Dose Effects Models for Lunar Space Missions Risk Assessment

Alessandro Bartoloni

Istituto Nazionale di Fisica Nucleare (INFN) Sezione di Roma 1, Roma, Italy

&

CERN

Who I am

After the MD in Electronics Engineering, I join the **Italian Institute of Nuclear Physics (INFN)** in 1992 working in the Rome division on the development of supercomputers for theoretical physics numerical simulations.

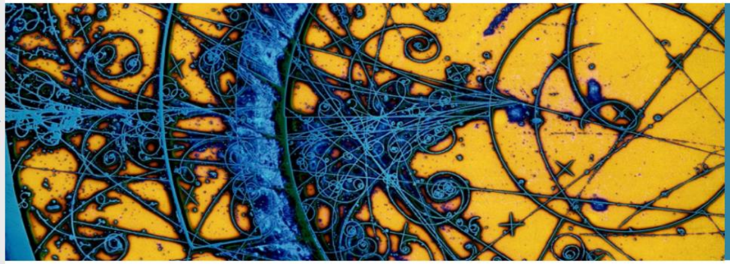
Later as User Associate at European Organization for Nuclear Research **(CERN)** I participated to the construction of the **CMS** detector that in 2012 was one of the experiments that observed a new particle consistent with the predicted **Higgs boson**. .

For several years (1999-2011) I was a **Lecturer** at **the Faculty of Engineering at Sapienza University of Rome** responsible of courses on computer science subject

Since 2000 I am in the **Alpha Magnetic Spectrometer collaboration (AMS)** (http://ams02.space).

AMS02 is a state-of-the-art particle physics detector designed to operate as an external module on the International Space Station.

My actual principal fields of interest are Cosmic Rays' Physics, Space Radiation Science.



INFN

Istituto Nazionale di Fisica Nucleare

The Italian National Institute for Nuclear Physics

INFN has a long and prestigious tradition that started in **1951** with Enrico Fermi and his school

"I Ragazzi di Via Panisperna"

INFN FACILITIES (2022)

An International DNA.

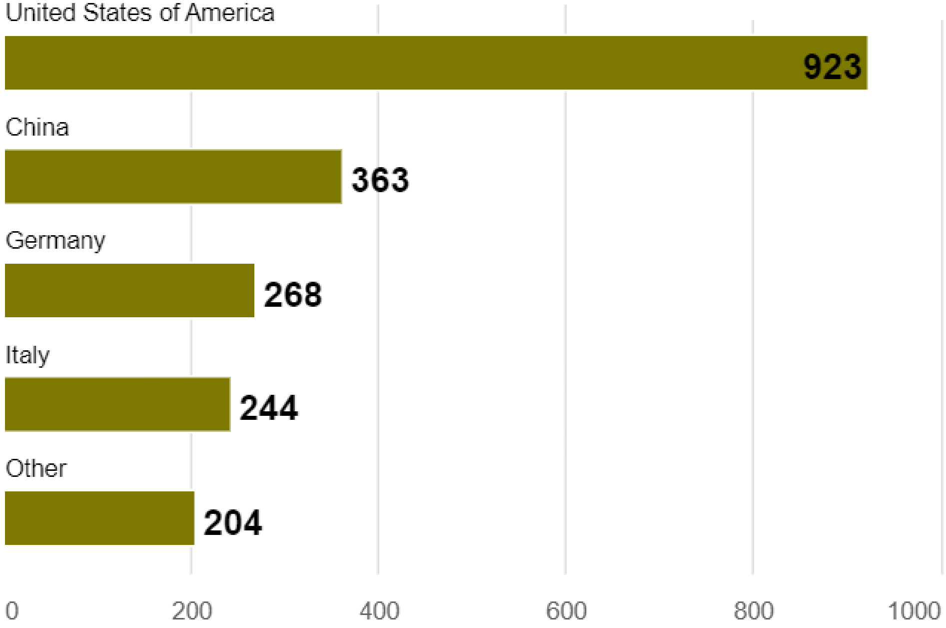
Dose-Effects Models for Space Radiobiology: An Overview on Dose-Effect Relationships

Publication Impact (November 2022)

Loop | Publication Impact | Dose-Effects Models for Space Radiobiology: An Overview on Dose-Effect Relationships (frontiersin.org)

Frontiers in Public Health
Published on 08 Nov 2021

3,113
TOTAL VIEWS



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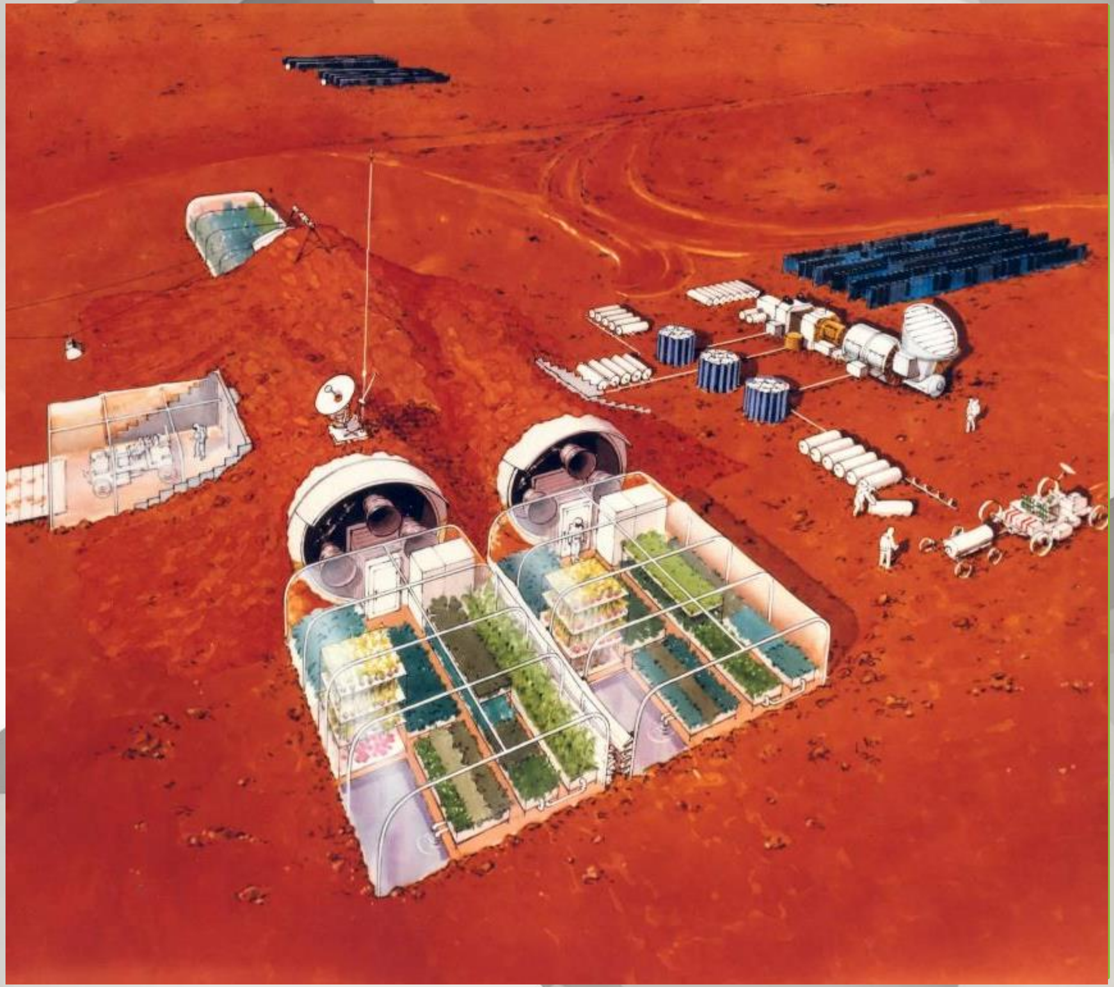


Outline

- AMS INFN Roma Sapienza Research Group
- Moon Space Radiation Environment
- Dose Effects Relationship Overview
  - The PubMed Search
  - Carcinogenesis Risk
  - Improvements and Conclusion
- Appendices
  - Central Nervous System Risk
  - Cosmic Ray Detectors in Space
  - A research topic collection initiative

INTRODUCTION

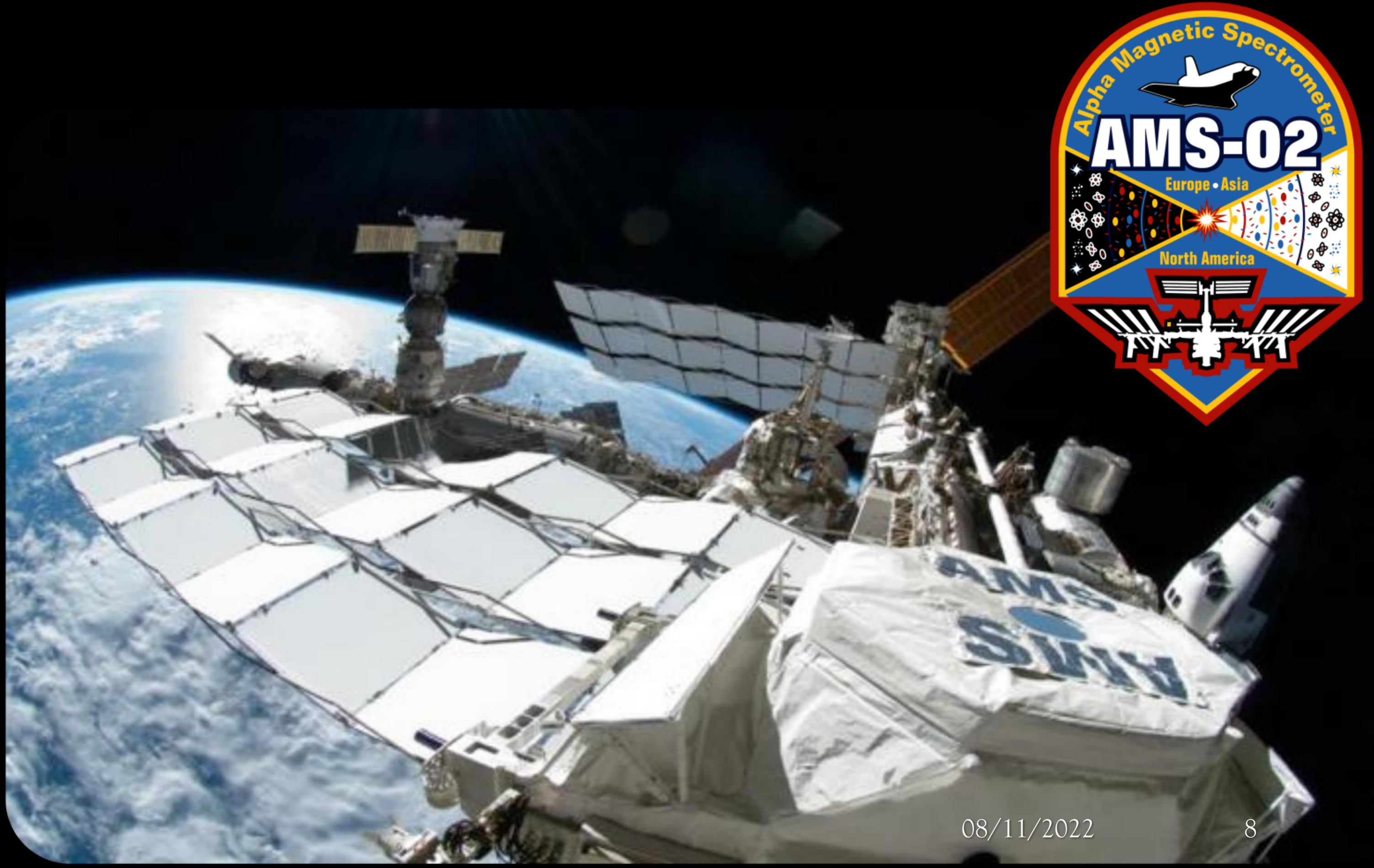
Alpha Magnetic Spectrometer (AMS)

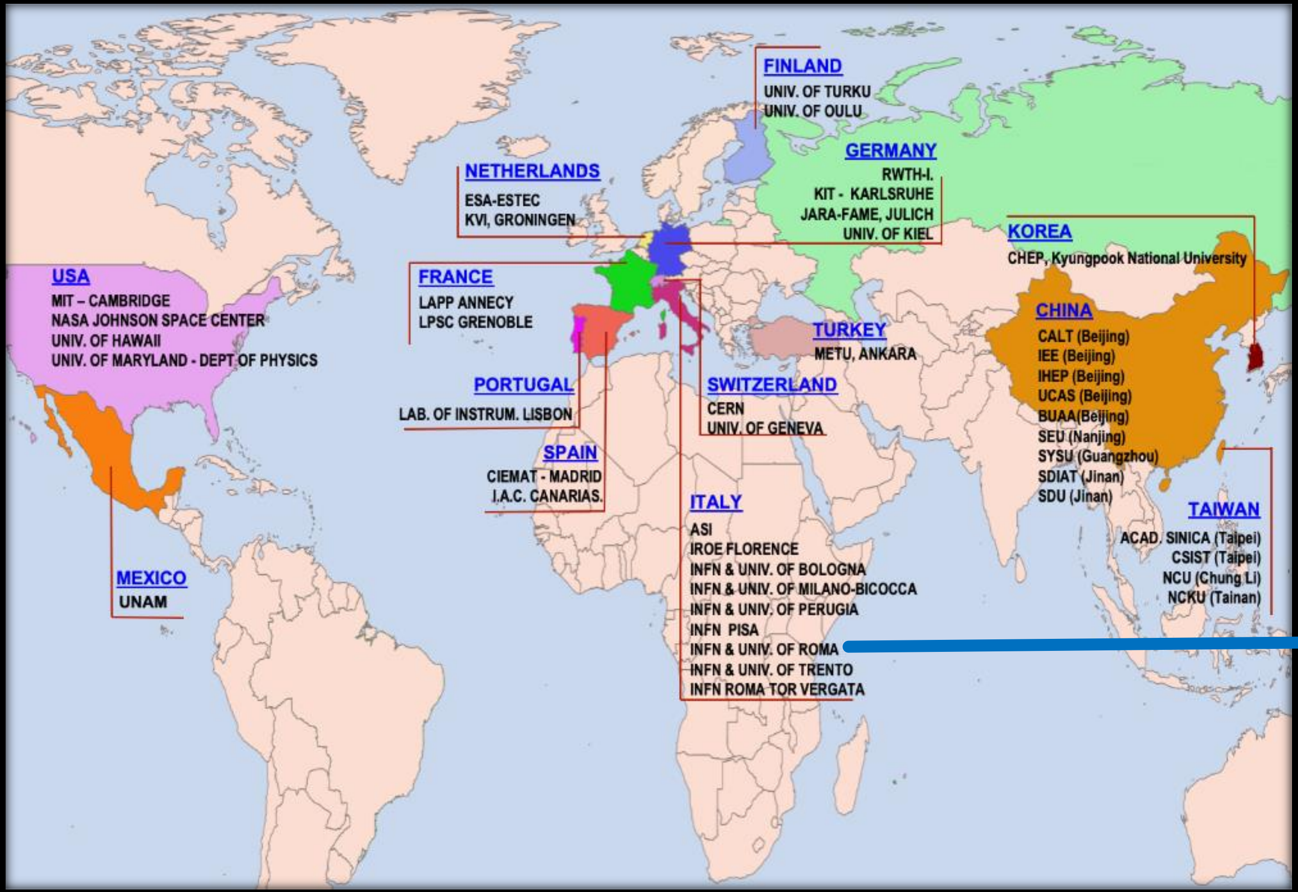
INFN ROMA SAPIENZA RESEARCH GROUP

The AMS SPRB collaboration was created in 2017 by the synergy of the AMS INFN Roma Sapienza (Italy) group leaded by Alessandro Bartoloni with the medical physics research group leaded by Lidia Strigari currently at IRCCS university Hospital of Bologna (Italy)

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

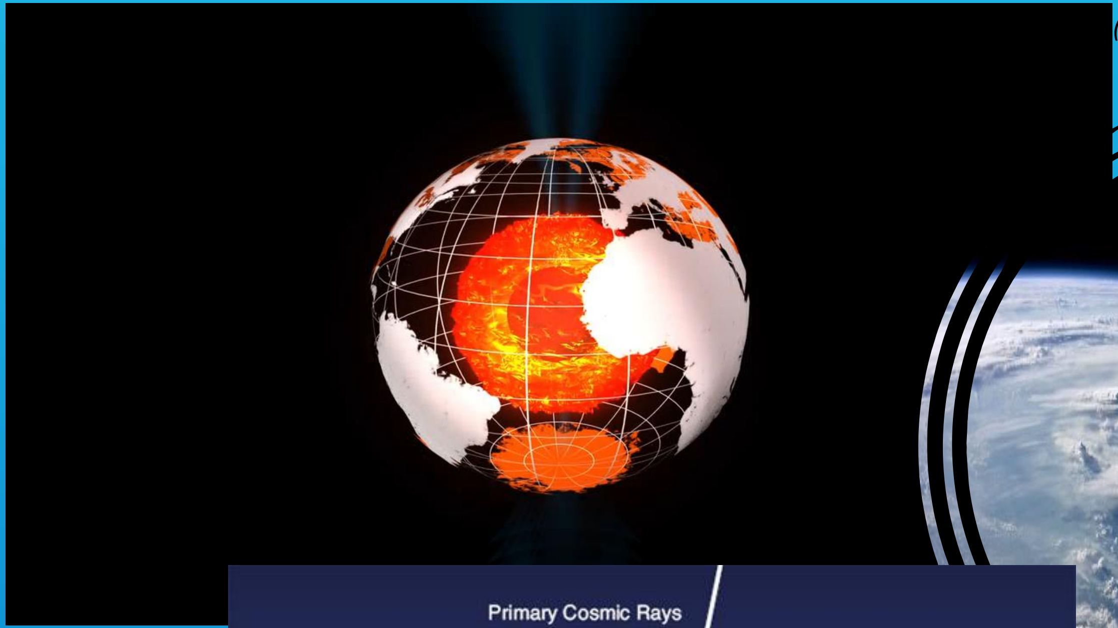
The AMS02 detector has collected so far more than 200 billion Cosmic Rays events.

More Info in the AMS-02 webpage:

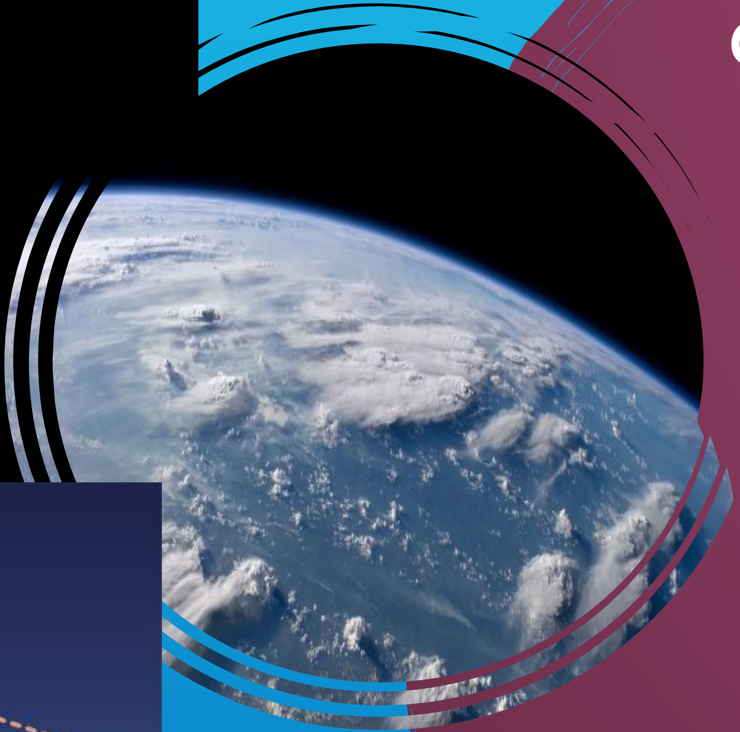
https://ams02.space

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)

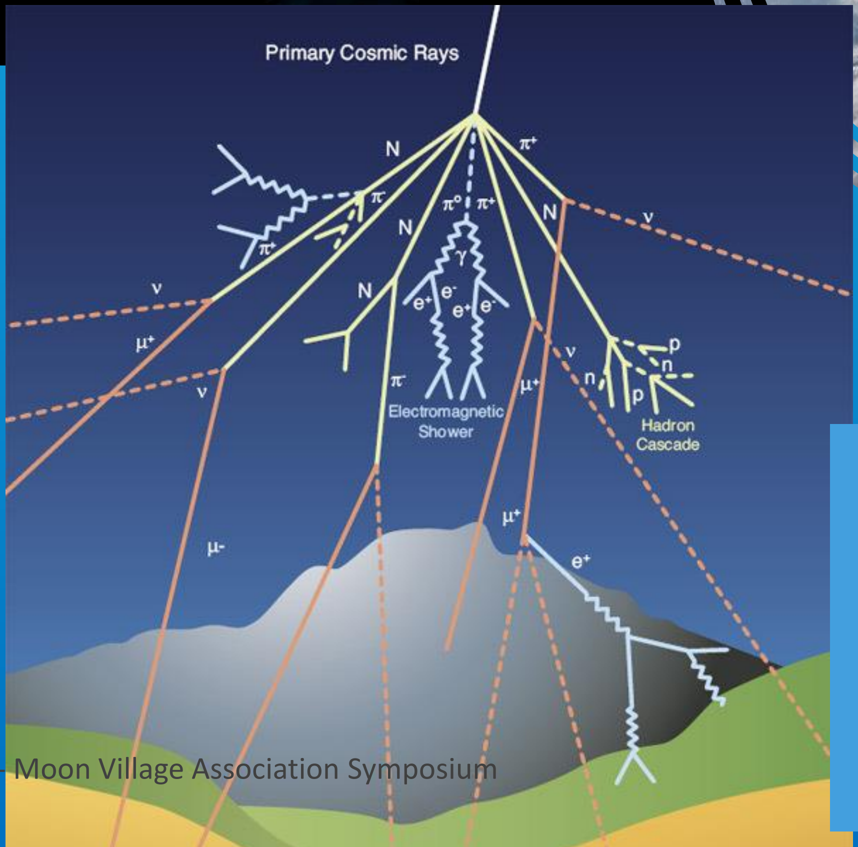


Cosmic Rays Interactions with the geo-magnetosphere

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,..)

