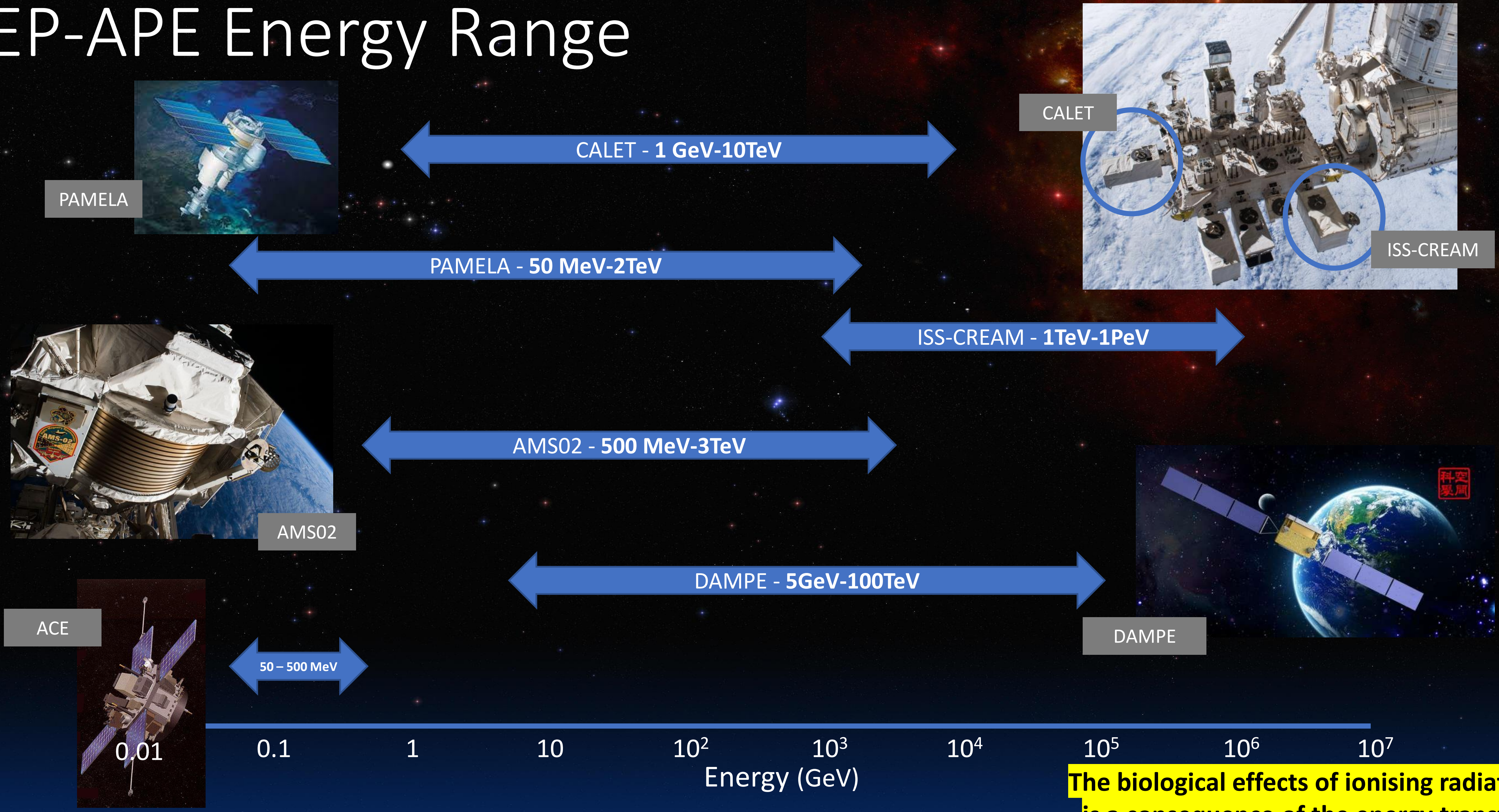
Published in: *Phys.Rev.Lett.* 126 (2021) 4, 041104

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

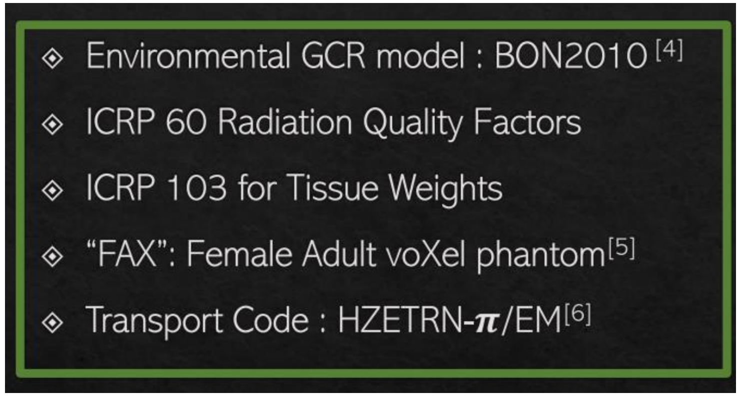
HEP-APE Energy Range

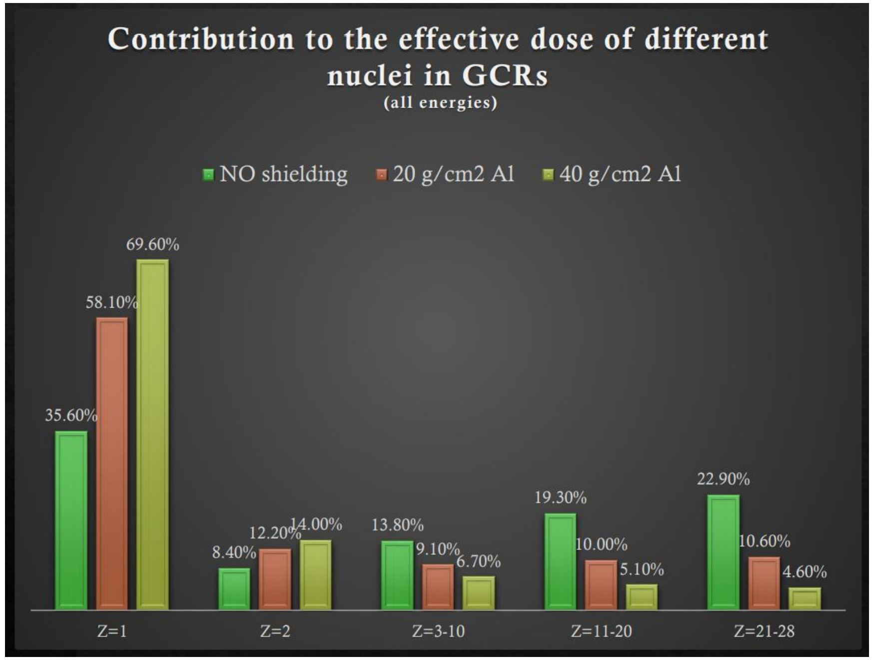


The biological effects of ionising radiation is a consequence of the energy transfer by ionization and excitation to body cells

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





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

1) Environmental Model Characterization:

- Use the enormous data at energies > 1Gev
- Improve affects the accuracy and precision of the risk assessment potentially underestimating the actual damage.
- Indeed, space radiation for LET greater than several keV/μm causes more serious damage than low-LET radiation to living cell/tissues.

2) Effective Dose Measurements:

Measurements only of absorbed doses, by passive dosimeters, are insufficient for investigating biological effects or assessing radiation risk for astronauts.

Dose equivalents need to consider the whole LET distributions, their QFs (up to 30), and RBE of high-LET particles constituting the space radiation environment.

3) Transport Code Validation :

Based on the detailed information of APE, Monte Carlo (MC) simulation code can be further implemented to better describe the interaction with the matter of GCR environments thanks to the improvement of accuracy of cross sections at high energy of elementary particles (electrons, protons), light and heavy nuclei (Helium to Iron and beyond).