Origin of Space Radiation and Consequent Risk

Three main components
None is constant in time

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

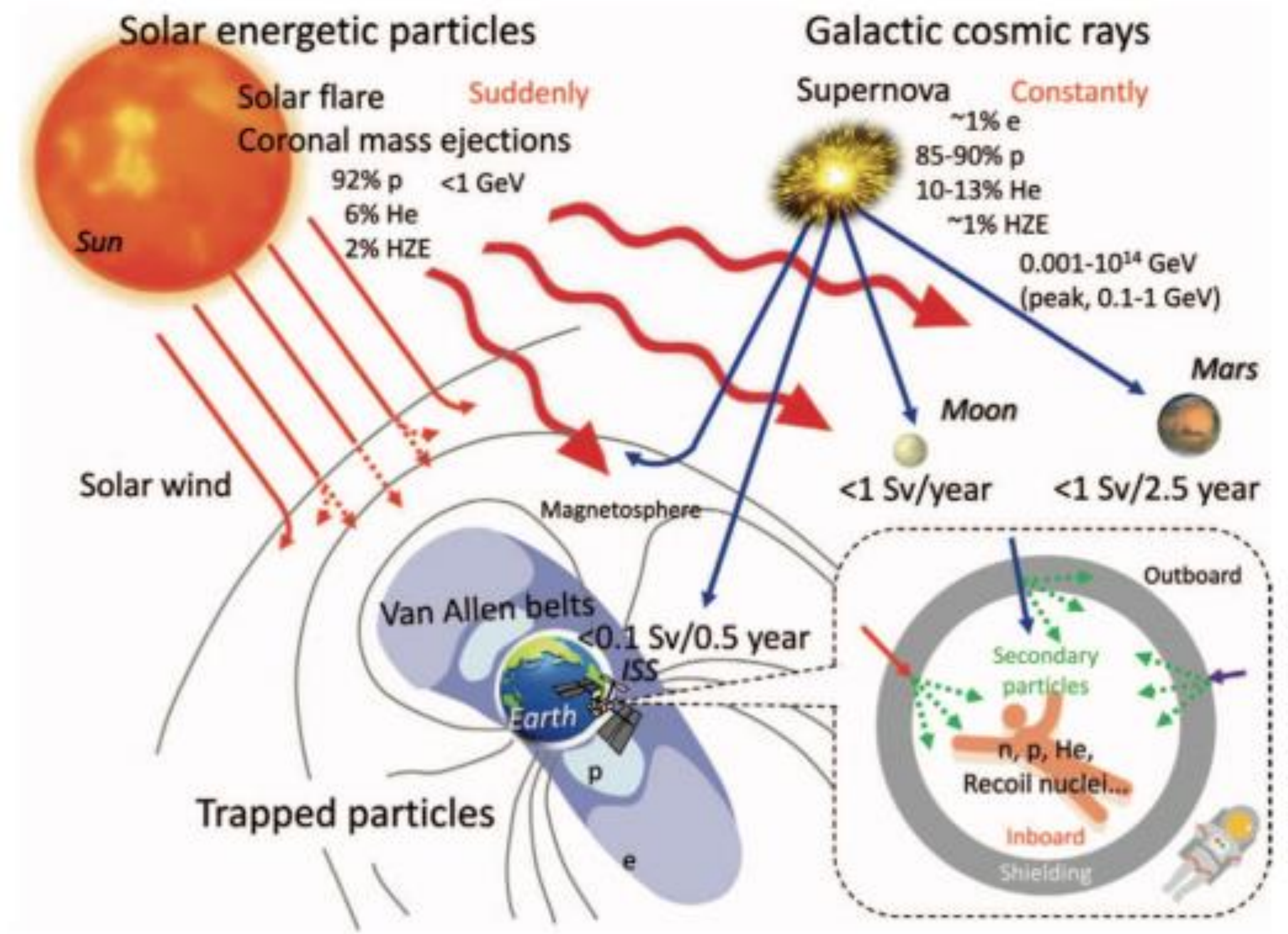


Image courtesy of European Space Agency (ESA)

The manned spaceflight especially Beyond the Low Earth Orbit (BLEO) could represent a concern for the health of astronauts.

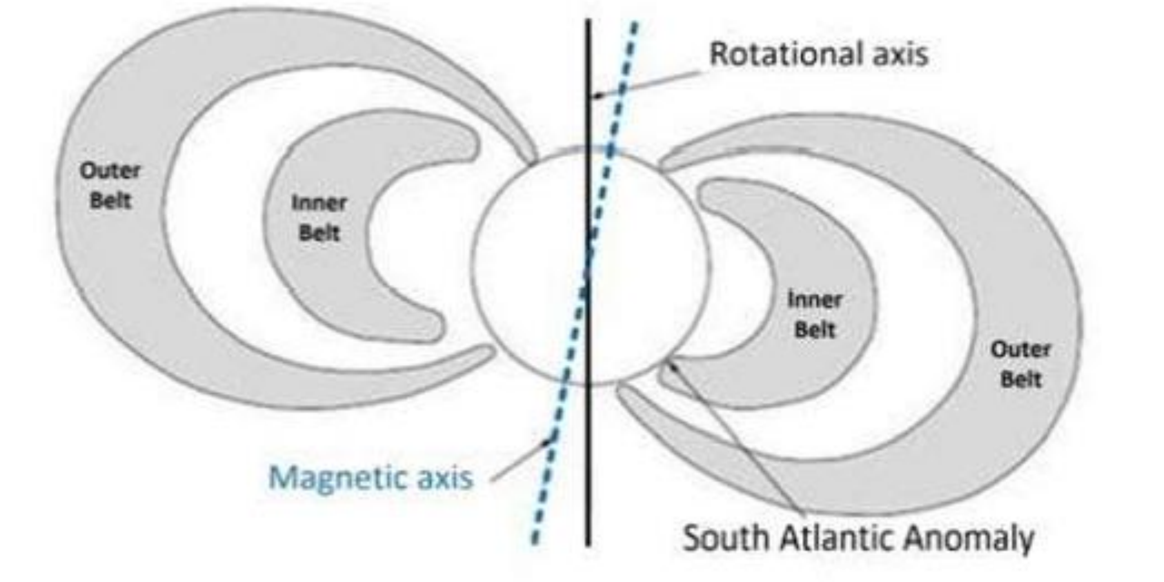
Images Courtesy of NASA

Travelling to the Moon to Stay

Apollo 11 data reports from dosimetry 1.8 mGy that the are optimistically equal to 1.8 mSv (Sievert indicates the biological effects).

Less that the annual dose expected on the Earth (2.-4.5 mSv)

Flight Path



Radiation Quality

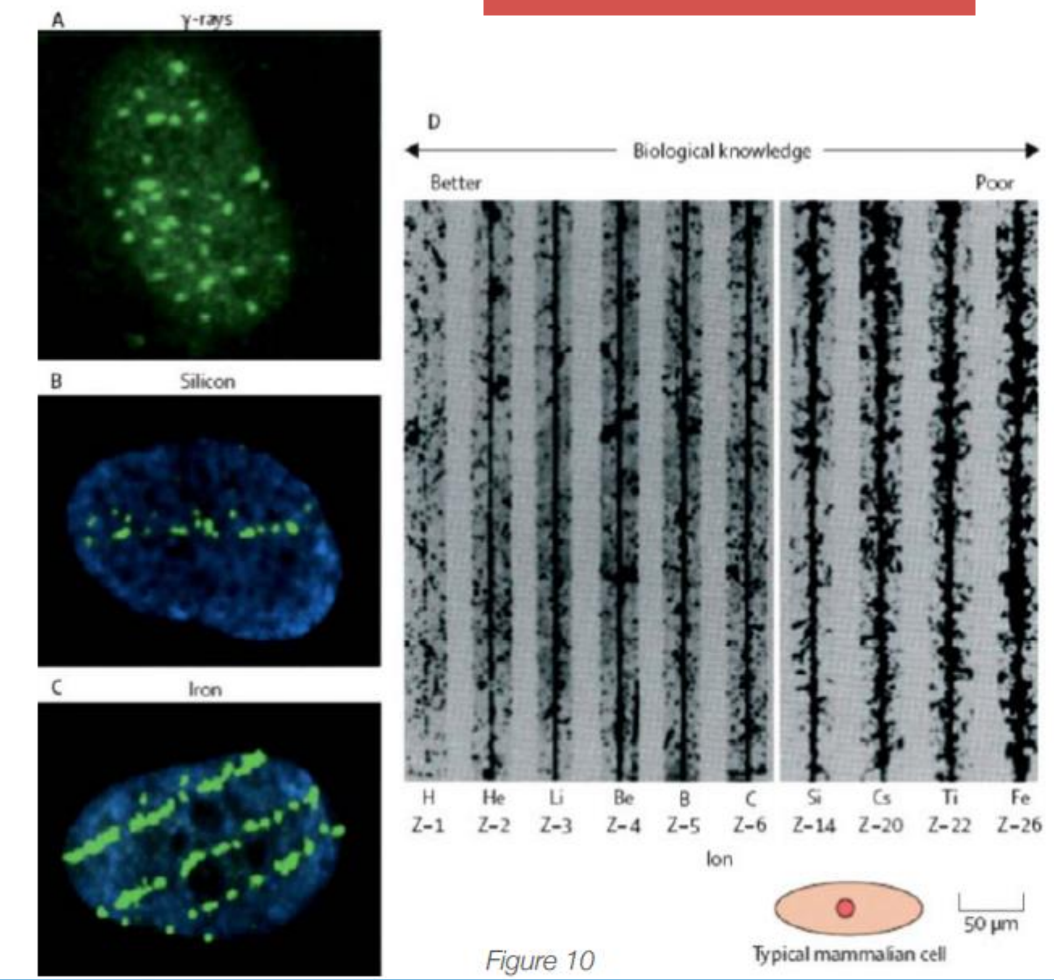


Figure 10

Travelling through the VAB (Worst Case Flight Path)

Radiation Analysis for Moon and Mars Missions

Andreas Märki

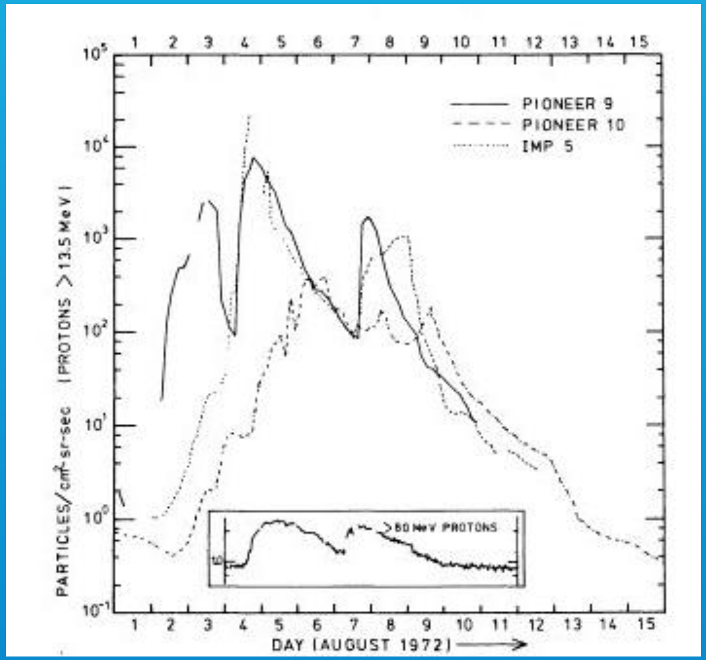
Märki Analytics for Space, Erlenbach ZH, Switzerland

Table 2. *Determination of the Radiation Dose for 4mm Al Shielding through the VAB.*

	Zone	Time in Zone	Dose Calculation	Dose
Path to the Moon	1E3 … 1E4 p^+	400s ≈ 7min	400s * (1/300)*465mSv/h	>0.2 mSv
	1E4 … 1E5 e^-	≈0s	≈0 mSv	≈0 mSv
	1E5 … 1E6 e^-	800s ≈ 13min	800s * (1/30)*355mSv/h	>2.6 mSv
	>(≈) 1E6 e^-	700s ≈ 12min	700s * (1/3)*355mSv/h	>(≈) 23.0 mSv
	1E6 … 1E5 e^-	2700s=45min	2700s * (1/30)*355mSv/h	>8.9 mSv
	1E5 … 1E4 e^-	1383s ≈ 23min	1383s * (1/300)*355mSv/h	>0.5 mSv
Total Outward				>35.2 mSv
Return Path	1E4 … 1E5 e^-	1500s=25min	1500s * (1/300)*355mSv/h	>0.5 mSv
	1E5 … 1E6 e^-	1200s=20min	1200s * (1/30)*355mSv/h	>3.9 mSv
	1E5 … 1E4 e^-	≈0s	≈0 mSv	≈0 mSv
Total Return				>4.4 mSv
Total Resulting Dose				>39.6 mSv >39.6 mGy
Apollo 11 Mission Dose				1.8 mGy

This analysis reports more than 70 mSv from VABProtons and Electrons using a 4mm Aluminum shields

The 4 August 1972 Solar Flare



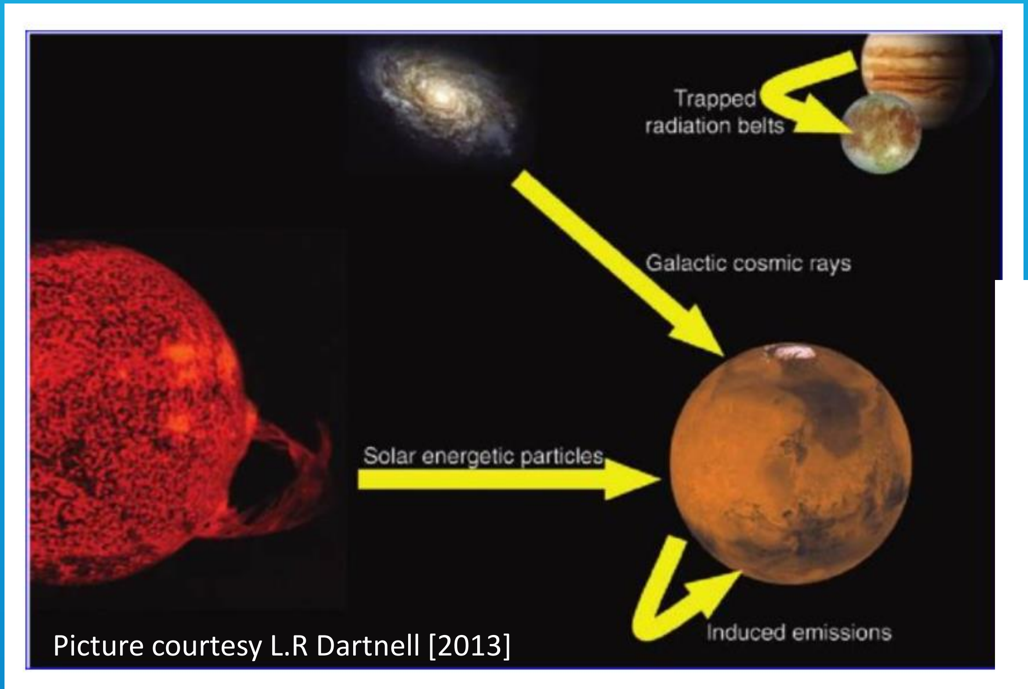
August 1972

April 1972

Sun Activities

December 1972

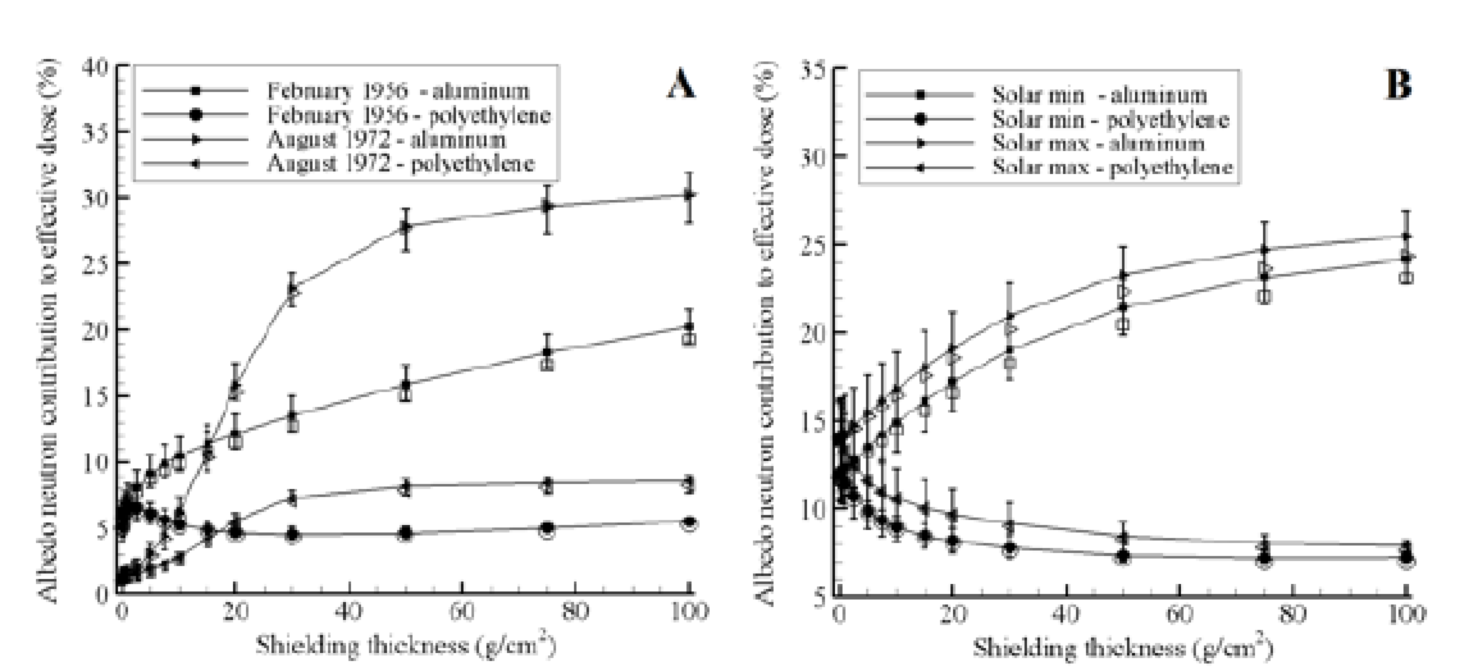
GCR and SEP interaction with the lunar surface



Picture courtesy L.R Dartnell [2013]

Albedo Radiation

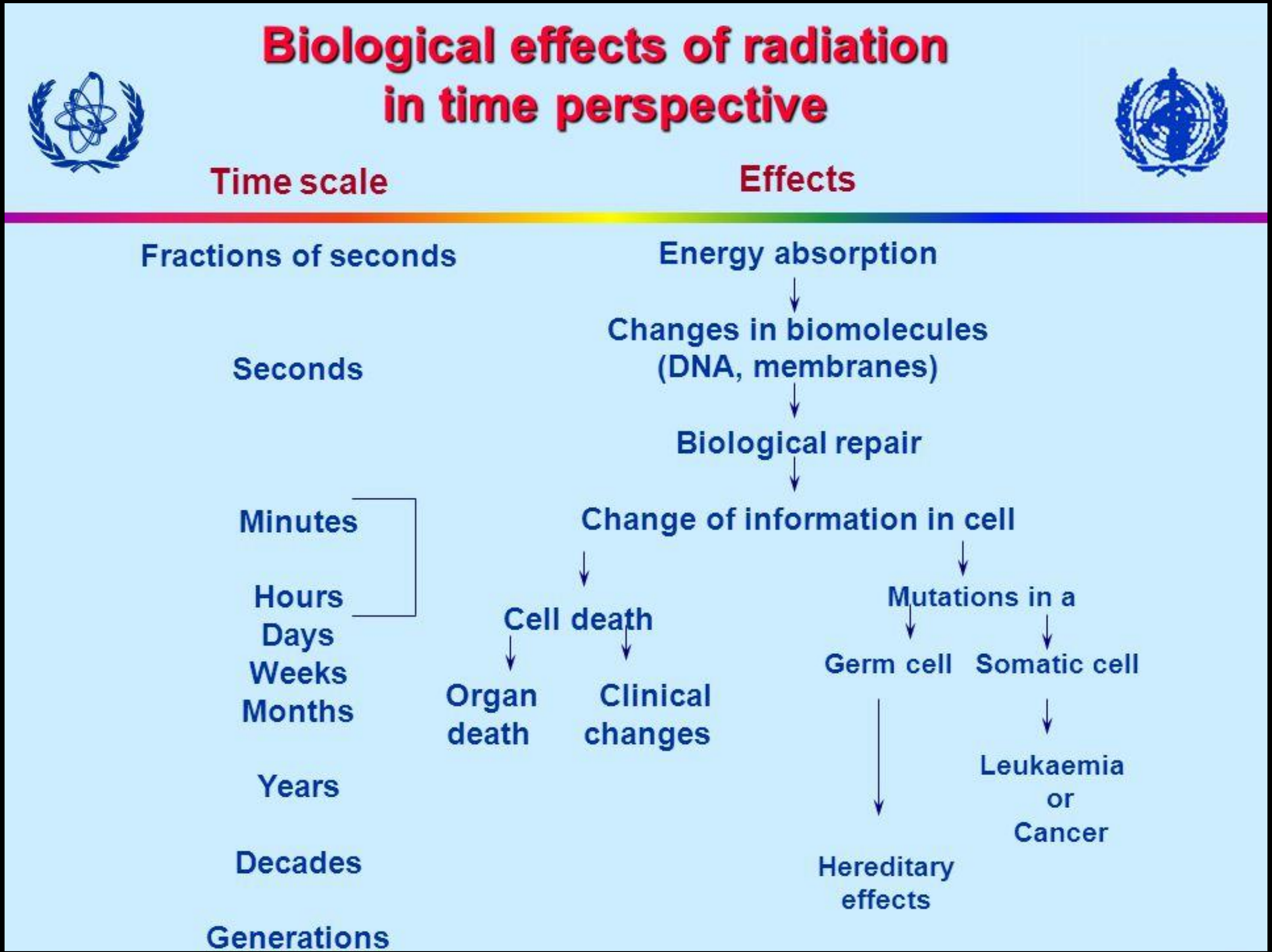
On the surface of the Moon the free space GCR or SPE environments interact with the planetary surface, yielding a back-scattered radiation field.



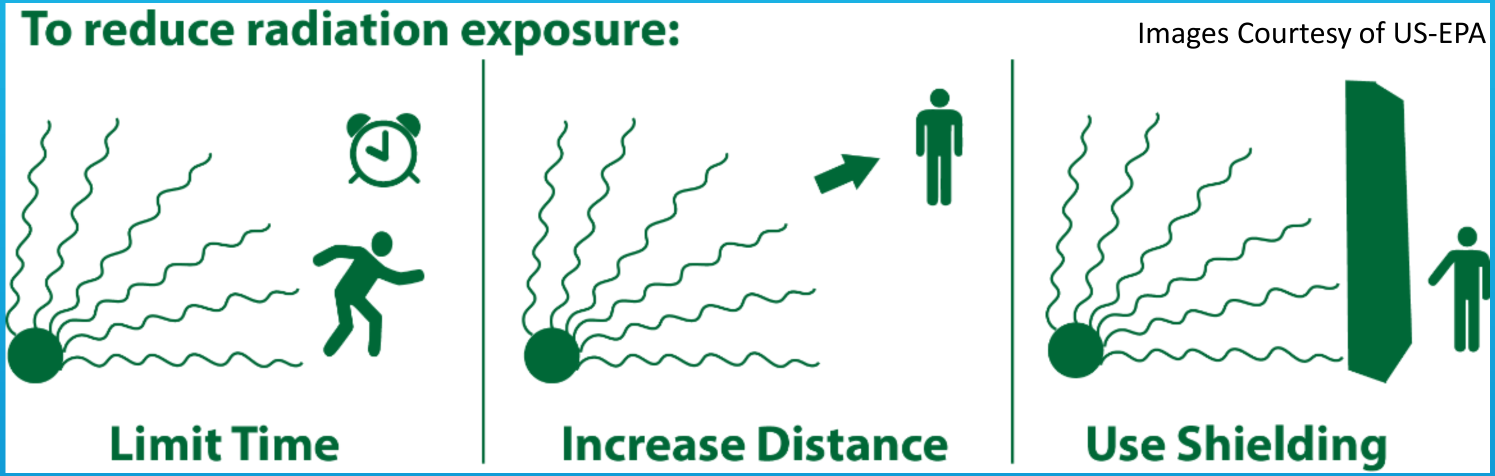
Percent Contribution to Effective Dose from Albedo Neutrons on Lunar Surface behind different types of shield From Slaba et Al [2011]

(Space) Radiobiology

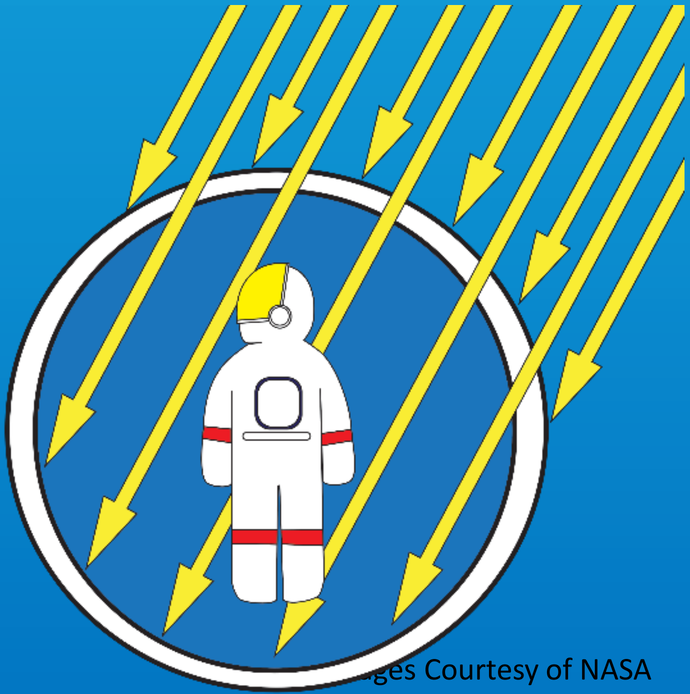
The limits in carrying out the space missions are due to health effects



Radioprotection criteria used on Earth….



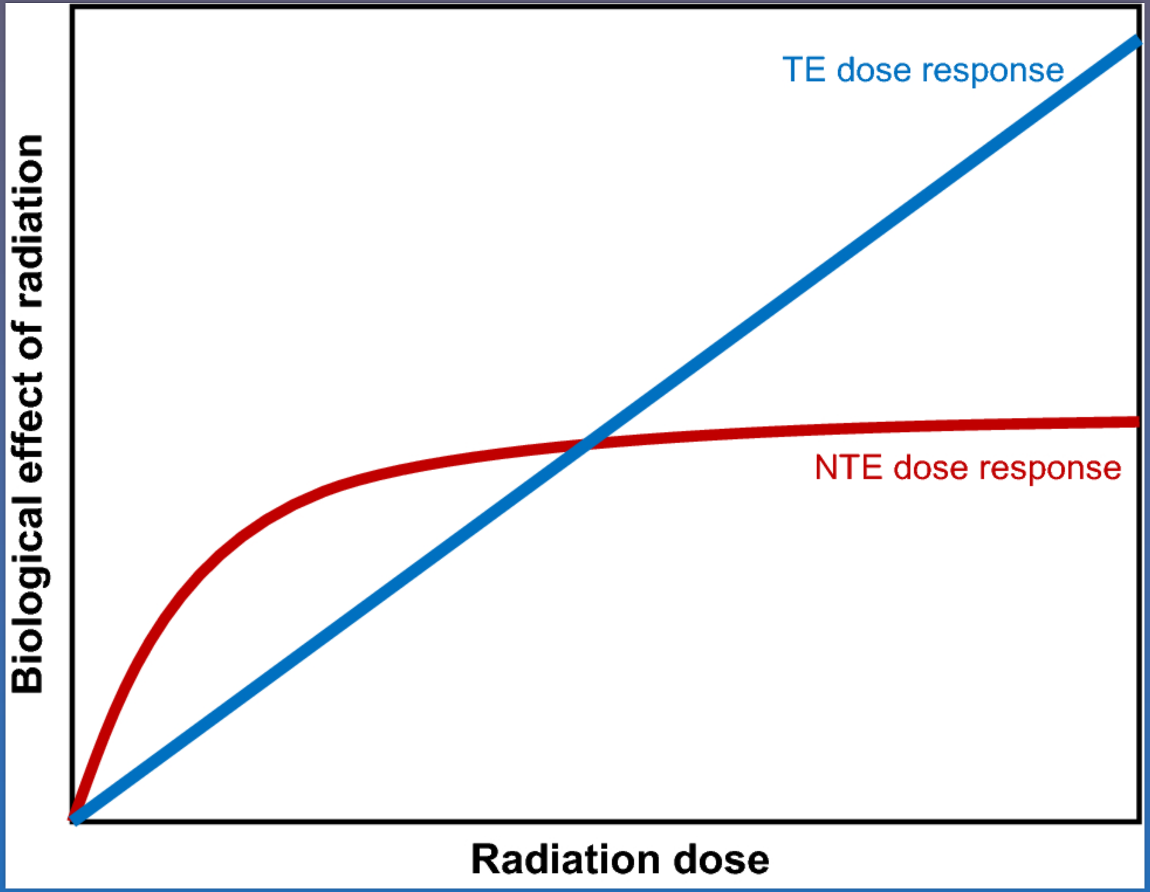
…do not work in space !



…ges Courtesy of NASA

Dose-Effect Relationship (DER)

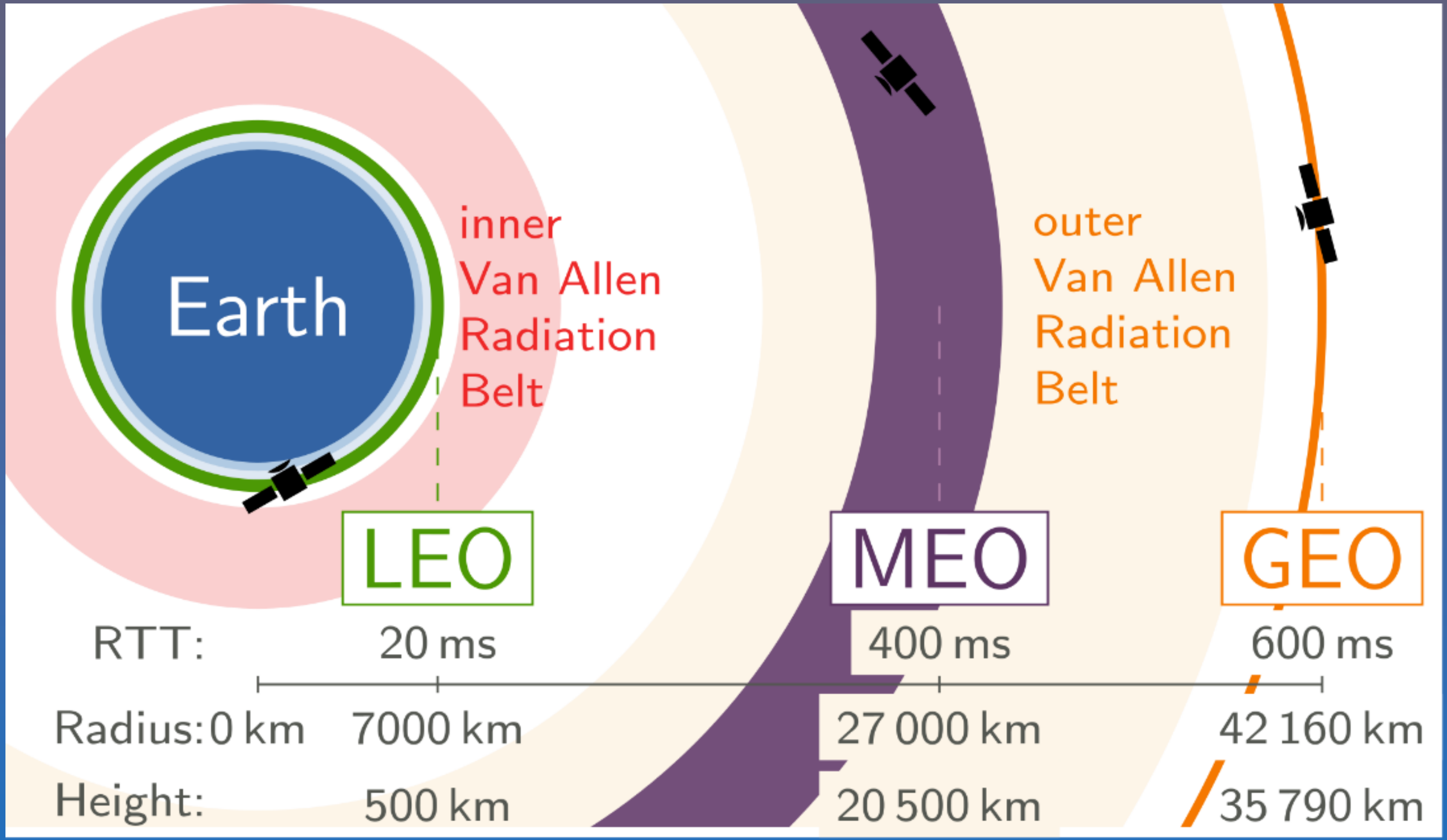
A crucial point to predict the toxicity of the space radiation expected for the astronauts/space workers is the creation of reliable mathematical models that describe the correlation between the exposition to IR and the possible damage to the organ at risk.



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

3 only reached a sub-orbital flight, 567 people reached the LEO

24 traveled in BLEO + 12 walked on the Moon



574 people have gone into space according to the FAI criterion (as 20 July 2021)

Space travelers have spent a cumulative total of over 77 years

DER Overview : the PUBMED search

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.

We made and publish in 2021 an extensive review of the existent literature to use as starting point for improvements this research areas

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

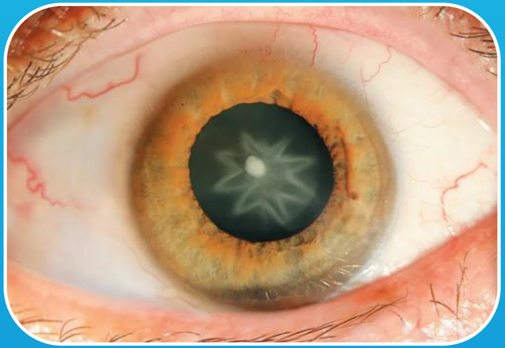
Lidia Strigari[1], Silvia Strolin[1], Alessio Giuseppe Morganti[2] and Alessandro Bartoloni[3*]

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

Articles dose-effect models exploration and identification

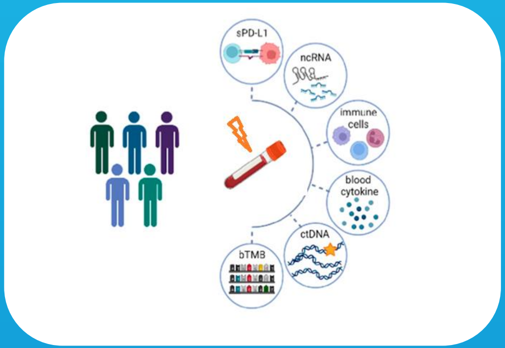
- Identification of
  - Types of irradiation
  - Data
  - Models
- Experimental Type
  - In Vitro
  - Pre-clinical
  - Clinical
- Study Type
  - Ground
  - Simulation
  - Spaceflight

«Eye-Flashes»

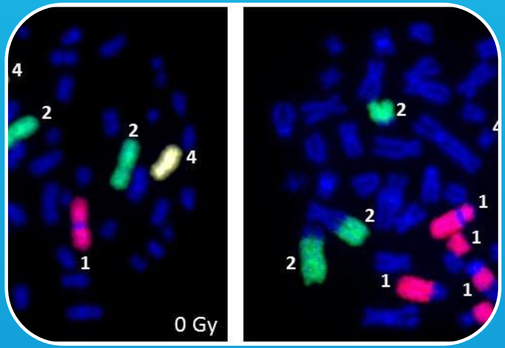


Cataract or

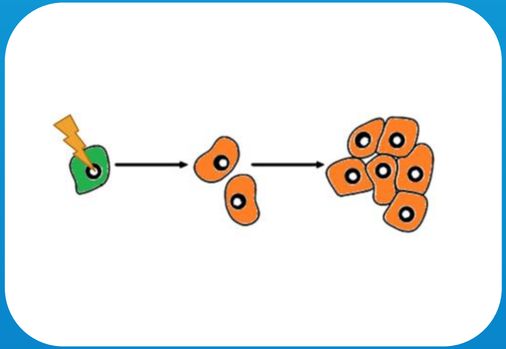
Visual impairments



Biomarkers

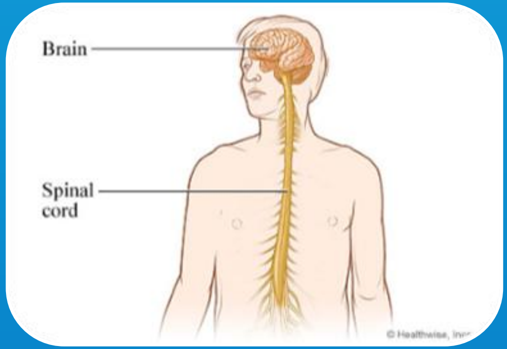


Chromosomal Aberrations

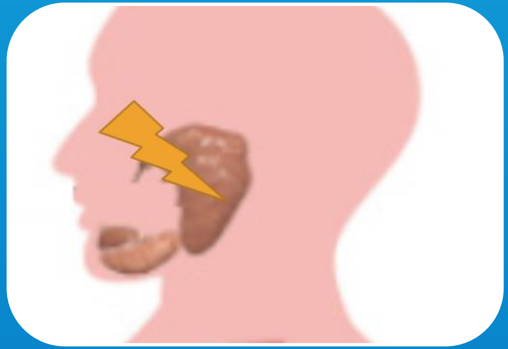


Carcinogenesis

Cardivascular Disease (CVD)



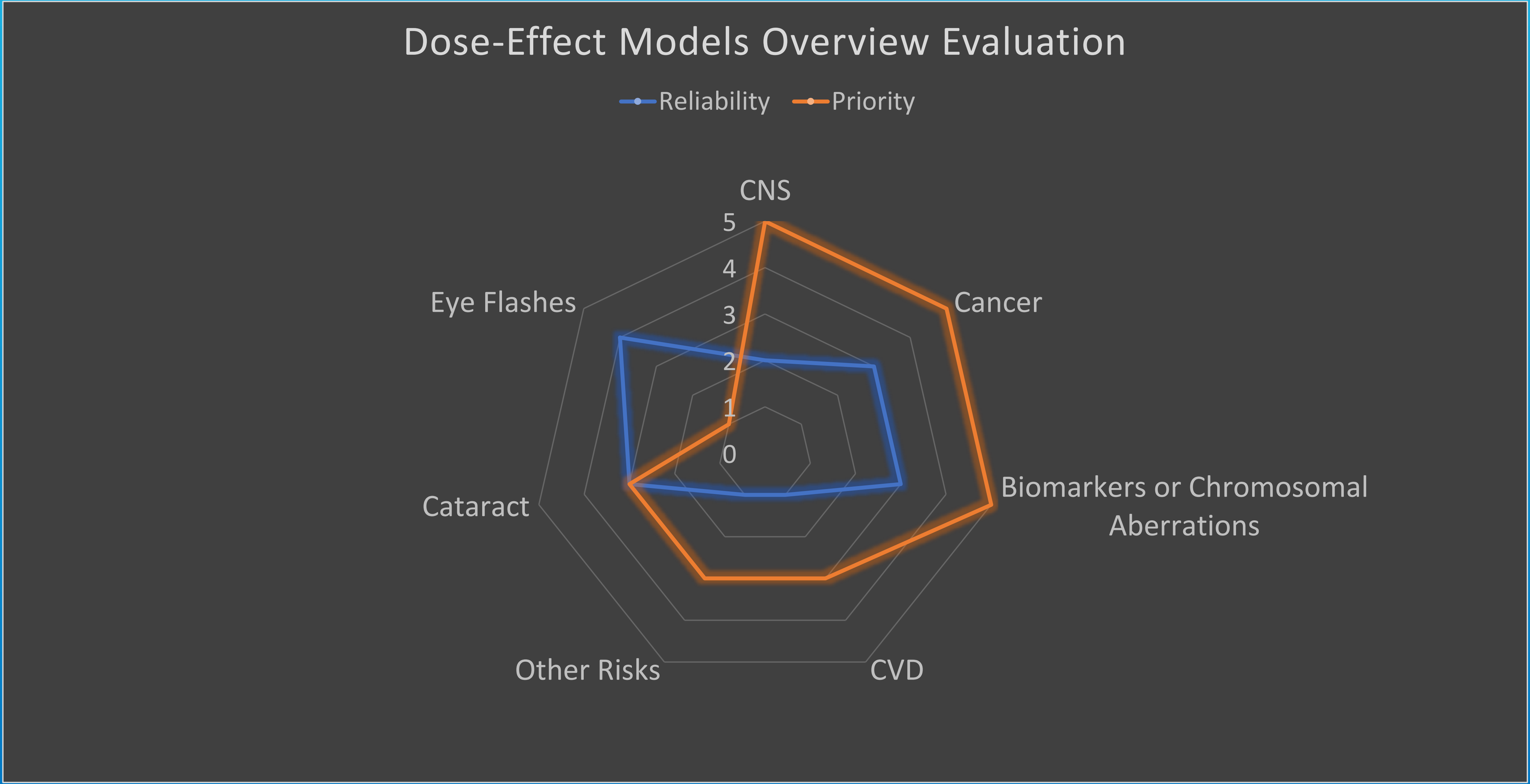
Central Nervous System (CNS)