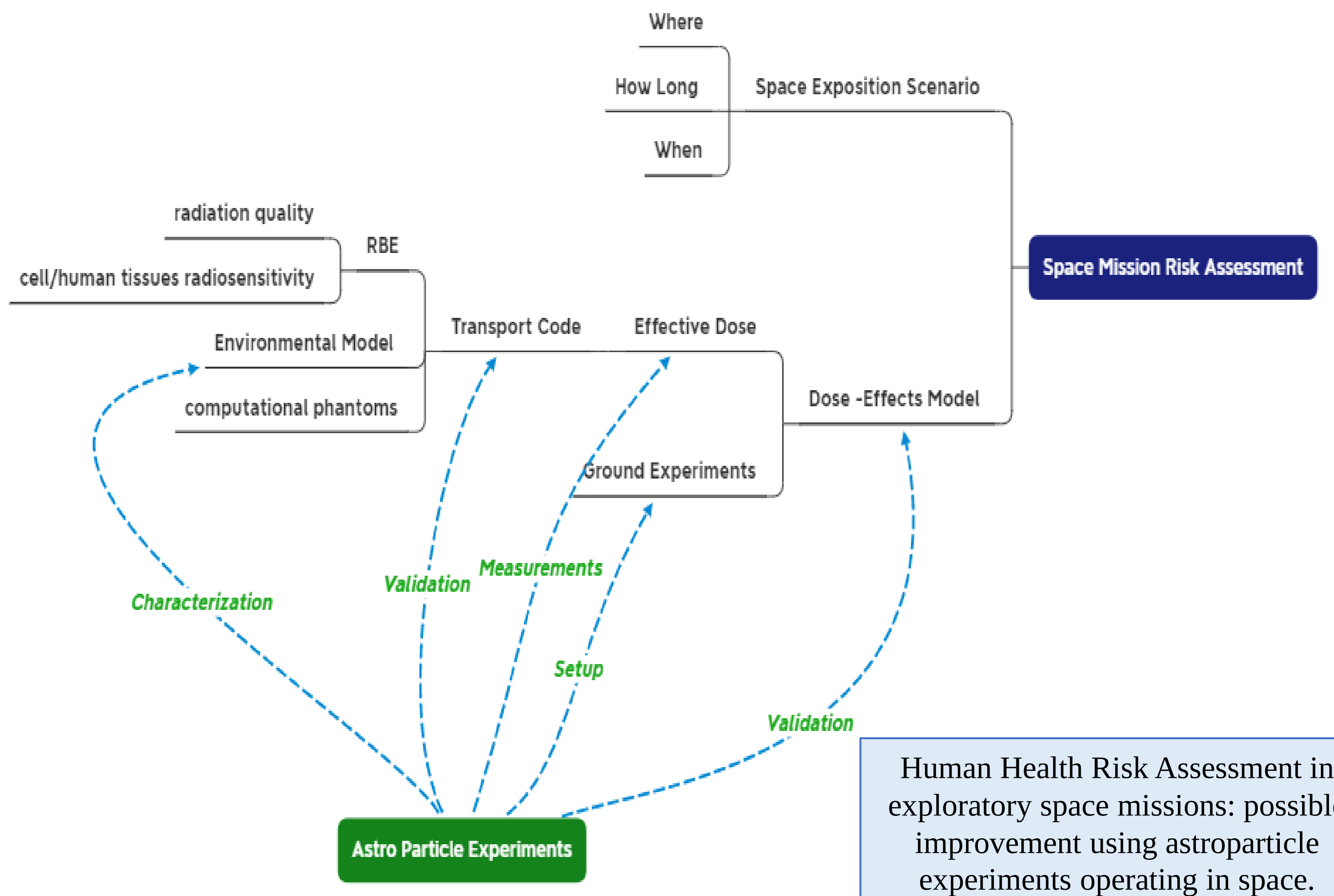
The implementation of transport code at these energies allows predicting the particle interactions with the known geometries of installed detectors. The determination of ray / particle tracing, energy spectrum and deposited energies collected in several materials can serve for a subsequent MC transport code validation (e.g. through a possible Bayesian approach).

The calculations of dose equivalents allow generating an accurate and precise database for subsequent MC simulation codes validation applied to human tissues. Moreover, MC codes can be used for designing ad hoc shielding of spacecrafts and space landers.

4) Space Exposition Scenario Dose Computation:

- Implementation of Montecarlo codes to calculate the dose and so predict/describe the effects of GCR particles interacting with cells, tissues/organs and astronauts, which can be modeled as geometries with increasing details and complexities.

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)

AGU ADVANCING EARTH AND SPACE SCIENCE

Space Weather

RESEARCH ARTICLE
10.1029/2020SW002456

The Badhwar-O'Neill 2020 GCR Model

T. C. Slaba[1] and K. Whitman[2]

[1]NASA Langley Research Center, Hampton, VA, USA, [2]University of Houston, Houston, TX, USA

Key Points:
- The Badhwar-O'Neill 2020 GCR model is presented
- The updated model is calibrated using new AMS-02 and PAMELA data
- Solar activity is described using ACE/CRIS daily integral flux measurements

Correspondence to:
T. C. Slaba,
tony.c.slaba@nasa.gov

Citation:
Slaba, T. C., & Whitman, K. (2020). The Badhwar-O'Neill 2020 GCR model. *Space Weather*, *18*, e2020SW002456. https://10.3847/10.1029/2020SW002456

Abstract The Badhwar-O'Neill (BON) model has been used for some time to describe the galactic cosmic ray (GCR) environment encountered in deep space by astronauts and sensitive electronics. The most recent version of the model, BON2014, was calibrated to available measurements to reduce model errors for particles and energies of significance to astronaut exposure. Although subsequent studies showed the model to be reasonably accurate for such applications, modifications to the sunspot number (SSN) classification system and a large number of new high-precision measurements suggested the need to develop an improved and more capable model. In this work, the BON2020 model is described. The new model relies on daily integral flux from the Advanced Composition Explorer Cosmic Ray Isotope Spectrometer (ACE/CRIS) to describe solar activity. For time periods not covered by ACE/CRIS, the updated international SSN database is used. Parameters in the new model are calibrated to available data, which include the new Alpha Magnetic Spectrometer (AMS-02) and Payload for Antimatter Matter Exploration and Light-nuclei Astrophysics (PAMELA) high-precision measurements. It is found that the BON2020 model is a significant improvement over BON2014. Systematic bias associated with BON2014 has been removed. The average relative error of the BON2020 model compared to all available measurements is found to be <1%, and BON2020 is found to be within ±15% of a large fraction of the available measurements (26,269 of 27,646 → 95%).

Dose-Effects Relationship

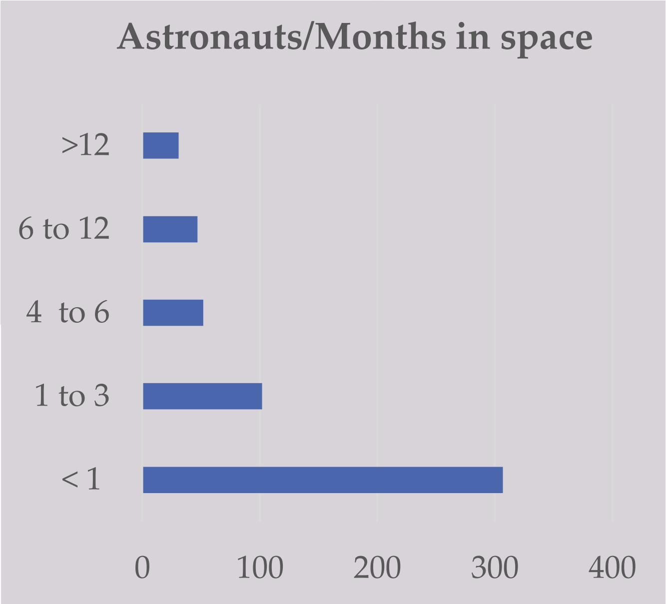
The known dose-effect relationships are based on a limited number of astronauts

(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.

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



Needs of an improvements

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

Summary

- In the coming years there will be a great interest for space human mission non only to explorate but also for a permanent presence of humans in LEO and outside the geomagnetosphere
- Space Radiation is a main concern and the first one showstopper in many human exploration scenarios.
- Dose-Effects models knowledge and other space radiobiology topics could benefit from the use of should be improved
- a synergy with the experience from the clinical field is crucial to perform this task
- Other important topics needs to be faced (e.g. Non-Targeted Effects, Individual Radiosensitivity)
- Astrparticle Experiments are a principal source of information to perform this investigations complementary to what is usually done in the research field.