Other Risks

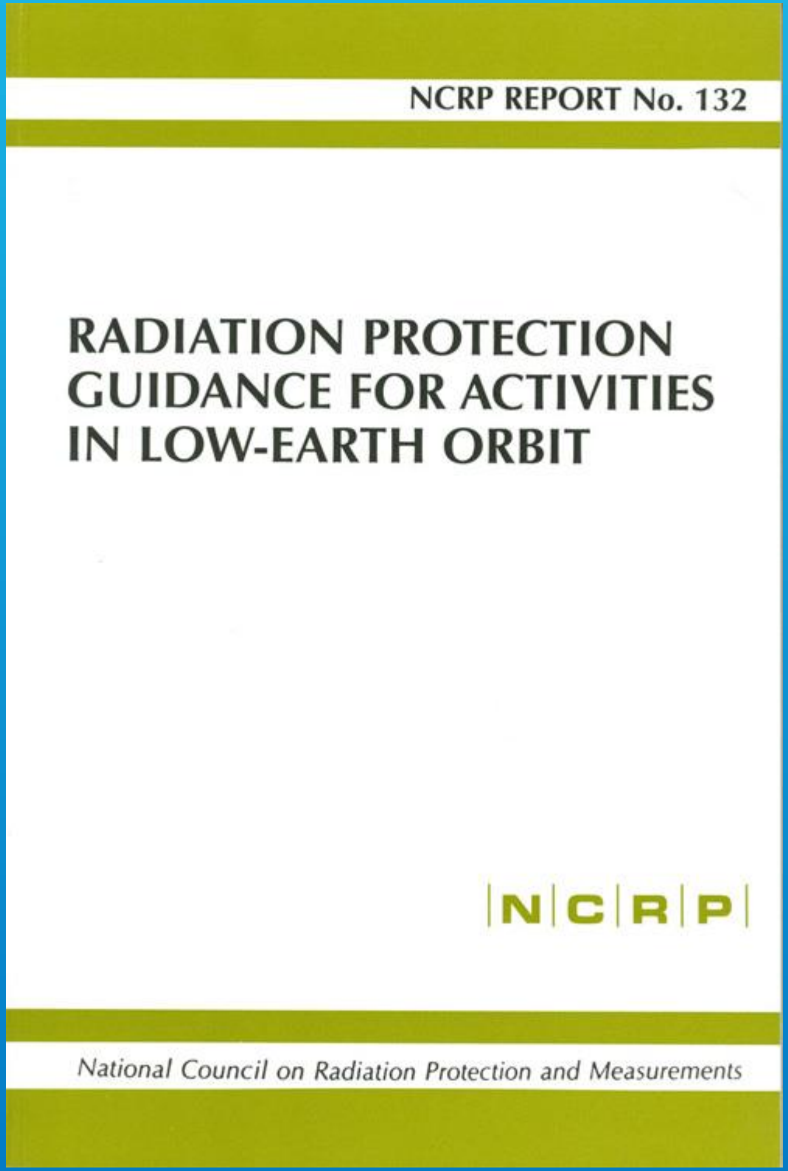
Analysed IR related health hazard

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.					


Dose-Effect Models Overview Evaluation
Reliability
Priority
CNS
Cancer
Biomarkers or Chromosomal Aberrations
CVD
Other Risks
Cataract
Eye Flashes
5
4
3
2
1
0

Dose Effects Relationship Overview
Carcinogenesis Risk

Spaceflight-Based Studies



About 3% risk of exposure-induced death is generally used as a basis for setting age- and gender-specific dose limits for astronauts

NASA/TP-2013-217375

Space Radiation Cancer Risk Projections and Uncertainties – 2012

Francis A. Cucinotta
NASA Lyndon B. Johnson Space Center
Houston, Texas

Myung-Hee Y. Kim and Lori J. Chappell
U.S.R.A., Division of Space Life Sciences
Houston, Texas

Spaceflight-Based Studies

After adjusting US cancer rates to remove smoking effects, and radiation risks for lung and other cancers, the radiation mortality risks for never-smokers were reduced compared to the average US population by more than 20% and 50% in the mixture model and multiplicative transfer model, respectively.

January 2022

NASA/TM–20220002905
NESC-RP-20-01589

Safe Human Expeditions Beyond Low Earth Orbit (LEO)

Azita Valinia/NESC
Langley Research Center, Hampton, Virginia

John R. Allen
NASA Headquarters, Washington, DC

David R. Francisco
Johnson Space Center, Houston, Texas

Joseph I. Minow
Marshall Space Flight Center, Huntsville, Alabama

Jonathan A. Pellish
Goddard Space Flight Center, Greenbelt, Maryland

Alonso H. Vera
Ames Research Center, Moffett Field, California

Radiation Carcinogenesis LTH Risk (LxC)

extract of Table in Fig 5.0-1 Matrix showing Human System Risks for different DRMs

LEO Short < 30 D	Low
LEO Long 30 D - 1 Y	Mid
Lunar Orbital Short <30 D	Low
Lunar Orbital Long 30 D- 1 Y	Mid
Lunar Orbital Short + Surface <30 D	Low
Lunar Orbital Long + Surface 30 D - 1 Y	Mid
Mars Preparatory < 1 Y	Mid
Mars Planetary > 730 -1224 D	Mid

Low Risk   Mid Risk   High Risk

Ground/Simulation Based Study

ICRP Publication 103

The 2007 Recommendations of the International Commission on Radiological Protection

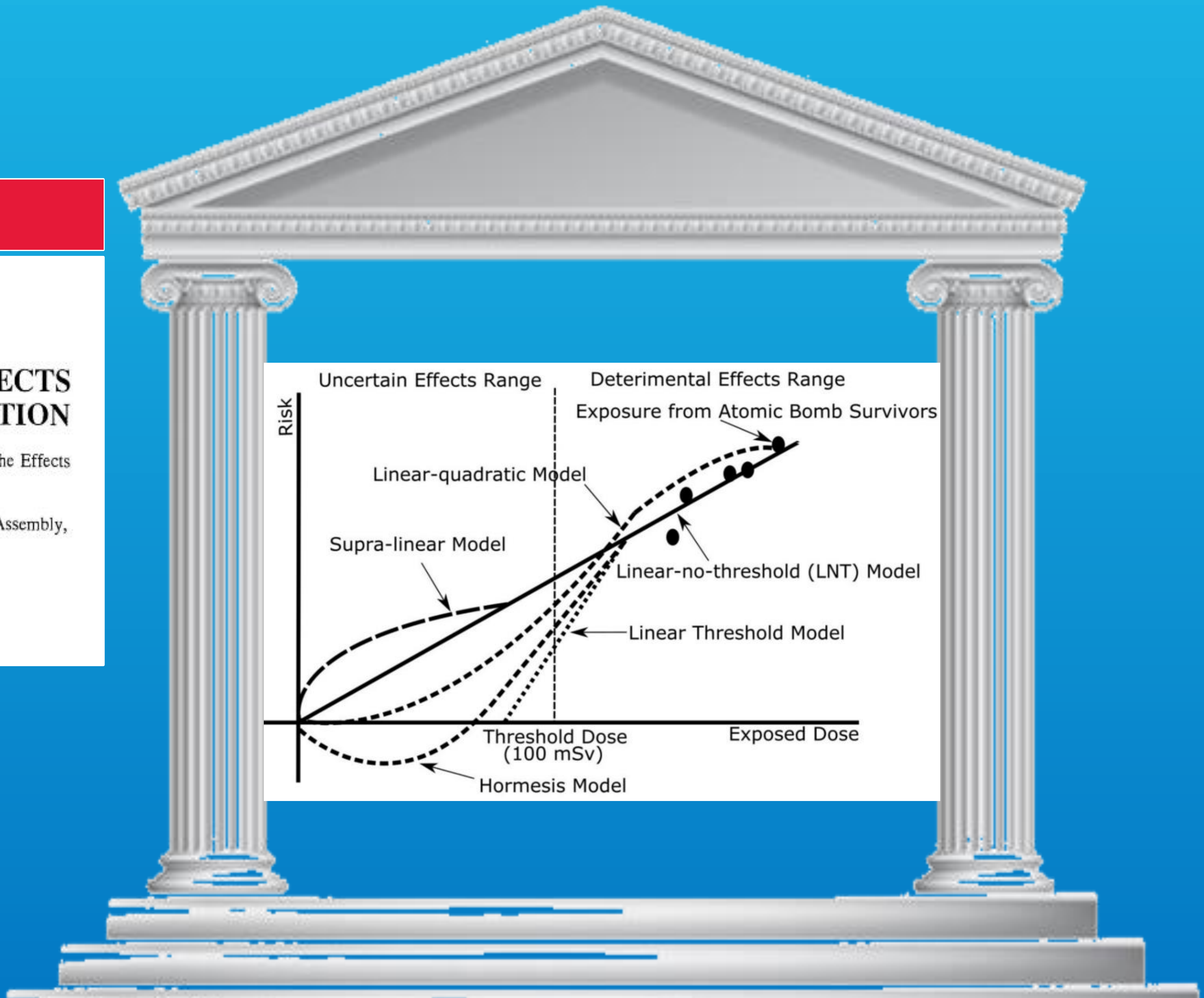
SOURCES AND EFFECTS OF IONIZING RADIATION

United Nations Scientific Committee on the Effects of Atomic Radiation

UNSCEAR 1993 Report to the General Assembly, with Scientific Annexes

NCRP COMMENTARY No. 24

HEALTH EFFECTS OF LOW DOSES OF RADIATION: PERSPECTIVES ON INTEGRATING RADIATION BIOLOGY AND EPIDEMIOLOGY



Differential Superiority of Heavy Charged-Particle Irradiation to X-Rays: Studies on Biological Effectiveness and Side Effect Mechanisms in Multicellular Tumor and Normal Tissue Models

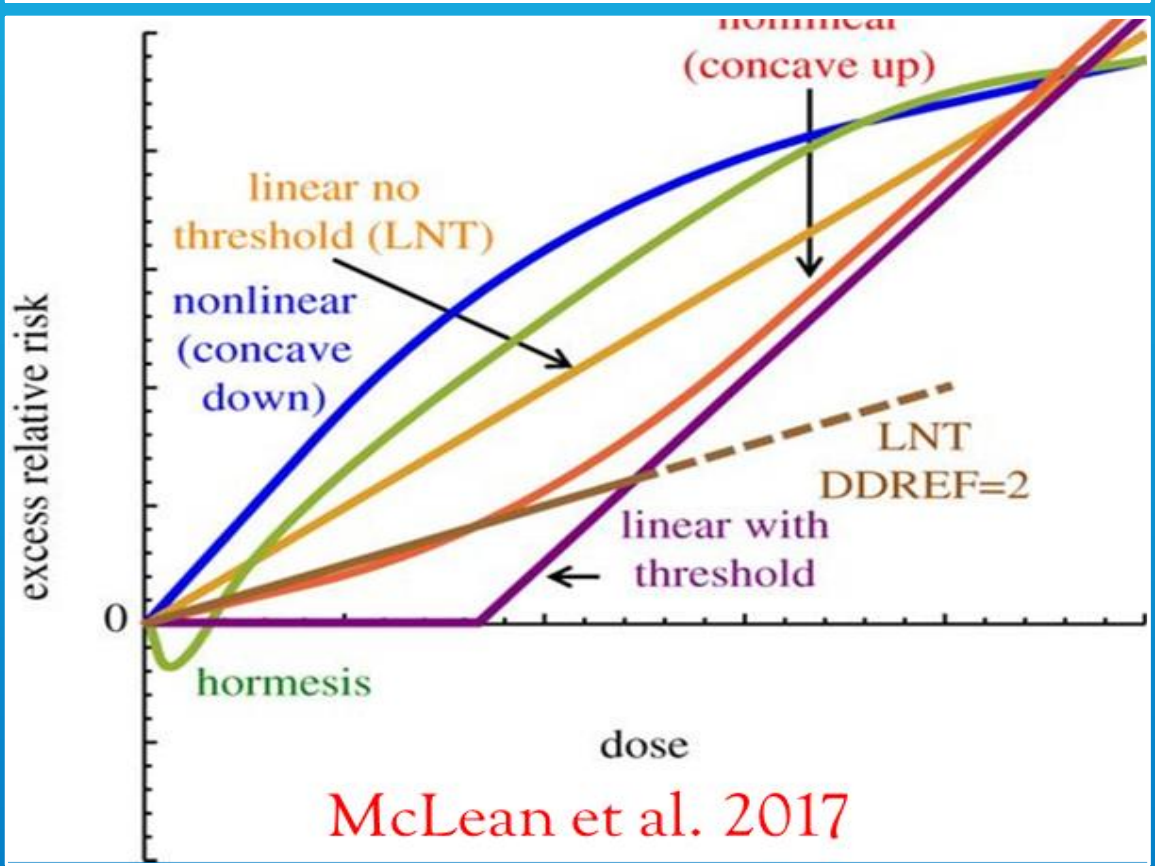
*Stefan Walenta and Wolfgang Mueller-Klieser**

A Critique of Recent Epidemiologic Studies of Cancer Mortality Among Nuclear Workers

Bobby R. Scott[1]

The Controversial Linear No-Threshold Model

Wolfgang Weber and Pat Zanzonico



Ground/Simulation-Based Study

uncertainties chain

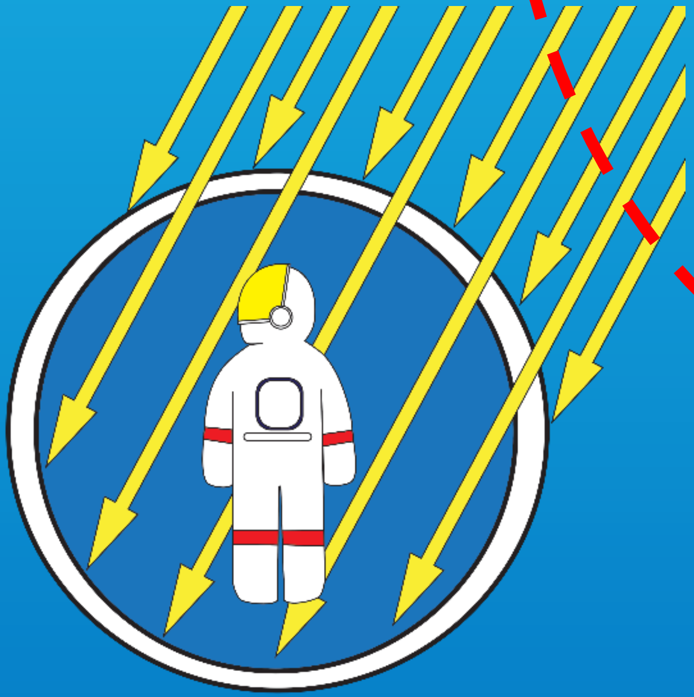
Quality factors of the particles constituting the GCR at low doses.

Radiation-induced cancer rates in the whole population and in astronauts

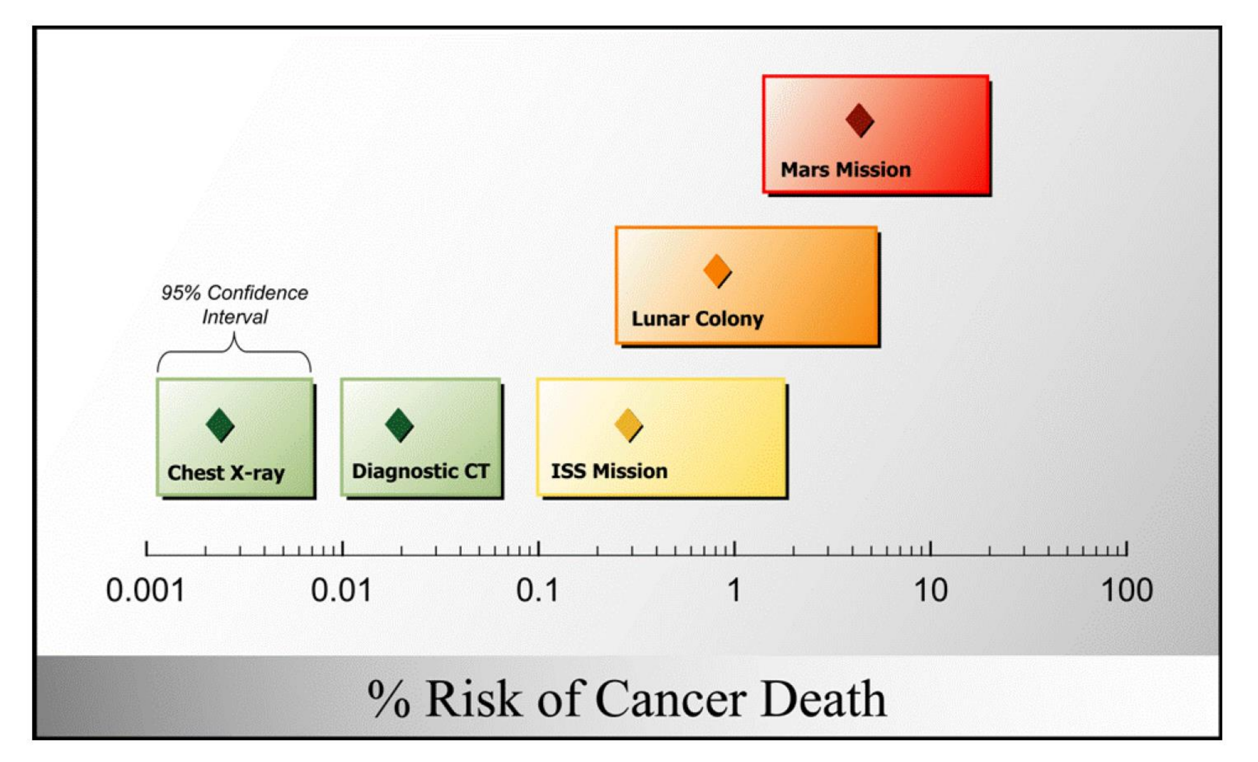
Dose measurements

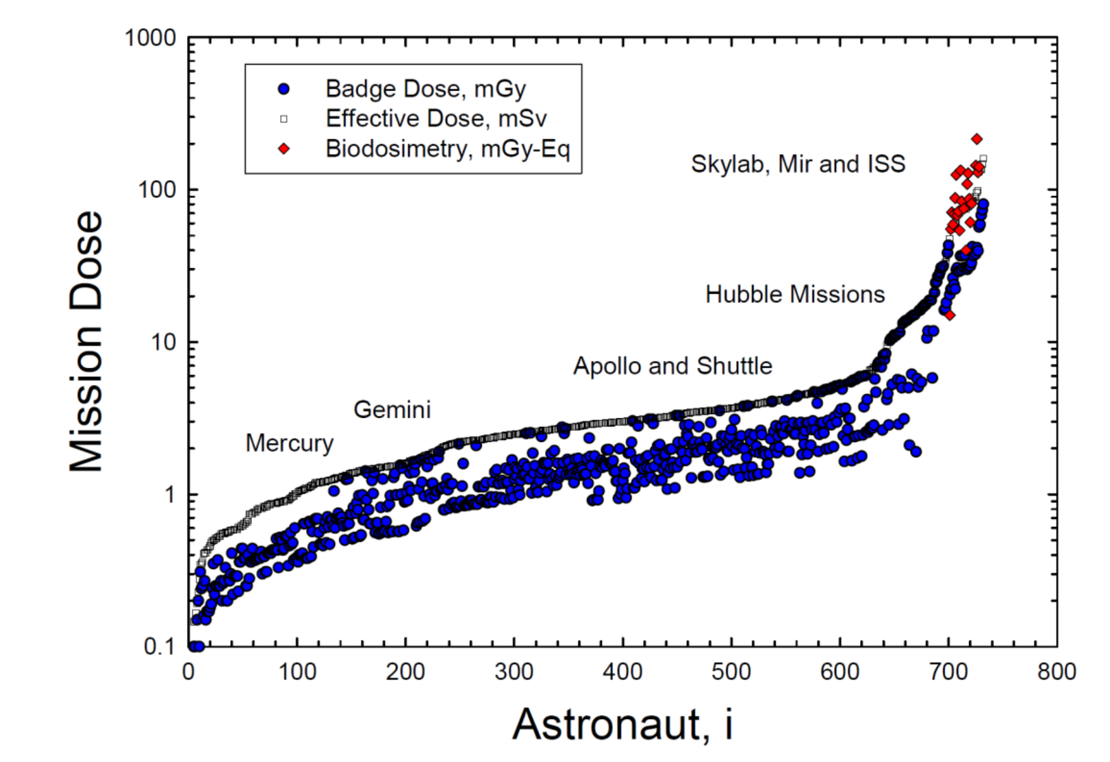
(During the Space Shuttle era, <100 mSv was accumulated by an astronaut)

No statistical significance evidence from the literature of radiation cancer induced death



- Small number of astronauts
- Better baseline features of astronauts
- Low cumulative doses
- Latency periods from years to decades

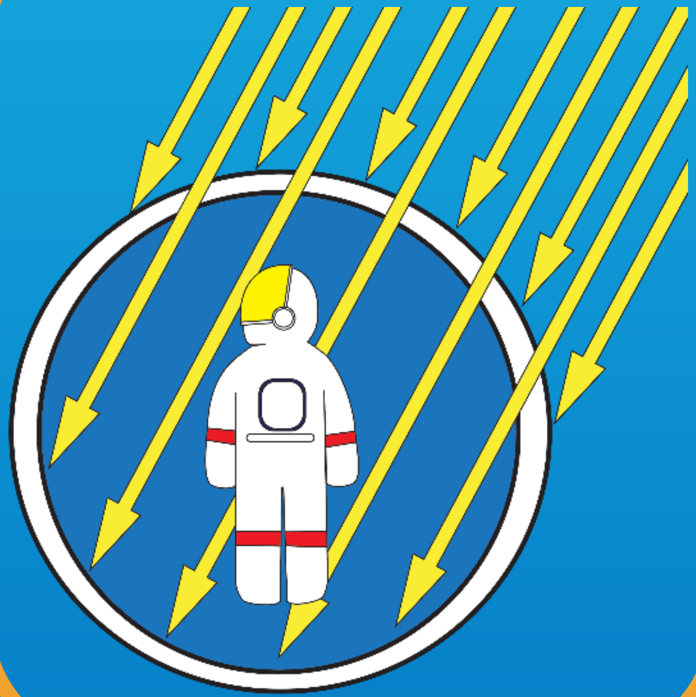




Uncertainties in risk projection for terrestrial and space exposures for adults of age 40 yrs, the typical age of astronauts on space missions, for several terrestrial exposures and missions on the International Space Station, a lunar colony, and the projections for a Mars mission. (Cucinotta et al. 2008).