THANKS for the attention !!!

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

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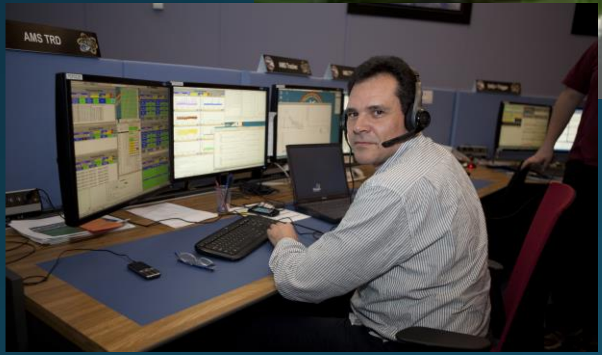
Miriam Santoro

Lidia Strigari

STVDIVM VRBIS

INFN
Istituto Nazionale di Fisica Nucleare

Policlinico S.Orsola-Malpighi
SERVIZIO SANITARIO REGIONALE
EMILIA-ROMAGNA
Azienda Ospedaliero-Universitaria di Bologna
ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA



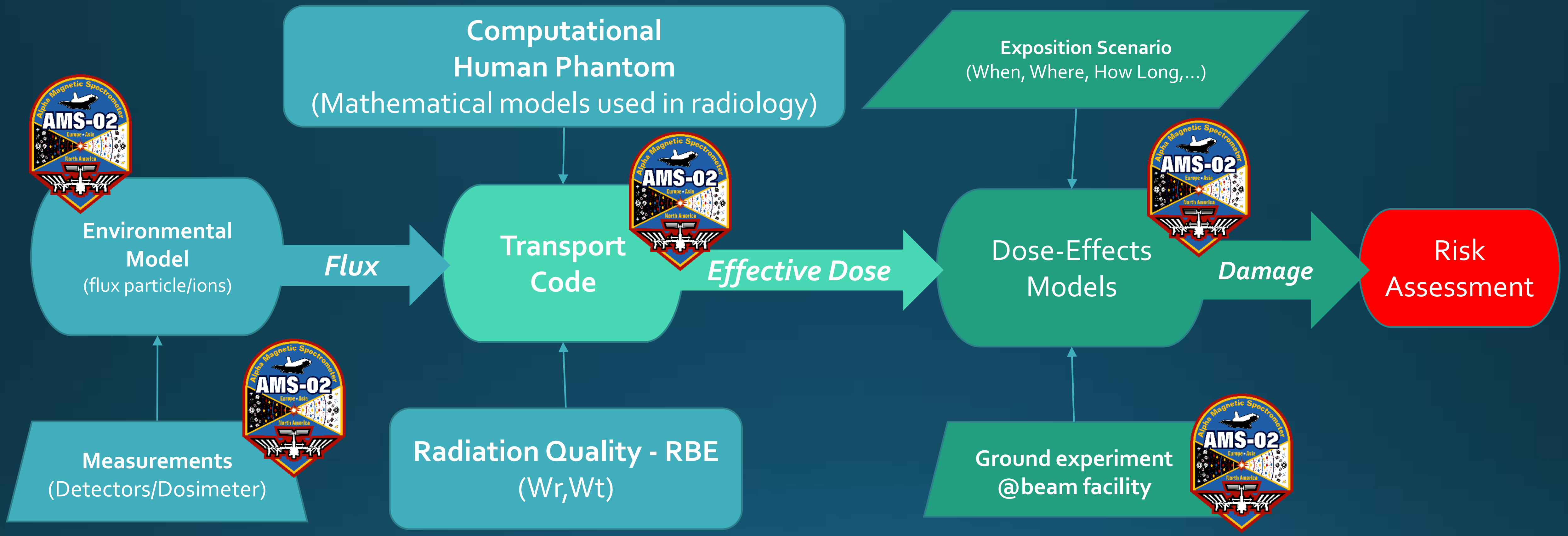
If you are interested to collaborate on the SPRB with our research group please contact

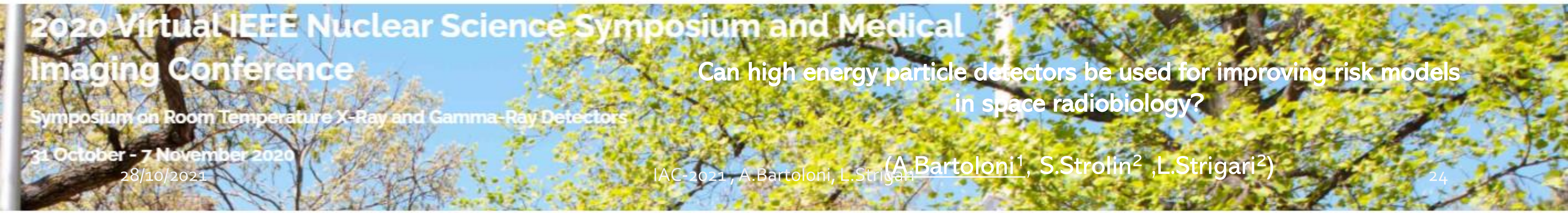
alessandro.bartoloni@roma1.infn.it

POST-DOC open position in Roma-Sapienza !

Backup slides

Radiation health hazard assessment in exploratory space missions





DAMPE

Table 1: Summary of the design parameters and expected performance of DAMPE instru

Parameter	Value
Energy range of γ-rays/electrons	5 GeV−10 TeV
Energy resolution[a] of γ-rays/electrons	$\leq$ 1.5% at 800 GeV
Energy range of protons/heavy nuclei	50 GeV−100 TeV
Energy resolution[a] of protons	$\leq$ 40% at 800 GeV
Effective area at normal incidence (γ-rays)	1100 cm^2 at 100 GeV
Geometric factor for electrons	0.3 m^2 sr above 30 GeV
Photon angular resolution[b]	$\leq 0.2^\circ$ at 100 GeV
Field of View (FoV)	~1.0 sr

Notes: [a]σ_E/E assuming Gaussian distribution of energies. [b]The 68% con ment radius.

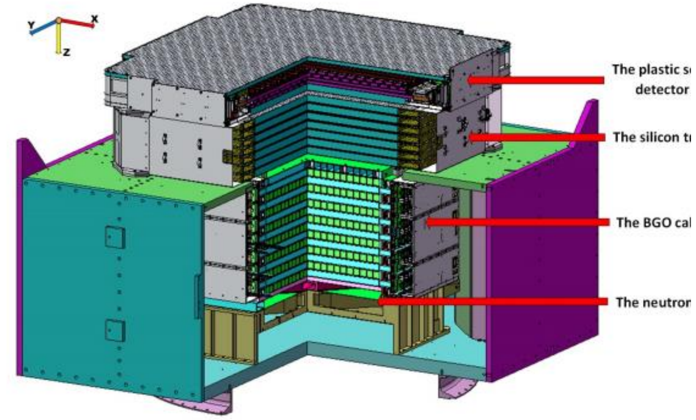


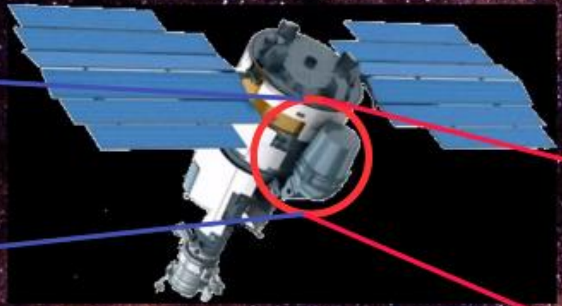
Figure 1: Schematic view of the DAMPE detector.

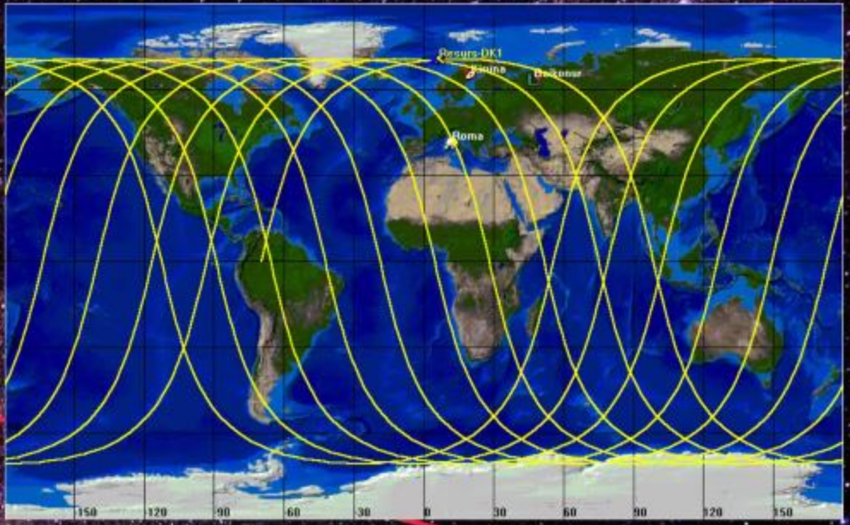
DAMPE: The Dark Matter Particle Explorer is a satellite-based space mission whose main purpose is the detection of cosmic electrons and photons up to energies of 10 TeV. The DAMPE instruments have also the capability to measure the fluxes and the elemental composition of the galactic cosmic rays nuclei up to 100 TeV. It is in data taking since 2015 and consists of: a double layer of Plastic Scintillator Detector; a Silicon-tungsten Tracker-converter; an electromagnetic calorimeter and a Neutron Detector. In the first's years of operations DAMPE has collected and send to the earth more than 6 billion of cosmic ray events.

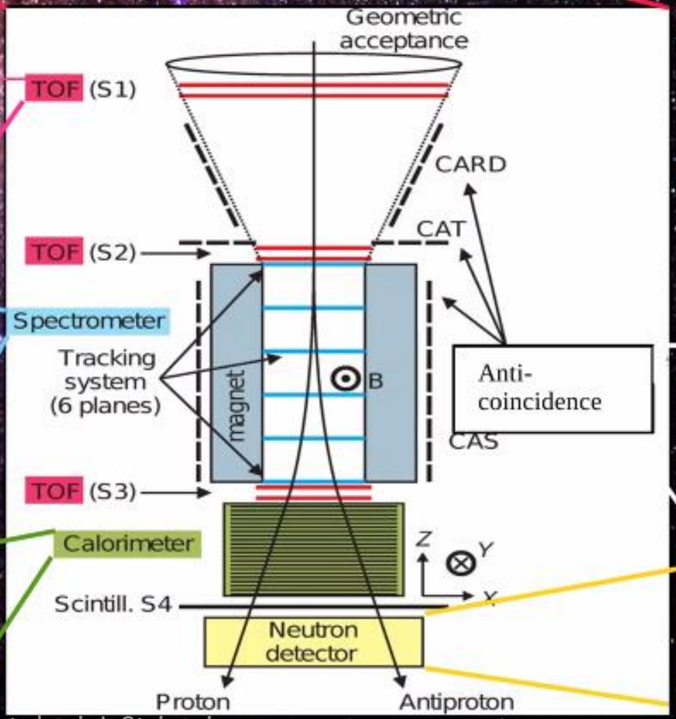
PAMELA

1 AU from the Sun July 2006 – March 2016

Quasi polar orbit, 350/600 km, lowest geomagnetic cutoff ~ tens of MeV.







24 bars of plastic scintillator disposed on six plane, S11, S12, S21, S22, S31, S32: velocity, absolute charge Z<8.

Six plane of double side microstrip silicon detector inside a magnetic cavity: rigidity, absolute charge Z<6, charge sign.

44 planes of Si detector interleaved with 22 tungsten planes, 16.3 radiation length: hadron lepton separation.

GF: 21.5 cm2 sr
Mass: 470 kg
Size: 130x70x70 cm
Power budget: 360 W

(CAS, CARD e CAT) nine plane of plastic scintillator around the apparatus: reject false trigger or multi-particle events.

36 proportional counter filled with 3He: improve hadron rejection.

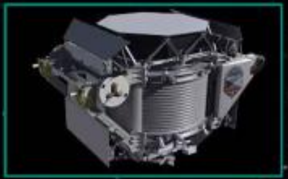
Galactic Cosmic Rays long-term modulation measurements

PAMELA

July 2006 – March 2016
Time of Flight + Magnetic spectrometer + Calorimeter
50 MeV – 1 TeV
e^+, e^-, p, He, He3, He4, D, H

Voyager I,II

1977 – Today
Solid state detectors, dE/dx vs E
1 MeV – 500 MeV
e^++e^-, p, Z~<20

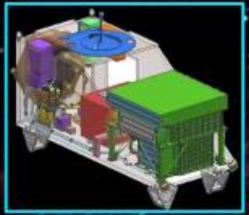


AMS-02

May 2011 – Today
Time of Flight + Magnetic spectrometer + Calorimeter + TRD + Cherenkov
500 MeV – 3 TeV
e^+, e^-, p, $\overline{p}$, He, He3, He4, D, C, O