Summary of mission personnel dosimetry from all past NASA crew (Cucinotta et al. 2008).

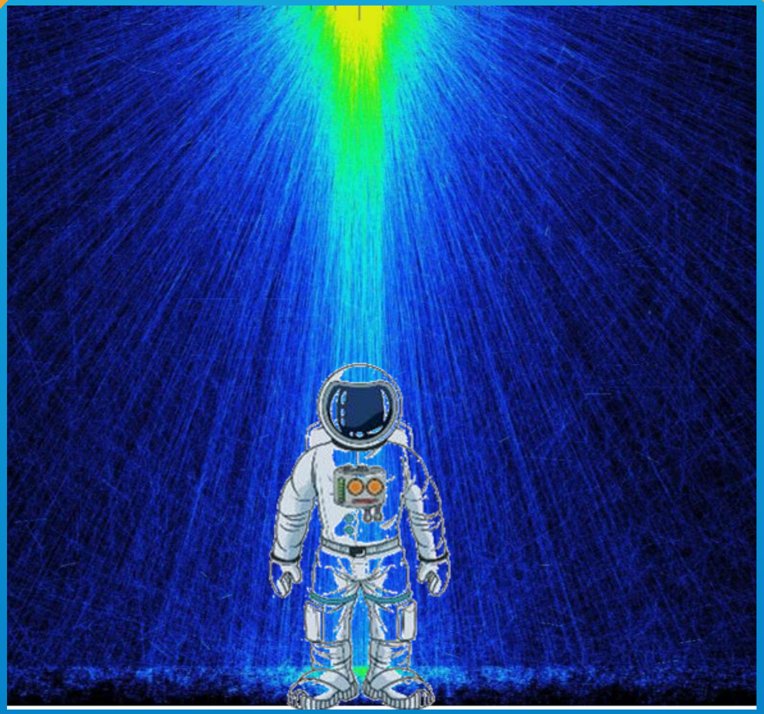
New Tools and Technologies will enable to increase the model's prediction precision



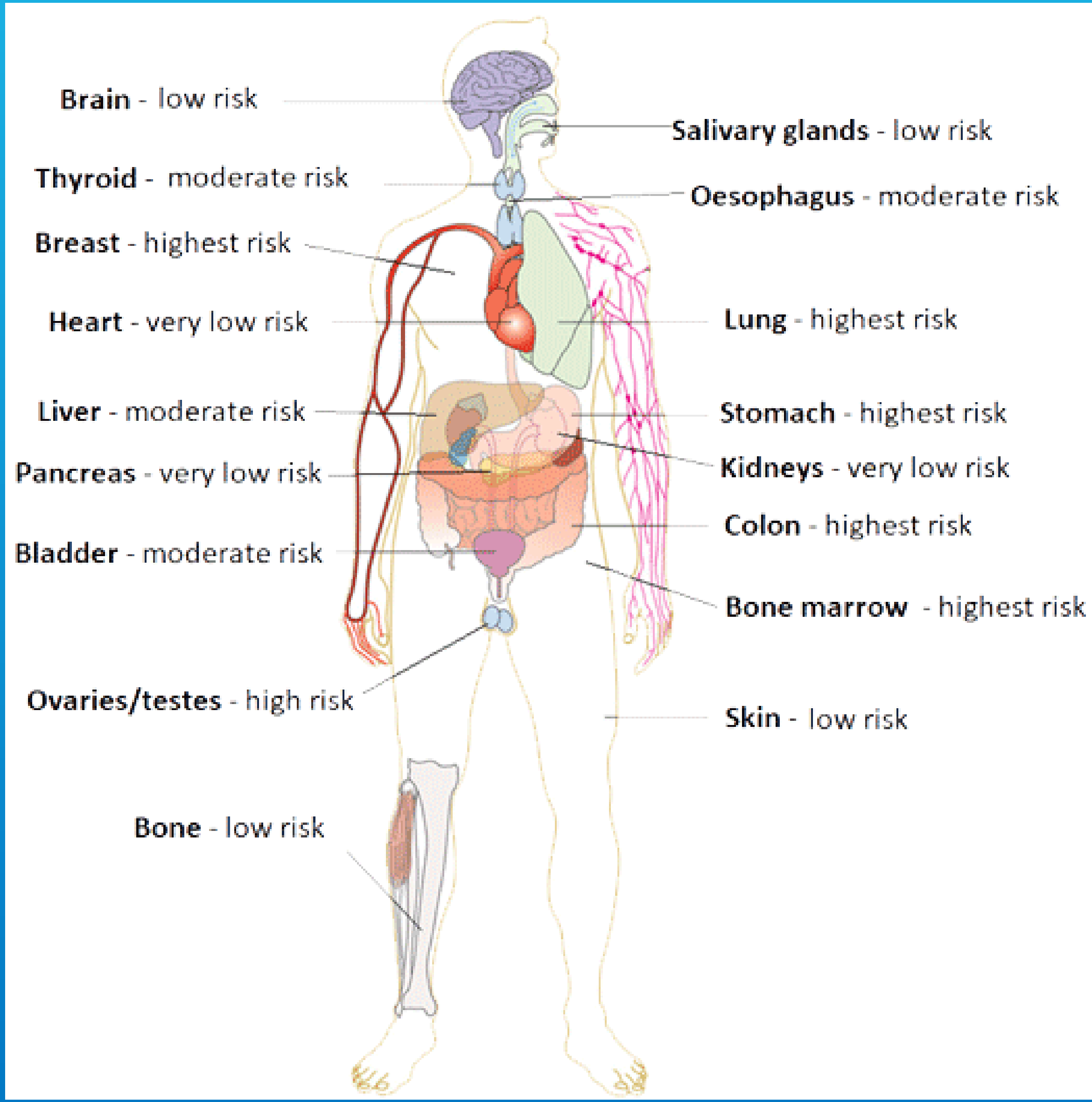
Modern instrumentation and detectors

Modern dosimeters

Ad hoc Monte Carlo calculation tools (e.g., HZETRN, URANOS)



Several Endpoints

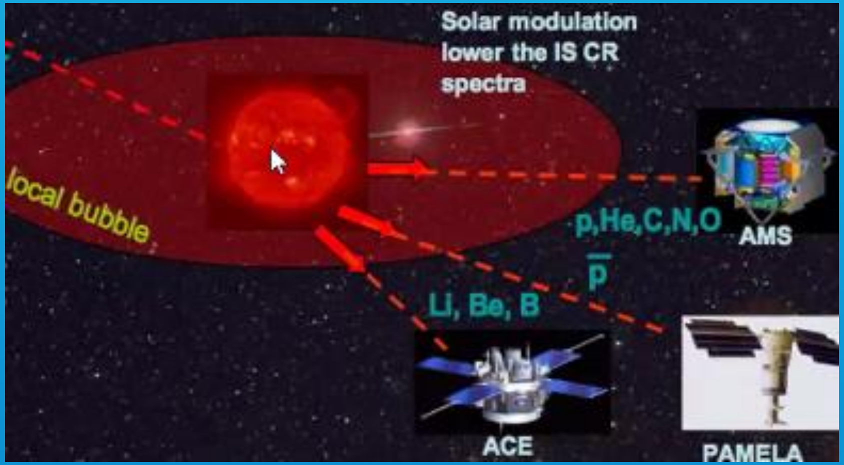


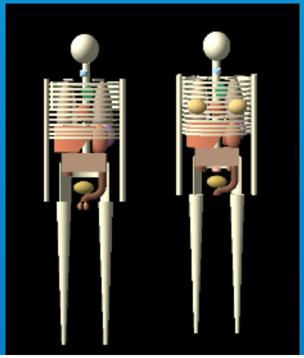
Several Outcome

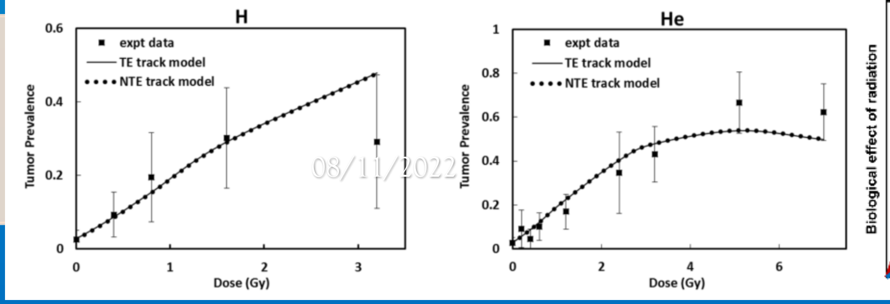
- Individual Risk Estimates
- Tumor Prevalence
- Increased Lifetime Risk of Death

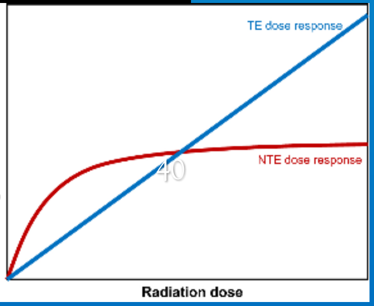
Possible improvements : Identification of sources of uncertainties

MC/Cosmic Rays Solar Modulation over time	• using space radiation data
shielding effects & design	• using space radiation data
Human models	using patients' images
Dose effect models (cancer & survival)	comparison of models /data



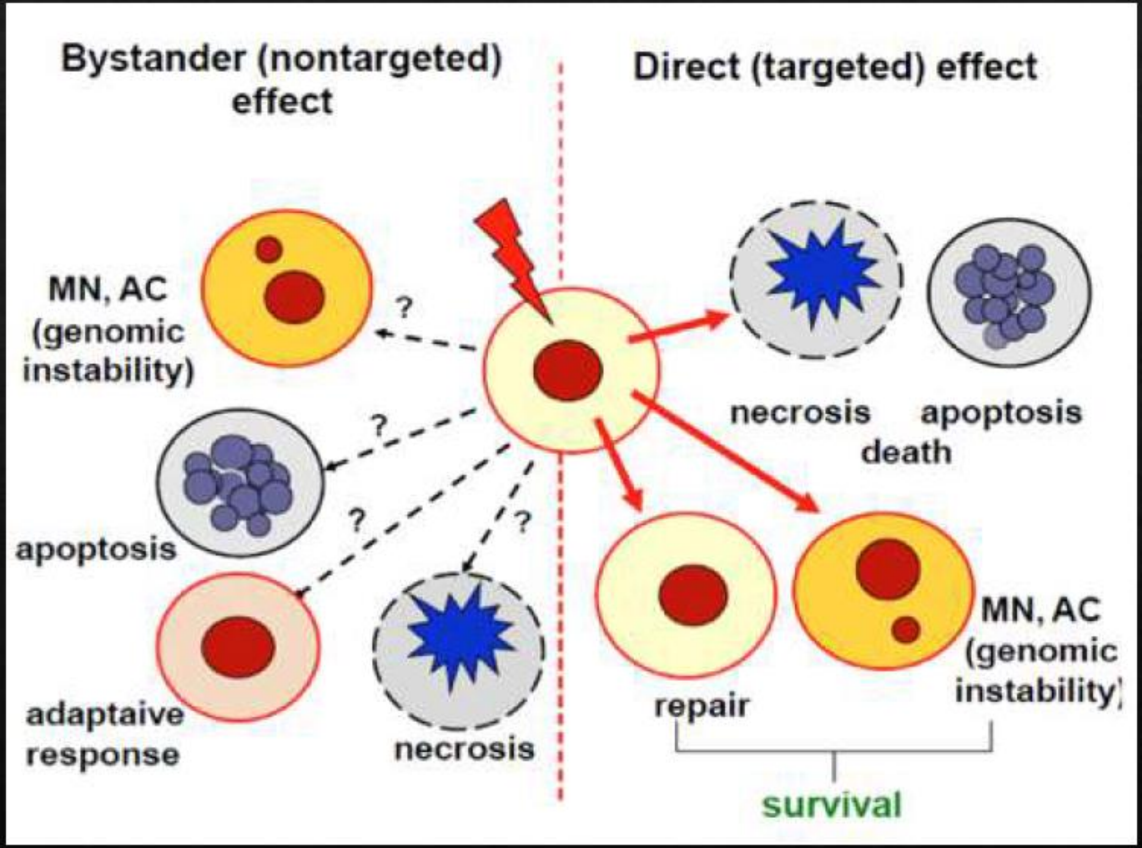






Target Effects vs Non Target Effects

- Non-targeted effects (NTEs) include bystander effects where cells traversed by heavy ions transmit oncogenic signals to nearby cells, and genomic instability in the cell's progeny.
- Studies on the Harderian gland, chromosomal aberrations at low dose and many mechanistic studies support the NTE model, with evidence of a supra-linear effect at low doses of NTE compared to a linear effects for TE .
- These NTEs are expected also at the fluences and for radiation species that occur in space.



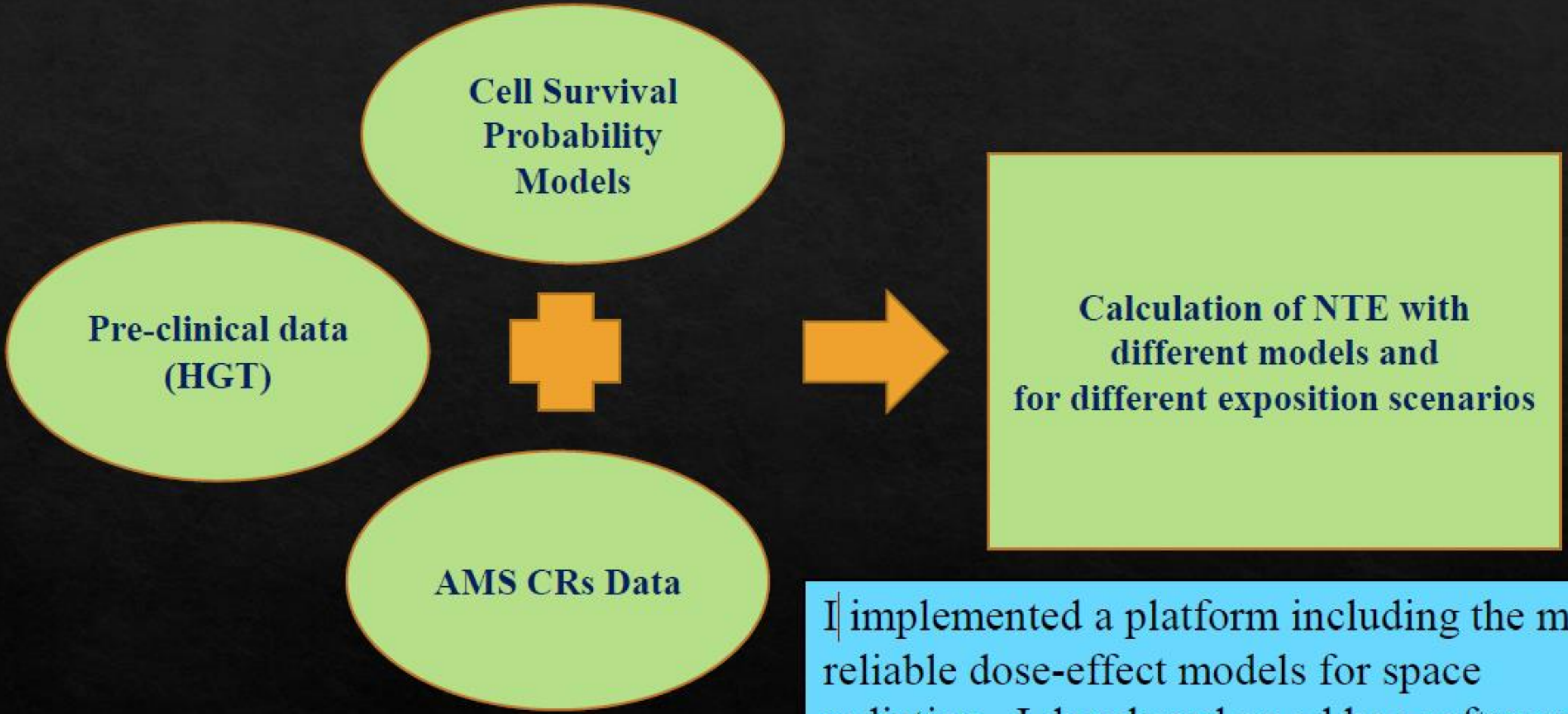
Non-Targeted Effects Models Predict Significantly Higher Mars Mission Cancer Risk than Targeted Effects Models

F. Cucinotta, Eliedonna E. Cacao • Published 12 May 2017 • Biology, Physics • Scientific Reports

Work in progress at Roma Sapienza AMS group

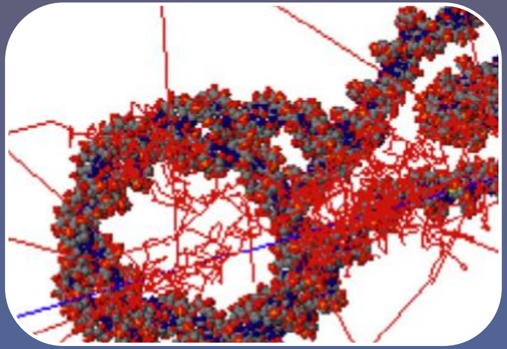
An example on Research activities on DEM in progress at AMS INFN Roma-Sapienza Group

A Tool for NTE components evaluation



I implemented a platform including the more reliable dose-effect models for space radiation, I developed an ad hoc software in R-script language (> 10,000 code lines).

Further investigation are required to produce dose-effects models that will allows to predict the risk due to radiation during the space exploration



Computer Simulation of interactions of IR with biological matter

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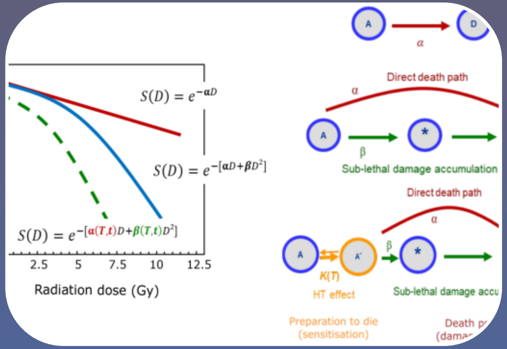
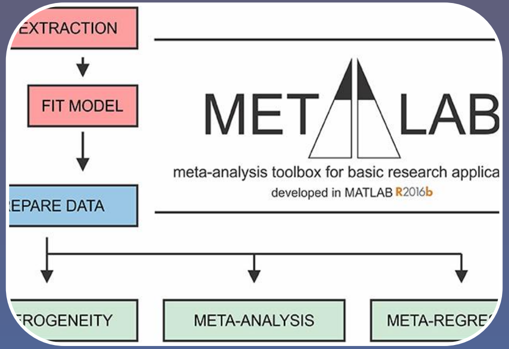
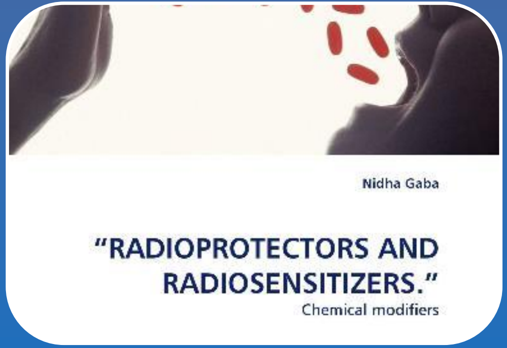
Synergy with the Clinical Field



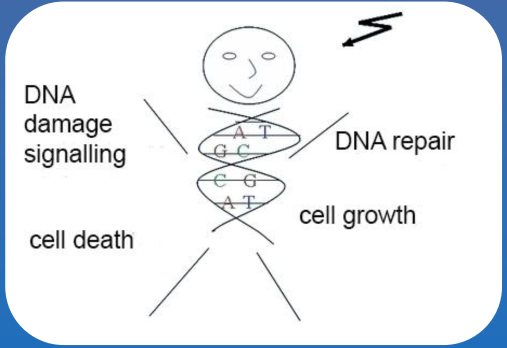
Mathematical Modelling



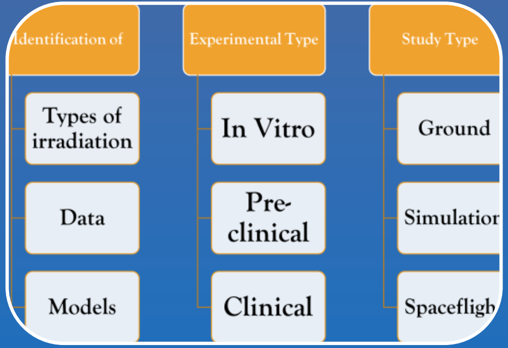
Quantitative Meta Analysis



Radioprotectors inclusion in DER



Individual Radio Susceptibility



Dose-Effects Model Integration Platform

Synergy with Astroparticle Experiments

Conclusions

Technological advancements might realize the dream of human space exploration, and crewed spaceflights to explore and colonize the Moon and Mars are on the agenda of space agencies.