ACE/CRIS

1997 – Today
Solid state detectors, dE/dx vs E
50 MeV – 500 MeV
Z < 30



CALET

August 2015 – Today
Charge detector + Calorimeter
1 GeV – 10 TeV
e^++e^-, p

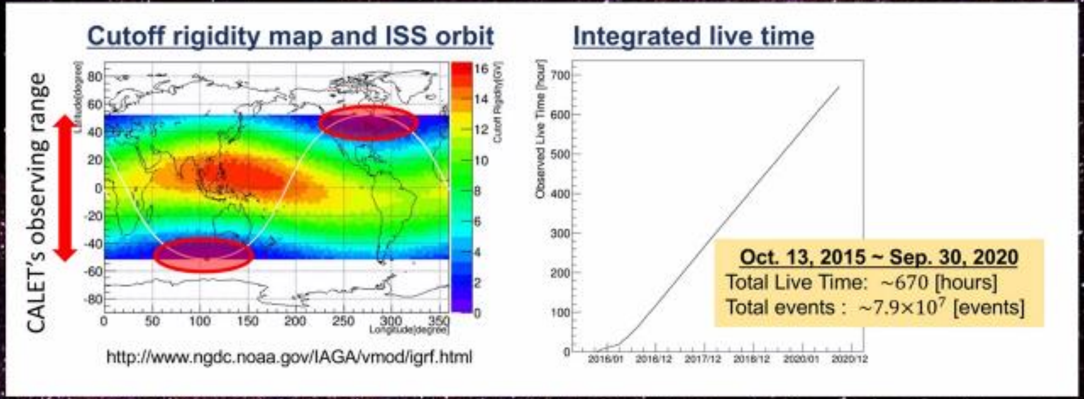
HEPD

February 2018– Today
Solid state detectors, dE/dx vs E
40 MeV – 300 MeV
p

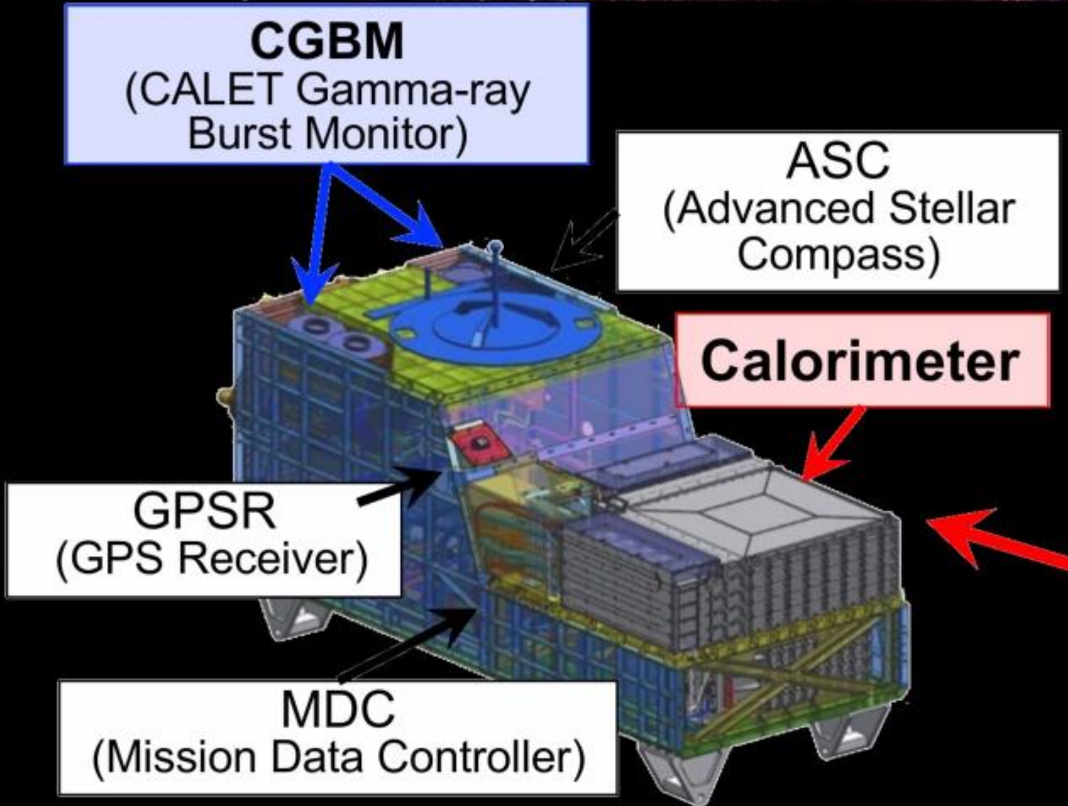
CALET

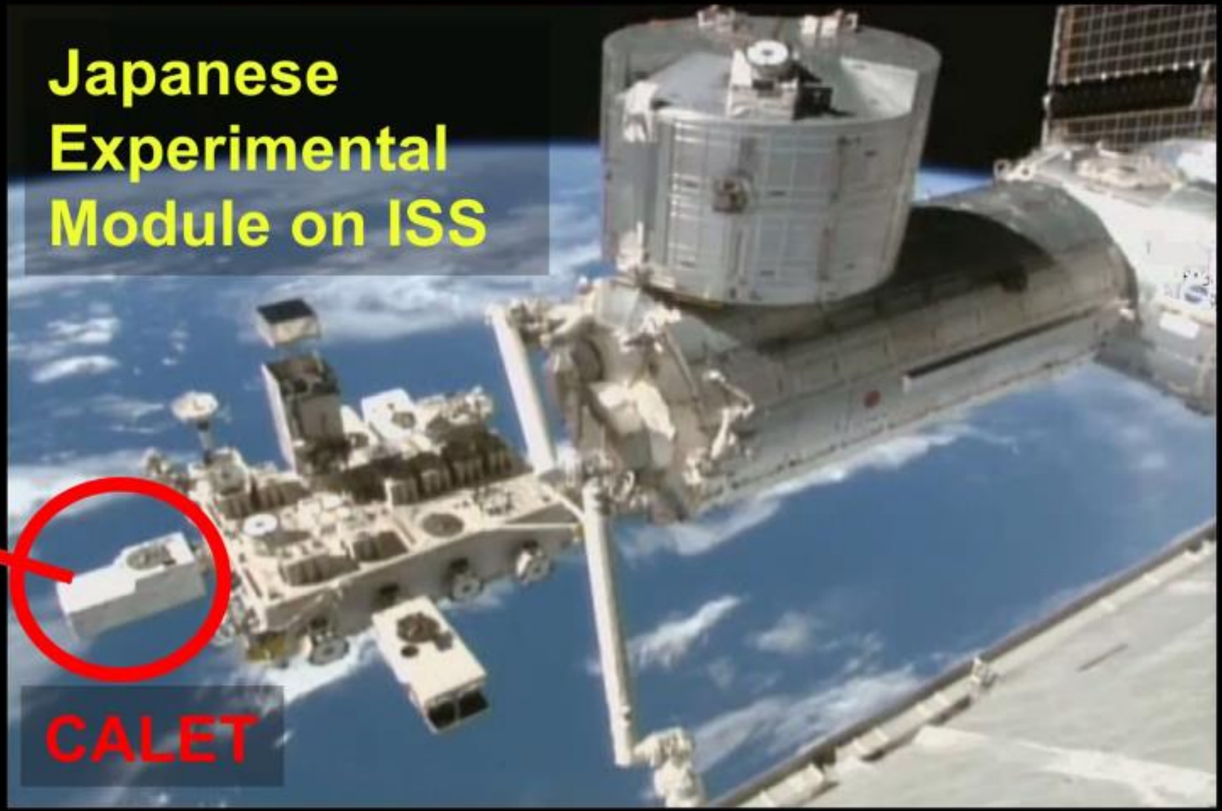
1 AU from the Sun 2015– Today

Low energy electron trigger (1GeV ~ 10GeV) is applied only at high latitude, cutoff rigidity < 5.0GV. In 1 cycle (~90 min.), LEE works 2 times for 90 sec.