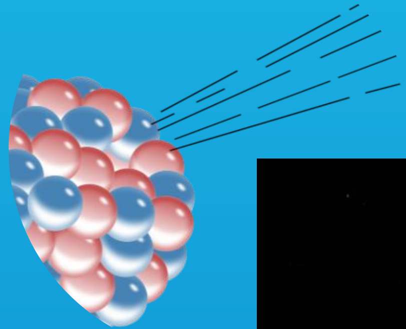
In the latest years, significant improvements have been made in the absorbed dose-effect estimation for predicting risks for human health on space exploration.

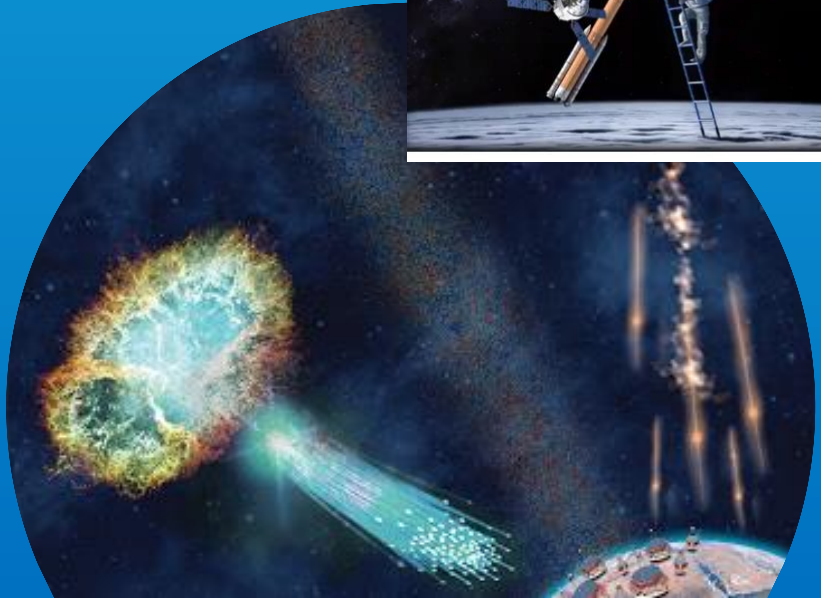
Unfortunately, the number of events helpful in modeling the radiobiological effects is still limited. On Earth experiments may reinforce knowledge on cancer and non-cancer space-radiation induced effects.

The AMS Roma Sapienza group is part of the scientific community investigating this crucial research topic for safe human exploration of space.

Actual research on DEM are on the evaluation in Non Target Effects in Carcinogenesis Risk

«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)*





THANKS FOR THE ATTENTION !

Alessandro Bartoloni

Alessandro.Bartoloni@cern.ch

Alessandro Bartoloni

AMS02 INFN ROMA and Sapienza University Web Site

Appendix I

Dose Effects Relationship Overview
RISK for the Central Nervous System

Space Radiation effects on CNS

The potential acute and late risk from GCR and SPEs for astronauts on board the ISS are not considered a major concern.

Instead, deep space exploration and long term (>1 year) mission are under consideration.

This was clear from the first Apollo space missions in the 60s/70s

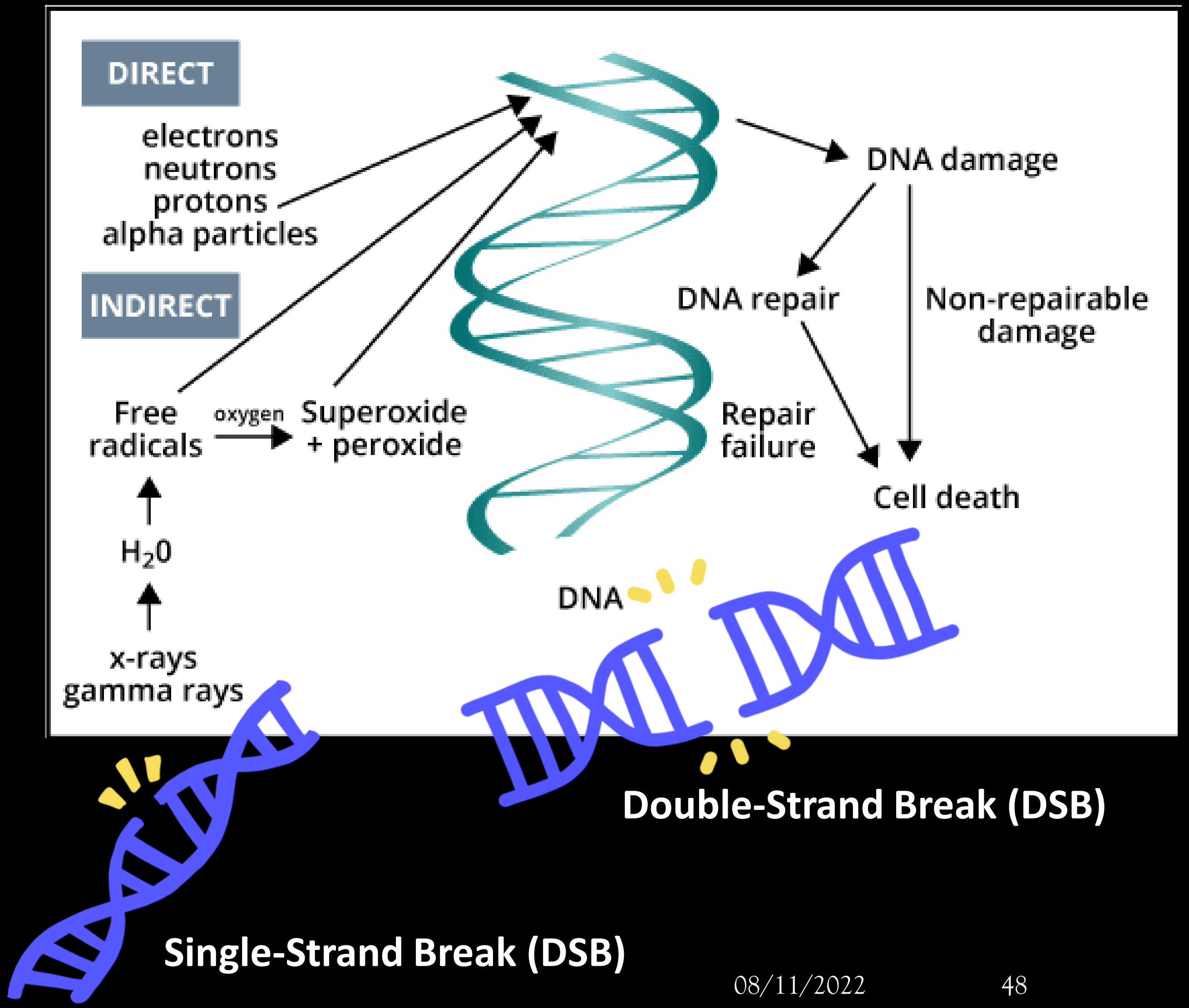
«I'm having these light flashes. I'm seeing this , like, flashing in my eyeballs. It was like fireworks in your eyeballs. It was spectacular.»

Charles Duke –Lunar Module Pilot of Apollo 16

Ionizing Radiation risk for CNS

Ionizing radiation particles have in the physical ability to generate free radicals that may cause direct or indirect DNA damage

also provide a source of metabolic stress to which the central nervous system (CNS) is particularly susceptible as compared to other tissue types.



Double-Strand Break (DSB)

Single-Strand Break (DSB)

Space Radiation effects on CNS
Early vs Late

- **Neurocognitive deficit**
- **Operant reactions**
- **Short Term memory detriments**
- **Altered motor function**

- *Neurocognitive deficit*
- *Operant reactions*
- *Short Term memory detriments*
- *Altered Motor function*
- **Altered Neuro Genesis**
- **Oxidative DNA Damage**
- **Alzheimer Disease**

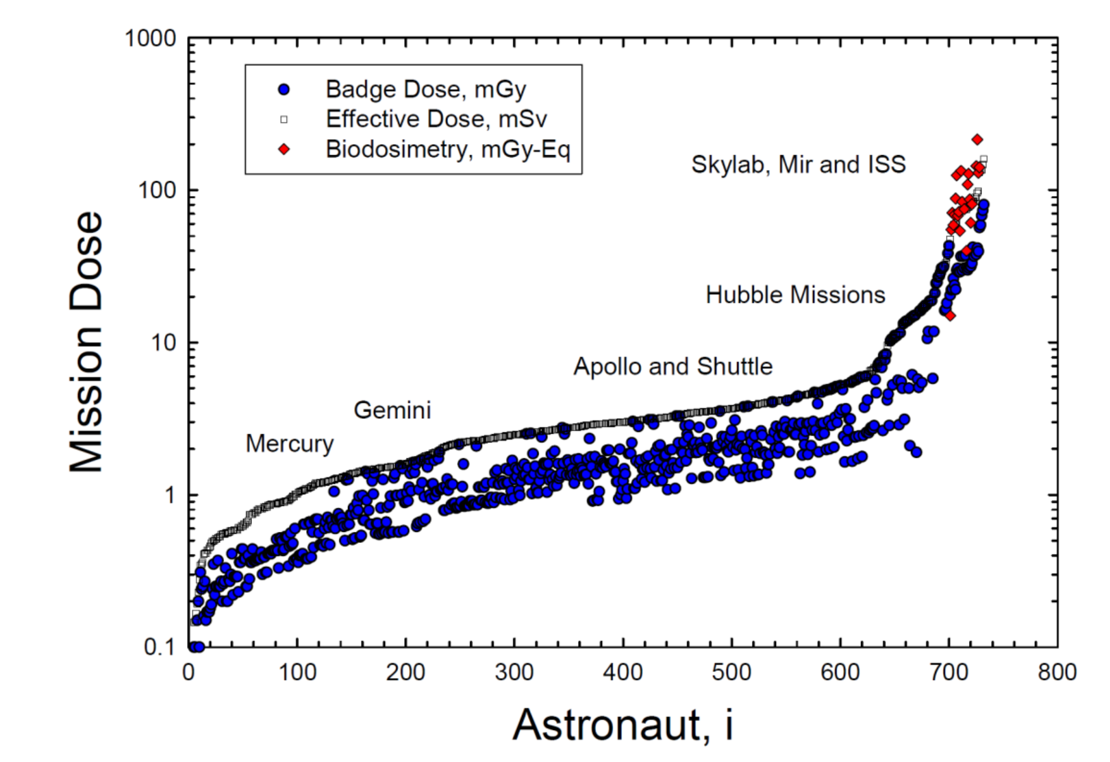
Radiation Toxicity in the CNS

The precise mechanism of neurotoxicity and neurodegeneration produced by the IR are not yet understood from a biological point of view.

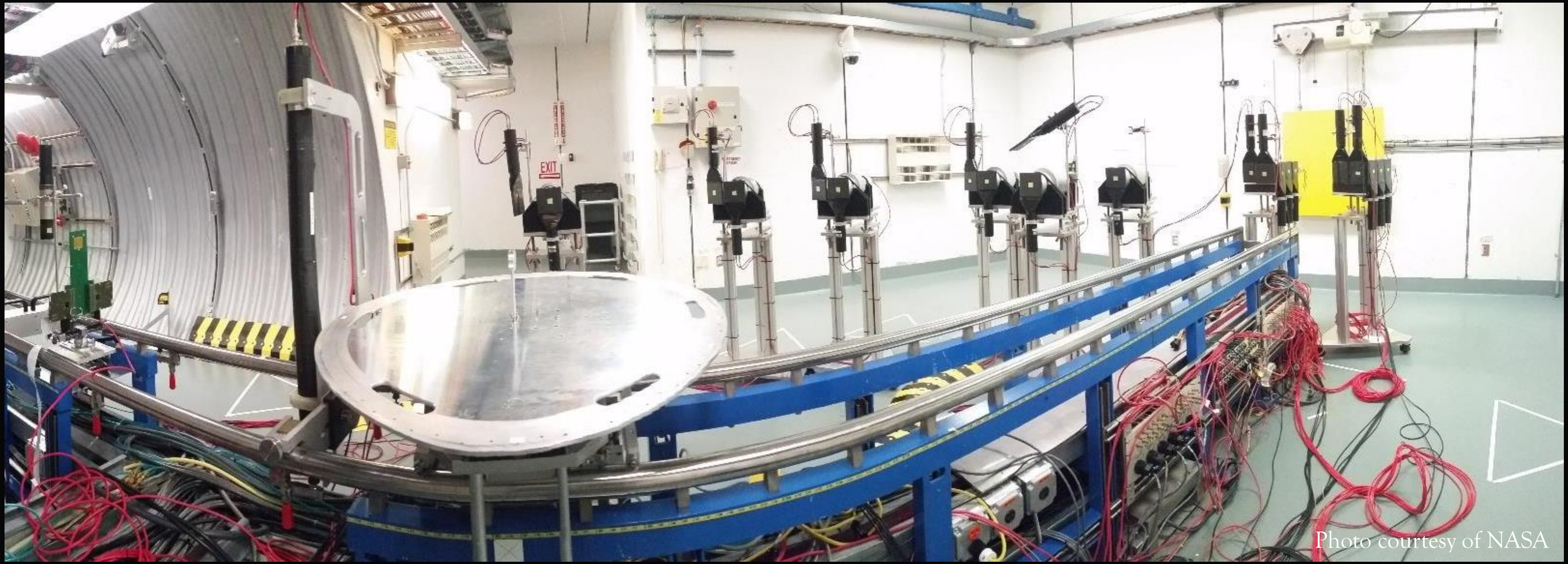
Instead, there are lots of studies describing :

- **How the radiation causes brain injury**
- **Factors that which determine whether toxicities occur**
- **Potential preventative and mitigation strategies**

On exploratory BLEO missions' astronauts will be exposed to a variety of particles (HZE) which differ in terms of particle energy and particle linear energy transfer (LET)



Summary of mission personnel dosimetry from all past NASA crew (Cucinotta et al. 2008).



Galactic Cosmic Ray Simulator & Particle Accelerator facilities

Studies on the effects of radiation on CNS has been done only on ground at the accelerator facility or through simulations

Dose effects relationship investigations

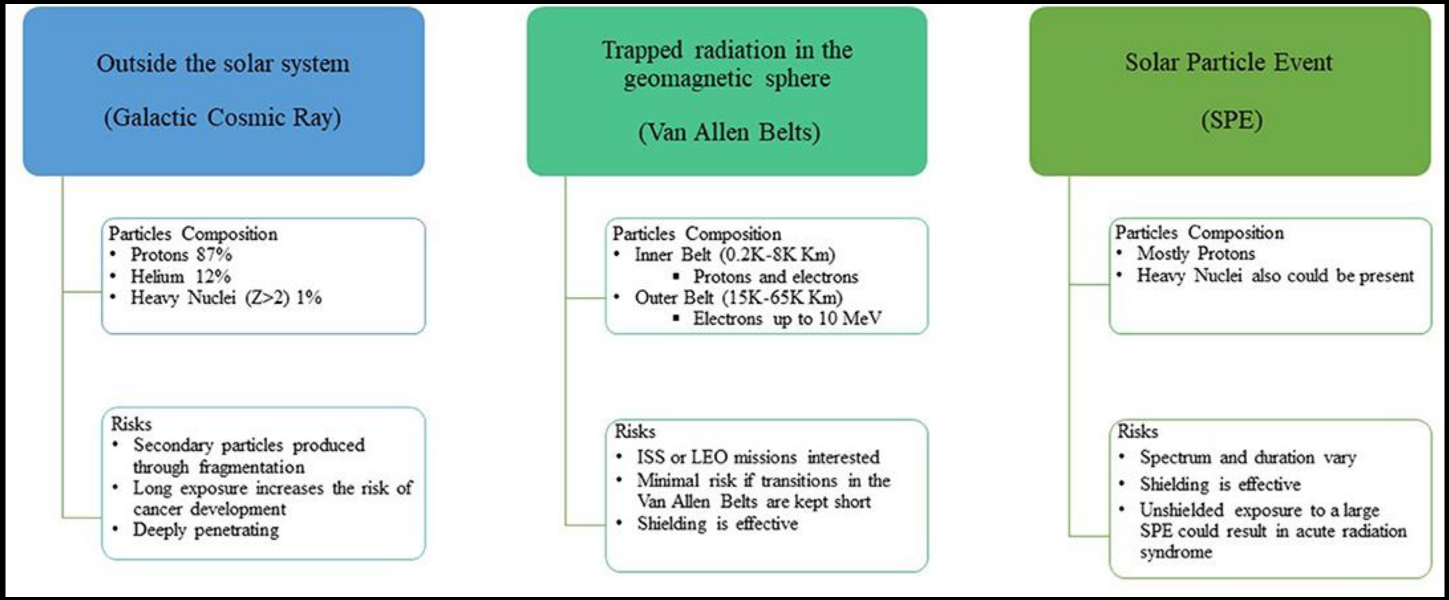
Particles used are a mixing of heavy-ion and protons to provide evidence for the CNS health risk for missions outside of LEO.

The doses used in experimental studies have been much higher than the annual GCRs dose.

Solar modulation is taken in account

In addition, the microgravity effects are also to be considered.

Space Radiation Composition



Dose effects relationship (CNS)

There are evidence that :

- doses as low as 20 cGy of simulated GCR radiation can significantly impair learning and memory in a rodent model
- proton radiation caused marked neurocognitive deficits at doses as low as 25 cGy.
- exhibition of significant changes in proteins associated with dopamine receptors and transporters in the brain at mission-relevant doses and dose rates. Further investigation is still mandatory to elucidate the impact of **dopamine changes** as a predictor for the CNS morbidity of the astronauts.
- CNS effects depend on multiple mechanisms leading to synapse changes, in fact the average lifetime of synapses varies in different brain regions and depends on the exposure time.
- Observations in mice revealed a dependence on **radiation quality and absorbed dose**, suggesting that microscopic energy deposition plays an important role.