Electron (e-+ e+): 1GeV –20 TeV
p--Fe: 10 GeV –1000 TeV

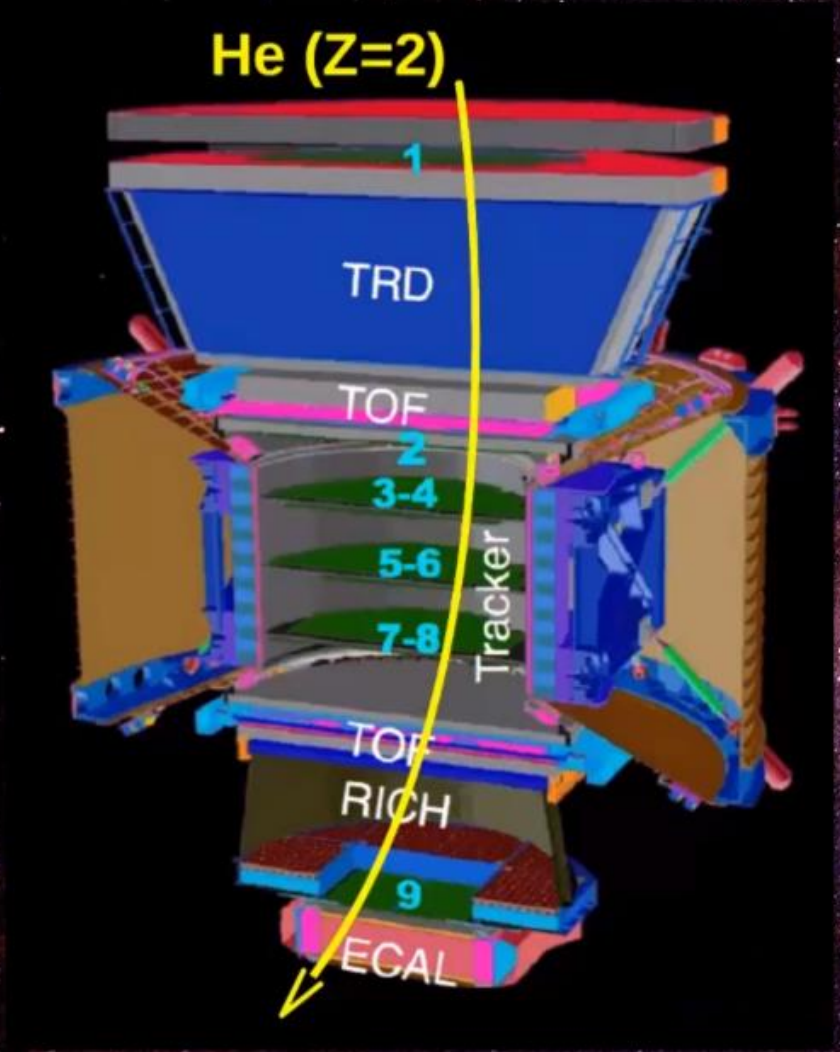


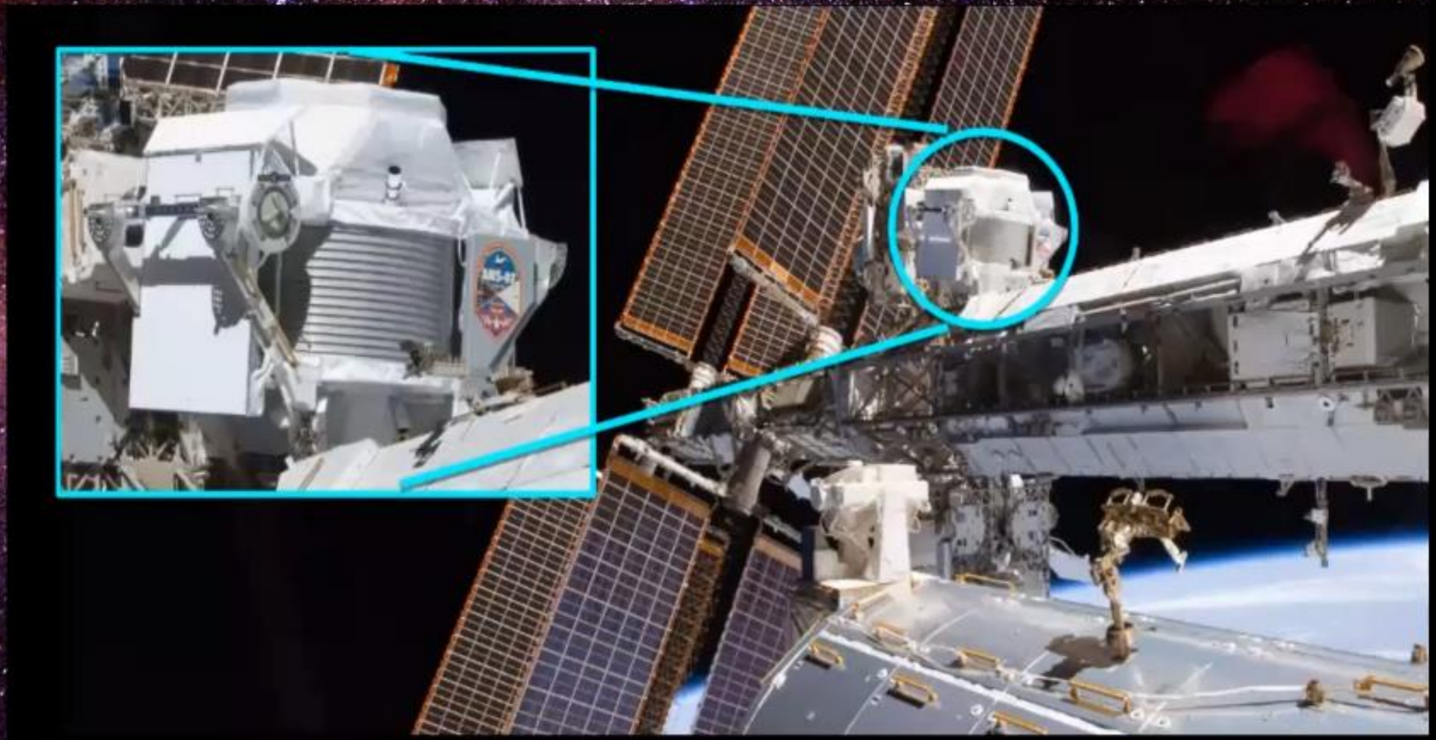


AMS02

Geometrical factor: ~ 550 cm2 sr
Mass: 4 tons

Transition radiation Detector: e+ e- identification
Silicon Tracker: Rigidity+Charge+sign
Time of Flight: Trigger+Velocity+Charge+Flight direction
RICH: Velocity+Charge
Calorimeter: e+ e- identification• e+ e- Energy

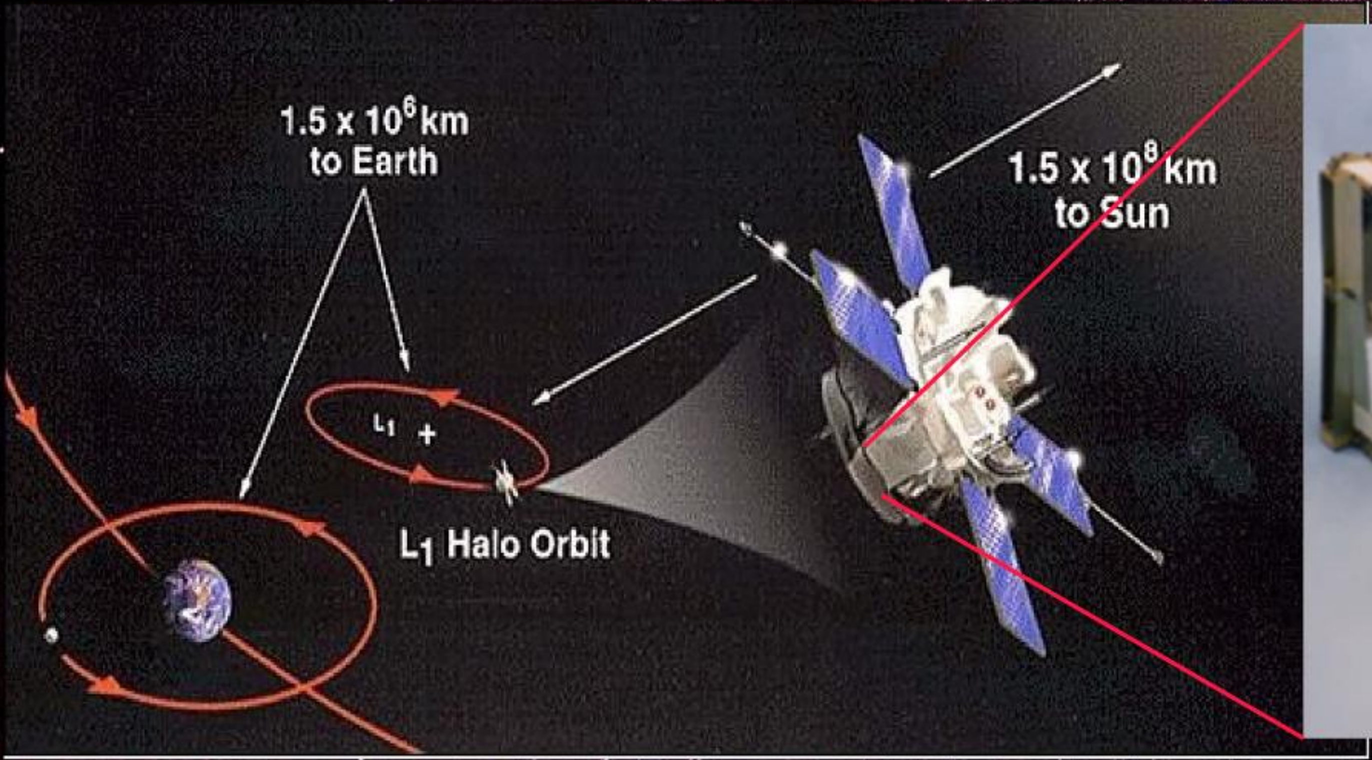


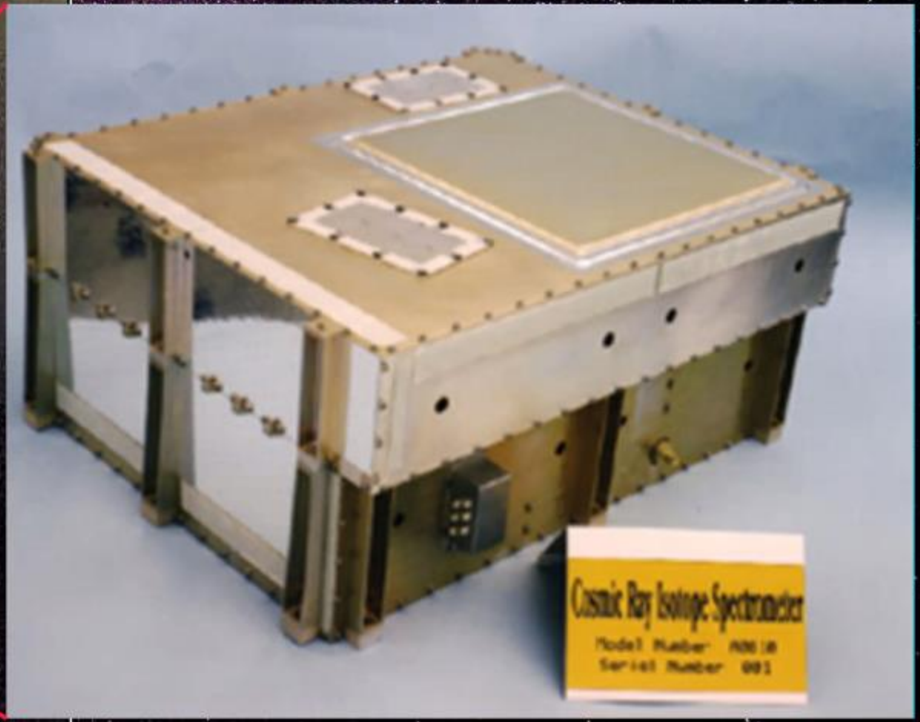


CRIS/ACE

Energy measurement: 4 stacks of thick silicon detectors, 50 – 500 MeV, Z<30
Particle trajectory: Scintillating Optical Fiber Trajectory (SOFT) system

Geometrical factor: ~ 250 cm2 sr



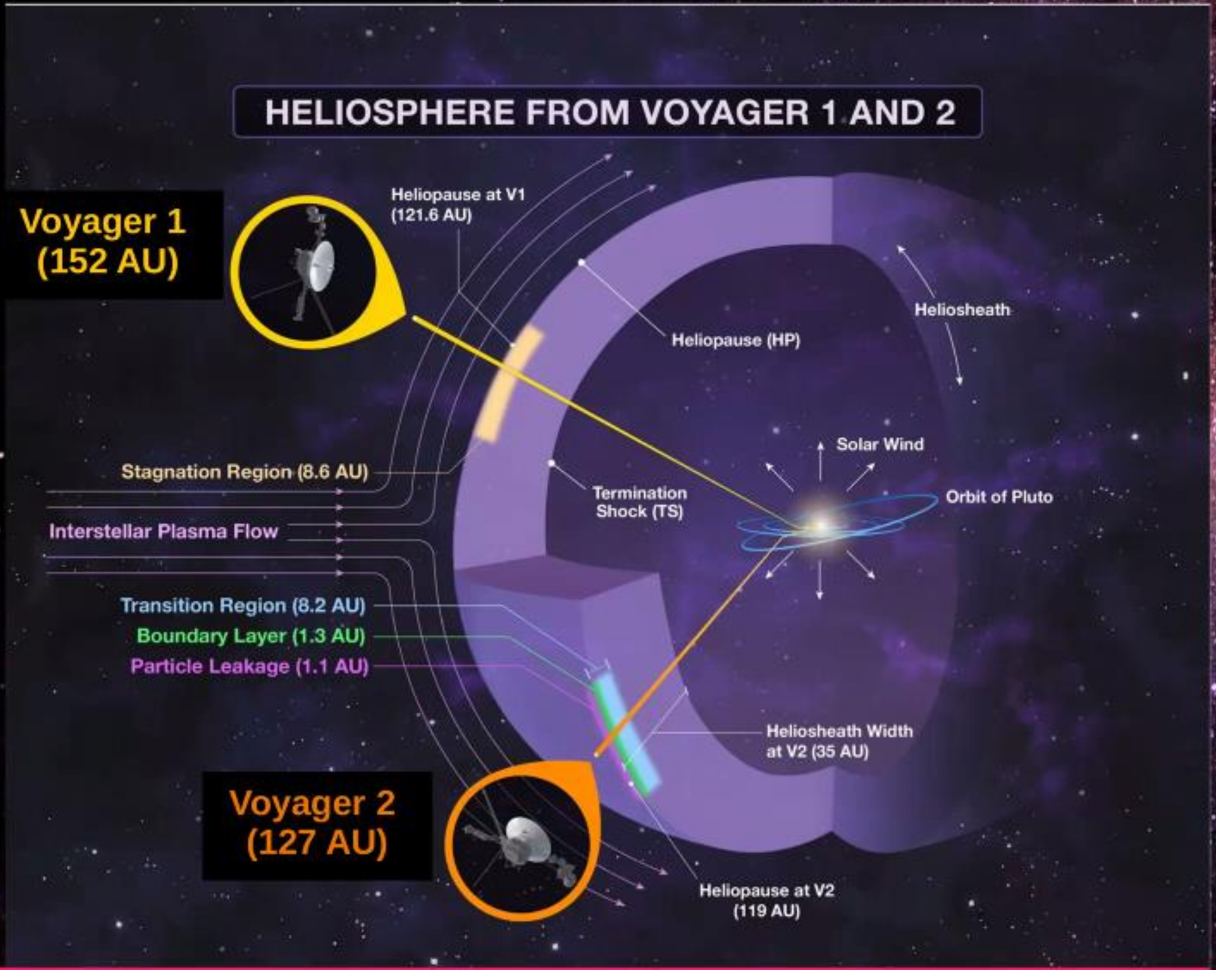


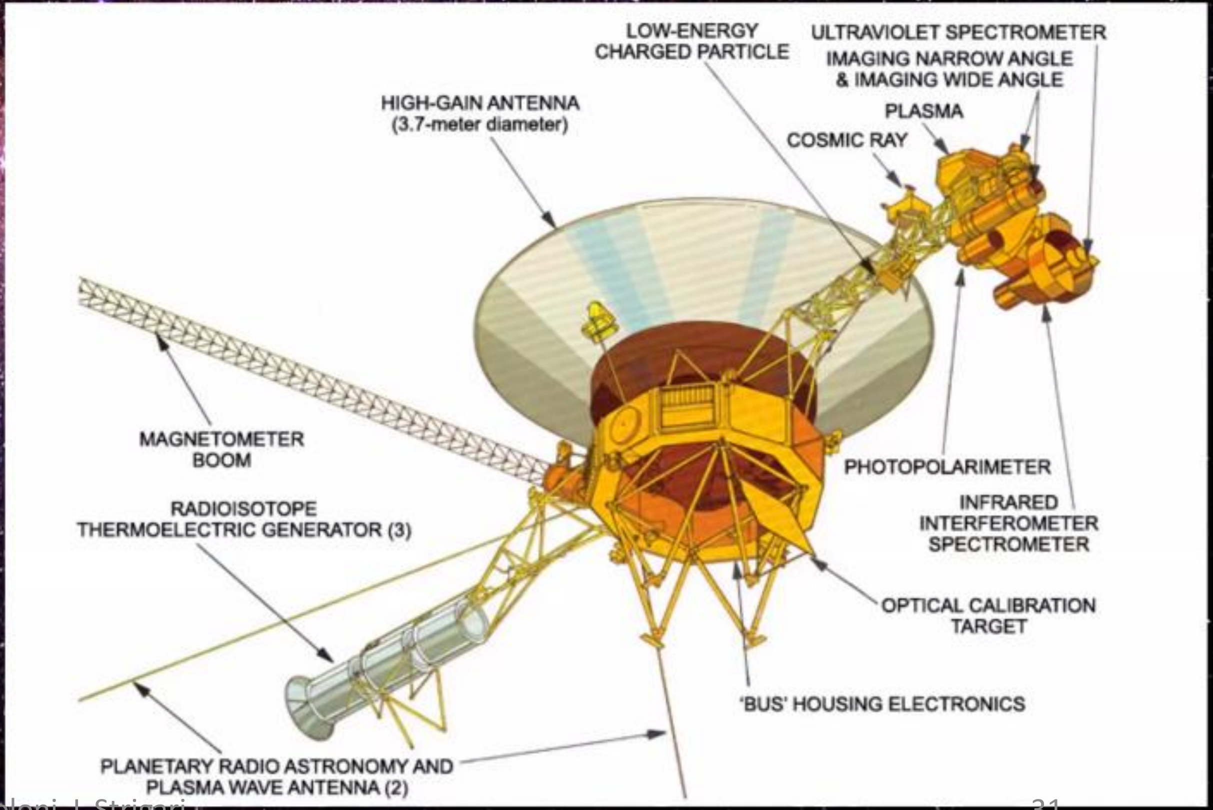
Voyager I

1 - 147 AU from the Sun 1977– Today

Geometrical factor: ~ 0.48 to 8 cm2 sr
Mass: 800 kg
Power budget: 470 Watts

Two high energy Telescopes (HET) :	solid state
Four Low Energy Telescopes (LET):	1-500 MeV/n
The Electron Telescope (TET) :	solid state, 3 – 110 MeV