Appendix II

Cosmic Ray Detectors in Space

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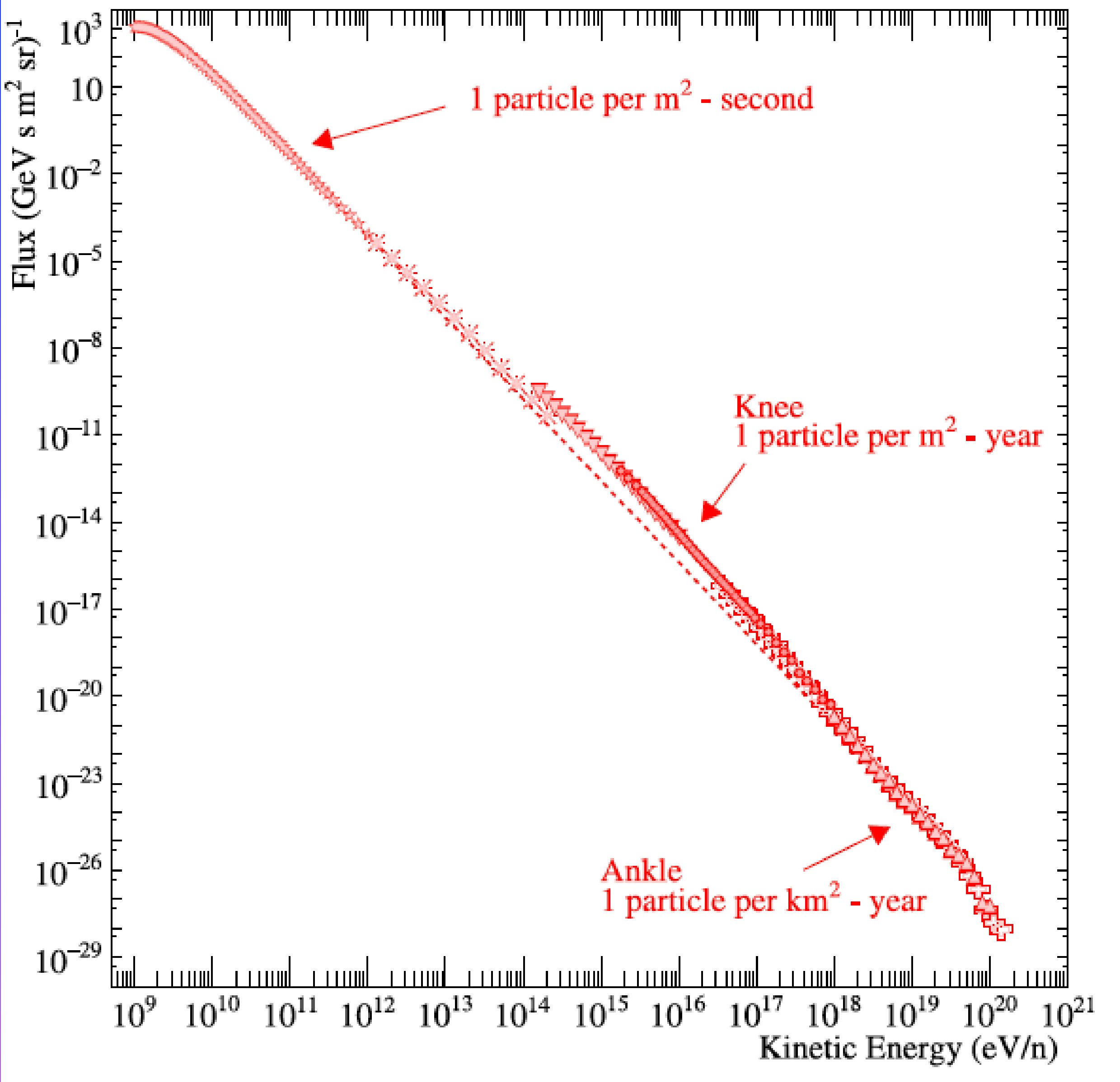


Credit C.Sparvoli

Energetic particles and completely ionized nuclei from outer space

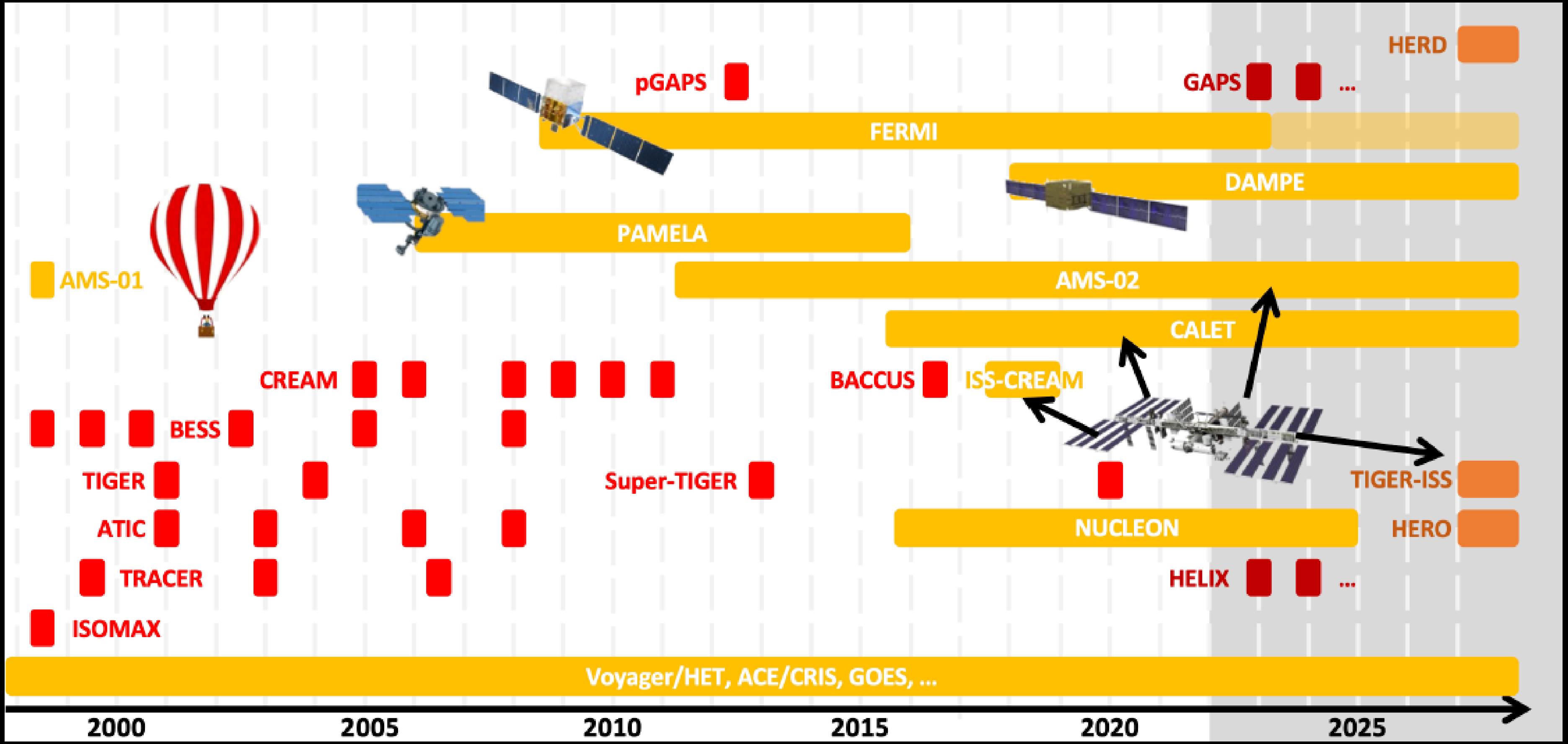
Many orders of magnitude in energy and flux

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

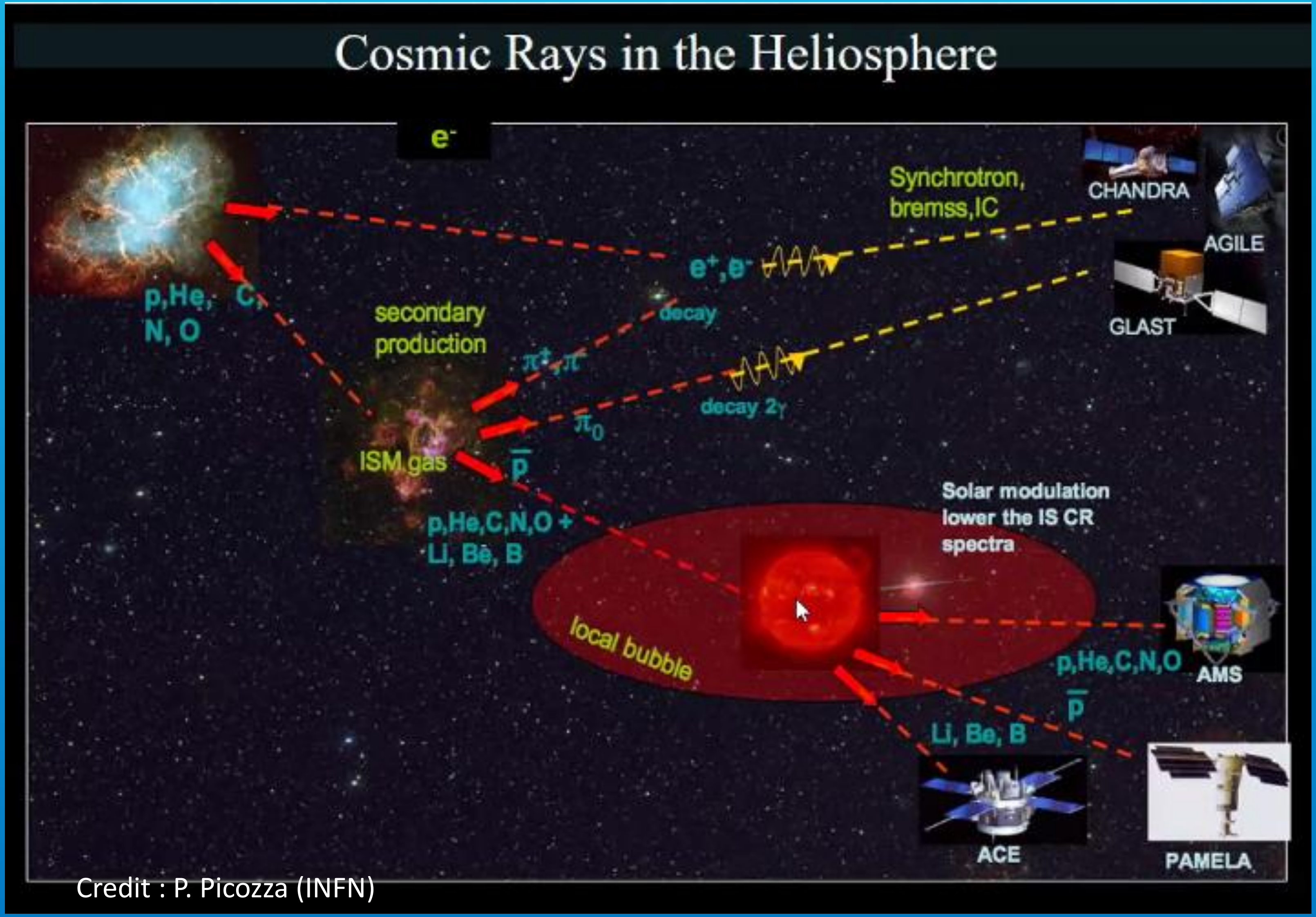


3 possible platform for instruments and detectors
baloons , Satellites , International Space Station

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.



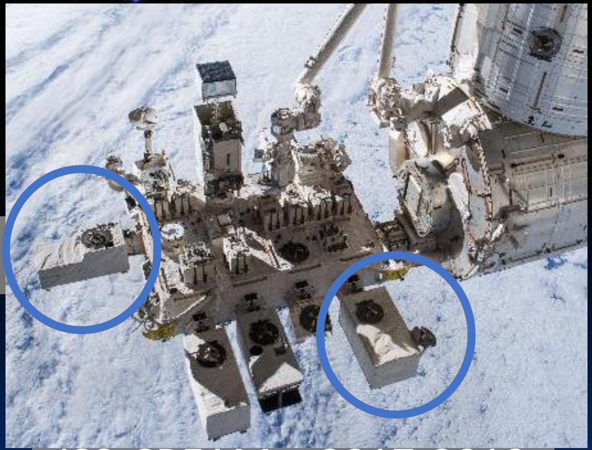
Principal Operating Cosmic Ray Space Detectors

International Space Station based

Satellite Based

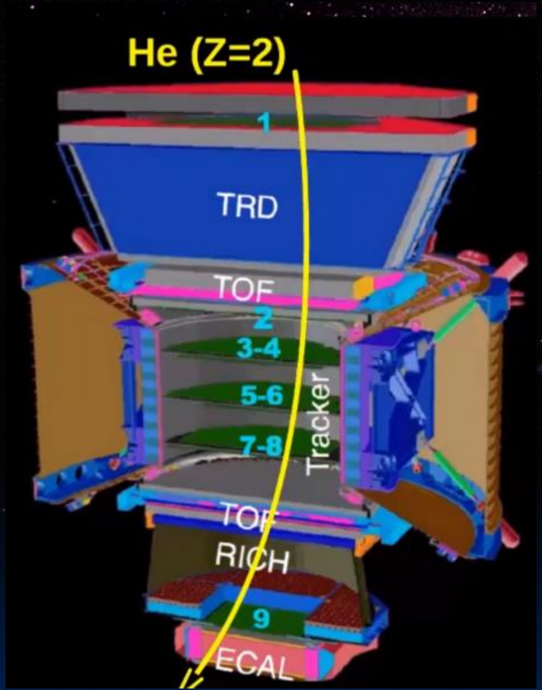
an ensemble of instruments each one designed to capture and measure the cosmic ray particles

AMS02 – 2011



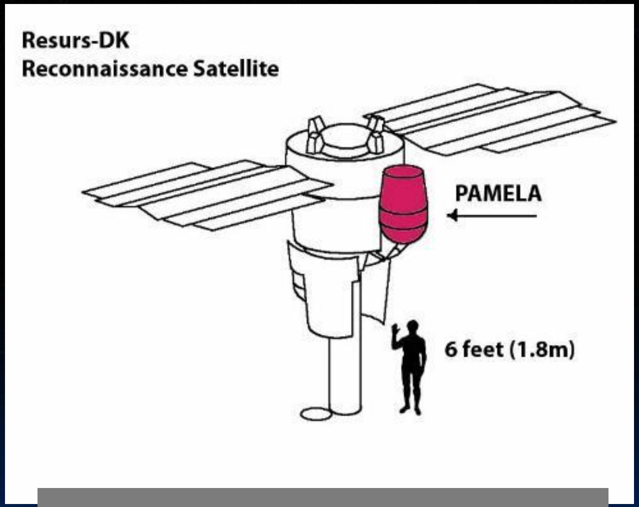
CALET - 2015

ISS-CREAM – 2017-2019



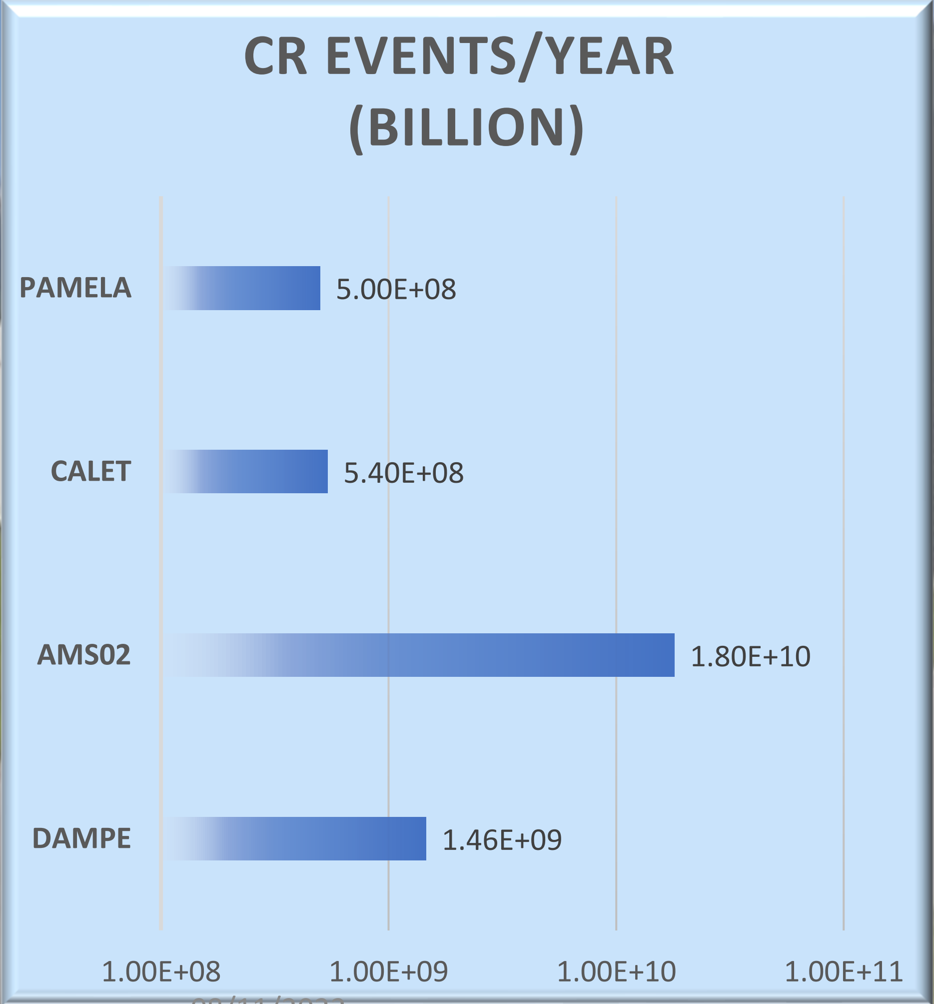
ACE - 1997

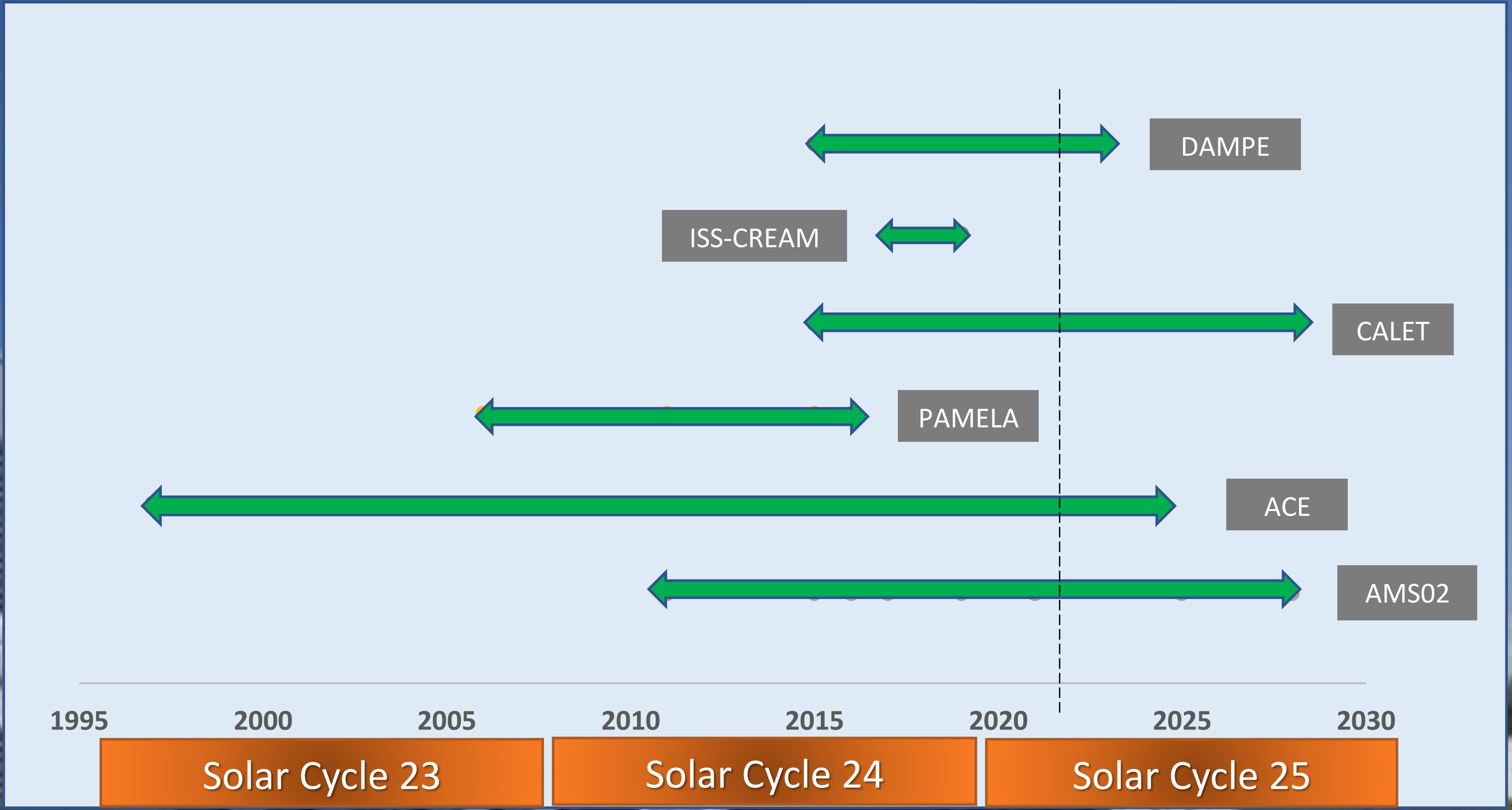
DAMPE - 2017



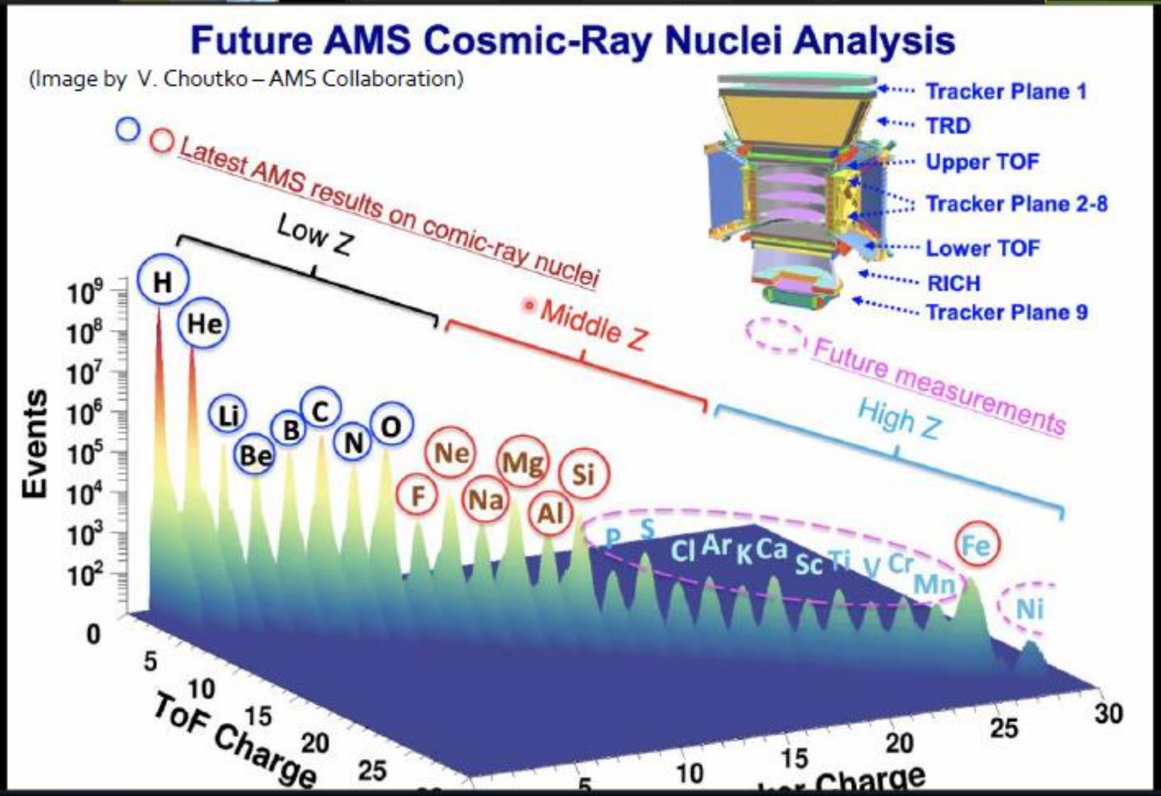
PAMELA – 2006-2016

Missions Operations





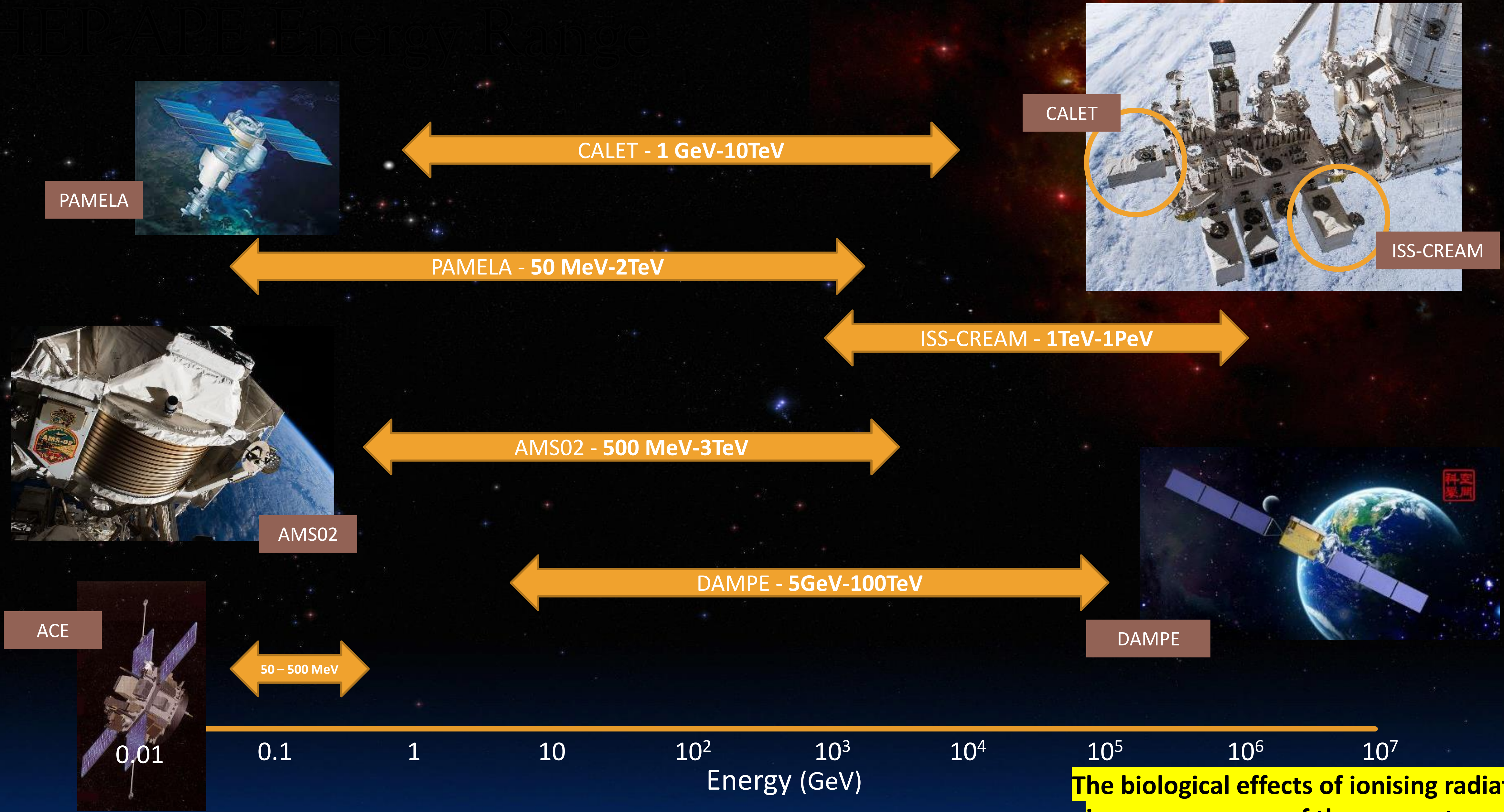
Cosmic Ray Components Identification	
e+,e-	ALL
p+,p-	ALL
D,He	ALL
Low-Z (<=8)	ALL (PAMELA up to Z=6)
Middle-Z	AMS02, CALET, ISS-CREAM, ACE, DAMPE
High-Z (>14)	AMS02, CALET, ISS-CREAM, ACE, DAMPE



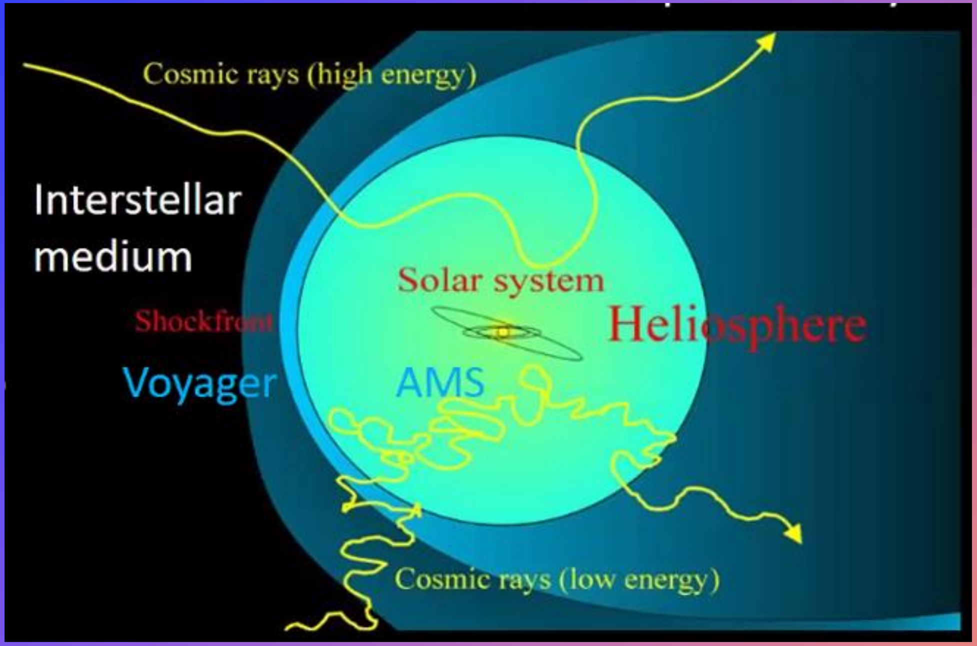
Properties of Iron Primary Cosmic Rays: Results from the Alpha Magnetic Spectrometer
AMS Collaboration • M. Aguilar (Madrid, CIEMAT) et al. (Jan 29, 2021)
Published in: *Phys.Rev.Lett.* 126 (2021) 4, 041104

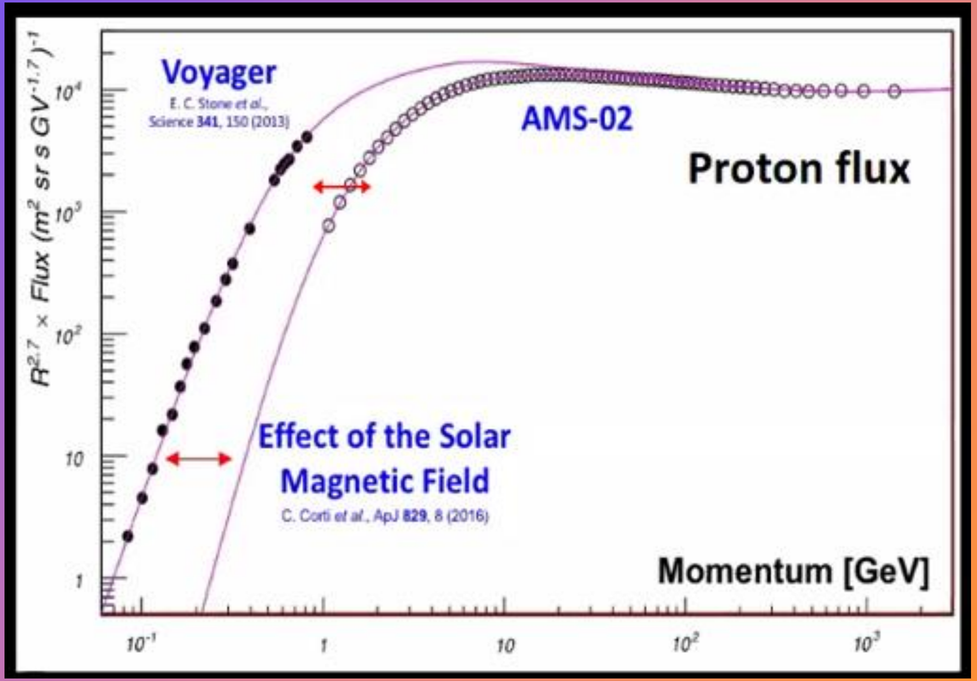
Properties of Heavy Secondary Fluorine Cosmic Rays: Results from the Alpha Magnetic Spectrometer
AMS Collaboration • M. Aguilar (Madrid, CIEMAT) et al. (Feb 25, 2021)
Published in: *Phys.Rev.Lett.* 126 (2021) 8, 081102

HEP-APE Energy Range



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

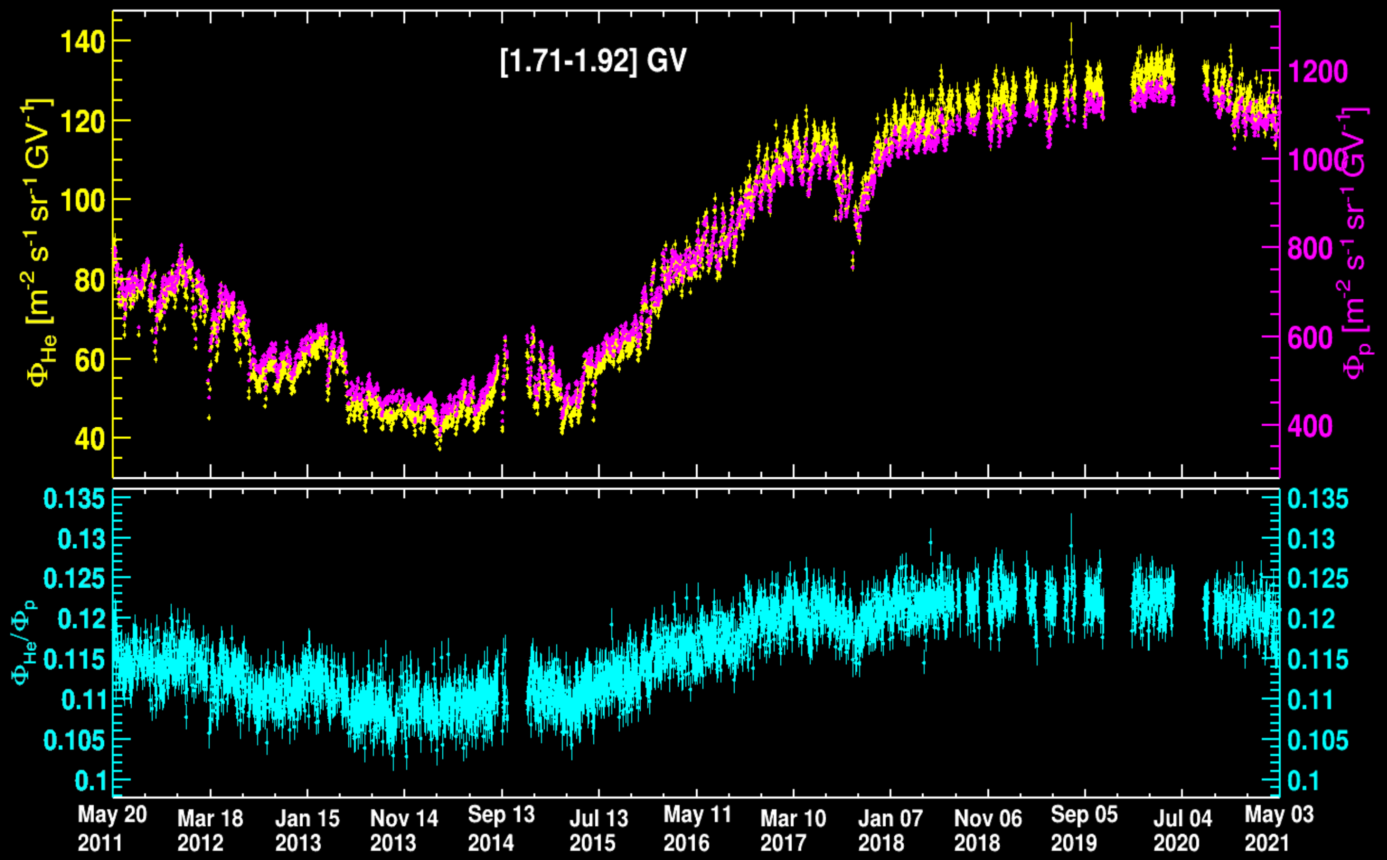
Cosmic rays from interstellar medium are «screened» by the Heliosphere.

This effect is particularly visible at low energies

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

Properties of Daily Helium Fluxes
AMS Collaboration • M. Aguilar (Madrid, CIEMAT) et al. (Jun 10, 2022)
Published in: *Phys.Rev.Lett.* 128 (2022) 23, 231102

Periodicities in the Daily Proton Fluxes from 2011 to 2019 Measured by the Alpha Magnetic Spectrometer on the International Space Station from 1 to 100 GV
AMS Collaboration • M. Aguilar (Madrid, CIEMAT) et al. (Dec 27, 2021)



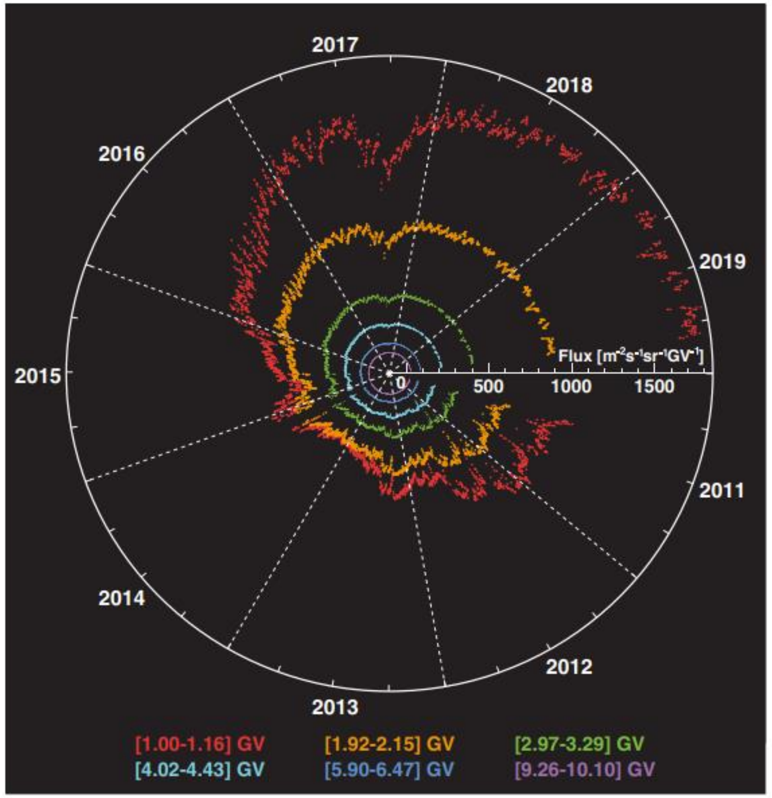
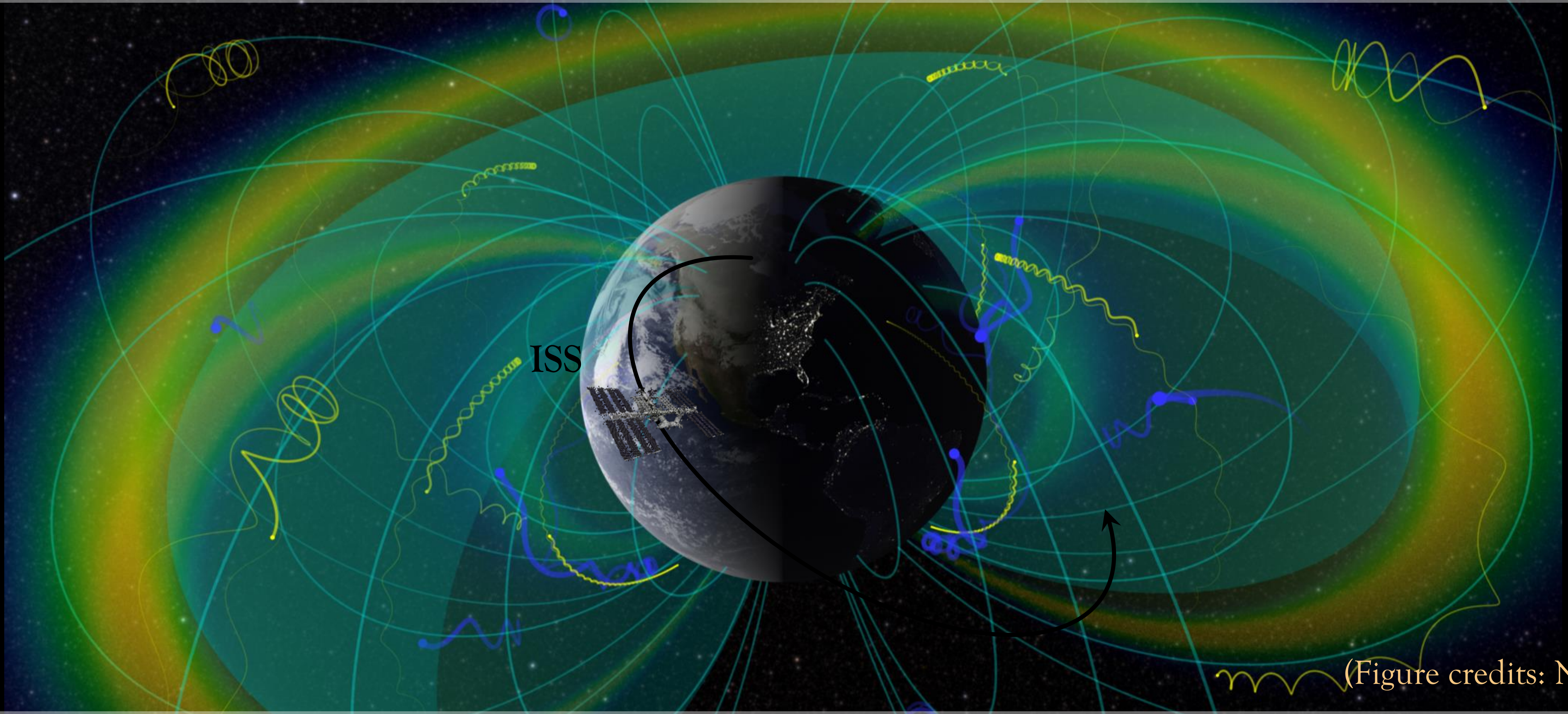


FIG. 1. The daily AMS proton fluxes for six typical rigidity bins from 1.00 to 10.10 GV measured from May 20, 2011 to October 29, 2019 which includes a major portion of solar cycle 24 (from December 2008 to December 2019). The AMS data

Short term Solar Modulation of GCR

Daily Proton and Helium Fluxes and Helium to Proton flux ratio

Cosmic Rays in the Magnetosphere



(Figure credits: NASA)

Particles **trapped** in the Earth magnetic field create regions of **high radiation** called **Van Allen belts**. The ISS crosses one of the belts over South America, causing a sudden increase of the observed radiation known as the **South Atlantic Anomaly**.

Appendix III

A Research Topic Collection Initiative

«

THE RESEARCH TOPIC INITIATIVE

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


Alessandro Bartoloni
National Institute of Nuclear Physics of Rome
Rome, Italy


Nan Ding
Institute of Modern Physics, Chinese Academy of Sciences (CAS)
Lanzhou, China


Gianluca Cavoto
Sapienza University of Rome
Rome, Italy


Cristina Consolandi
University of Hawaii at Manoa
Honolulu, United States


Lidia Strigari
Dipartimento di Fisica Medica, IRCCS Azienda Universitaria di Bologna
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.