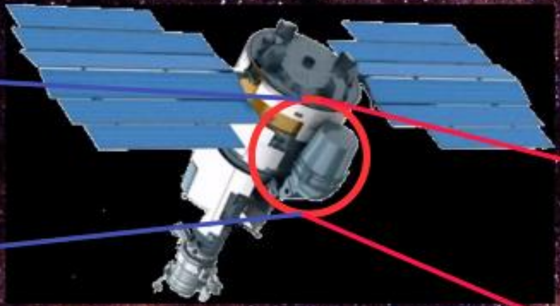


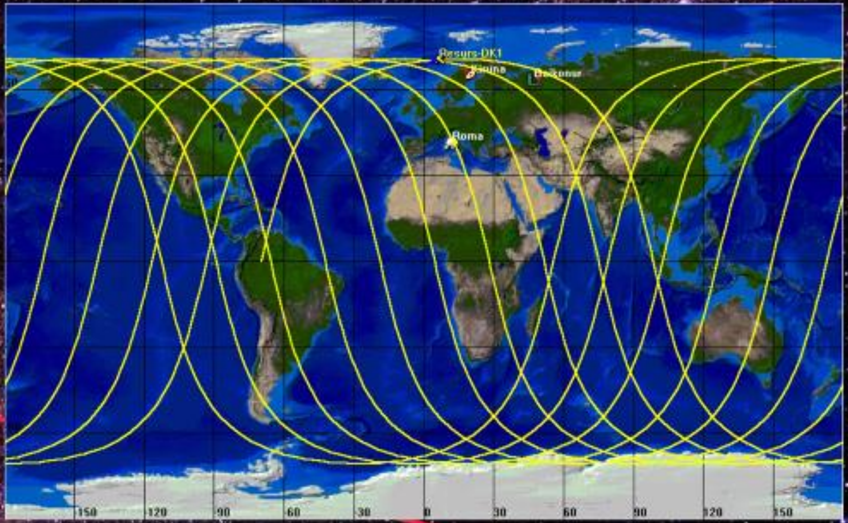
Engineers expect the spacecraft to continue operating at least one science instrument until around 2025

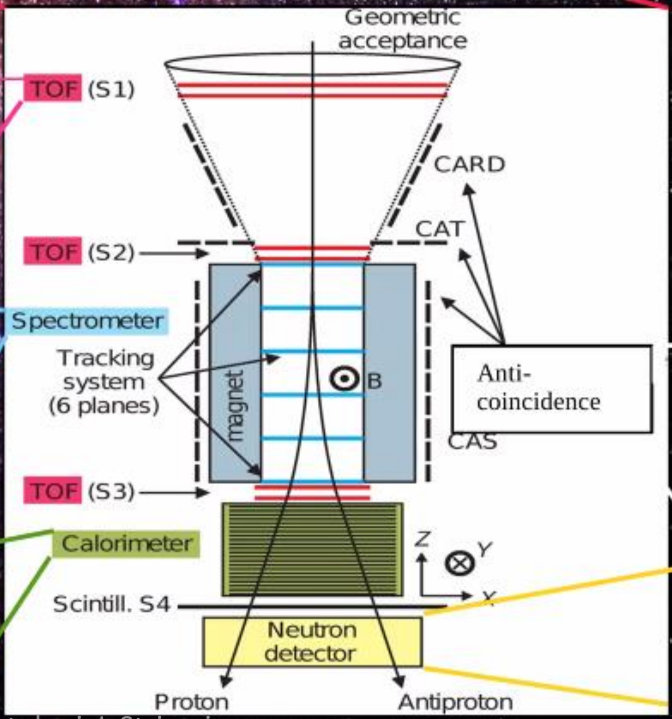
PAMELA

1 AU from the Sun   July 2006 – March 2016

Quasi polar orbit, 350/600 km, lowest geomagnetic cutoff ~ tens of MeV.







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Size: 130x70x70 cm
Power budget: 360 W

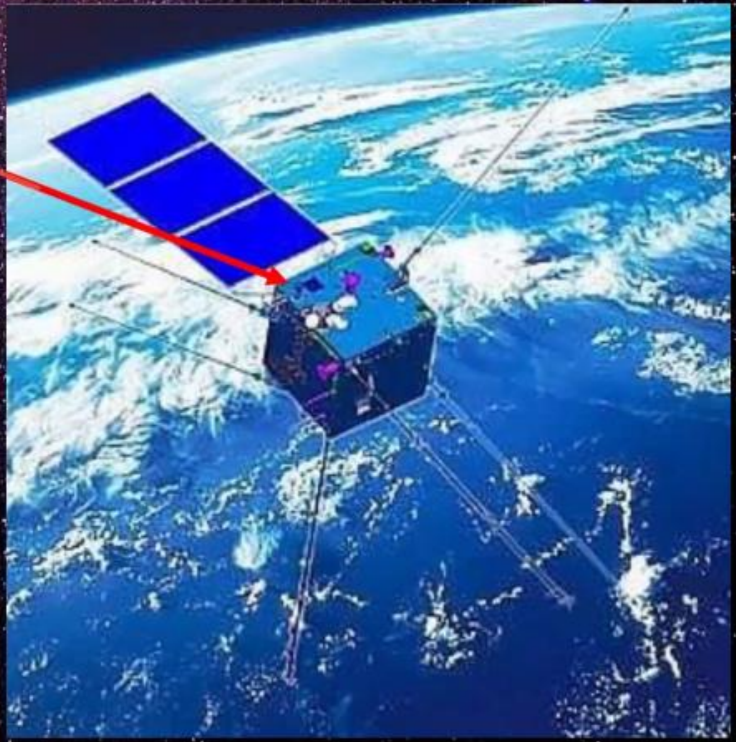
(CAS, CARD e CAT) nine plane of plastic scintillator around the apparatus: reject false trigger or multi-particle events.

36 proportional counter filled with 3He: improve hadron rejection.

CSES/HEPD

Geometrical factor: ~ 400 cm2 sr
Mass: 44 kg

TRACKER: double-sided Si microstrip
TRIGGER: 1 layer of plastic scintillator
CALORIMETER: plastic scintillatori + crystal (LYSO)
Proton 30 – 200 MeV, electron 3-100 MeV



CALET

CALET: The CALorimetric Electron Telescope is in operation since 2015 on the external platform of the Japanese experimental module (KIBO/JEM) by the ISS.

The instrument is optimized to precisely study the properties of extreme energy cosmic electrons up to dozens of TeV. It is also capable of measuring the relative composition and abundance of nuclei coming from space, from protons to the heaviest elements up to Z=40. In the first three years of operation CALET has collected and send to the earth more than 1.8 billion of cosmic rays events [10].

ISS-CREAM

ISS-CREAM: The Cosmic Ray Energetic and Mass for the International Space Station was successfully installed and activated on the Japanese Experiment Module Exposed Facility as an attached payload on 2017. The instrument is configured with complementary particle detectors capable of measuring elemental spectra for Z=1 up to Z=26 nuclei in the energy range from 1 up to 1000 TeV; as well as electrons at multi-TeV energies. [11]

ACE

ACE: The Advanced Composition Explorer is a satellite-based space mission that started its operation on 1998 with the aim to observe particles of solar, interplanetary, interstellar, and galactic origins, spanning the energy range from solar wind ions to galactic cosmic ray nuclei. It is located at the L1 Lagrange point, about 1.4 million kilometre from the Earth. Thanks to the multiple instruments on board ACE can measure particle and nuclei elements up to Z=30 in an energy range up to hundreds of MeV. The end of its operation is forecast not before the 2024.[12]

PAMELA

Another important satellite based cosmic ray observatory is the Payload for Antimatter Matter Exploration and Light-nuclei Astrophysics (*PAMELA)* that starting its data taking in 2006 and ends its operations in 2016, producing in this period accuracy measurements of the cosmic ray components (particle and light nuclei up to Z=6) [14]