INTERNATIONAL CONFERENCE ON RADIATION IN VARIOUS FIELDS OF RESEARCH

RAD 10th Jubilee Summer Edition

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Herceg Novi | Montenegro

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

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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.

In that sense **an innovative approach could come from state of the art instrumentation and detectors operating in space**, built for astroparticle measurements, allows for the estimation of GCR properties and absorbed dose with a greater accuracy, **thanks to the recent availability of the Alpha Magnetic Spectrometer (AMS) detector, installed on the International Space Station, that measures charged components of cosmic rays since 2011 and is approved to be operative for all the life cycle of the ISS**.

Outline

INTRODUCTION

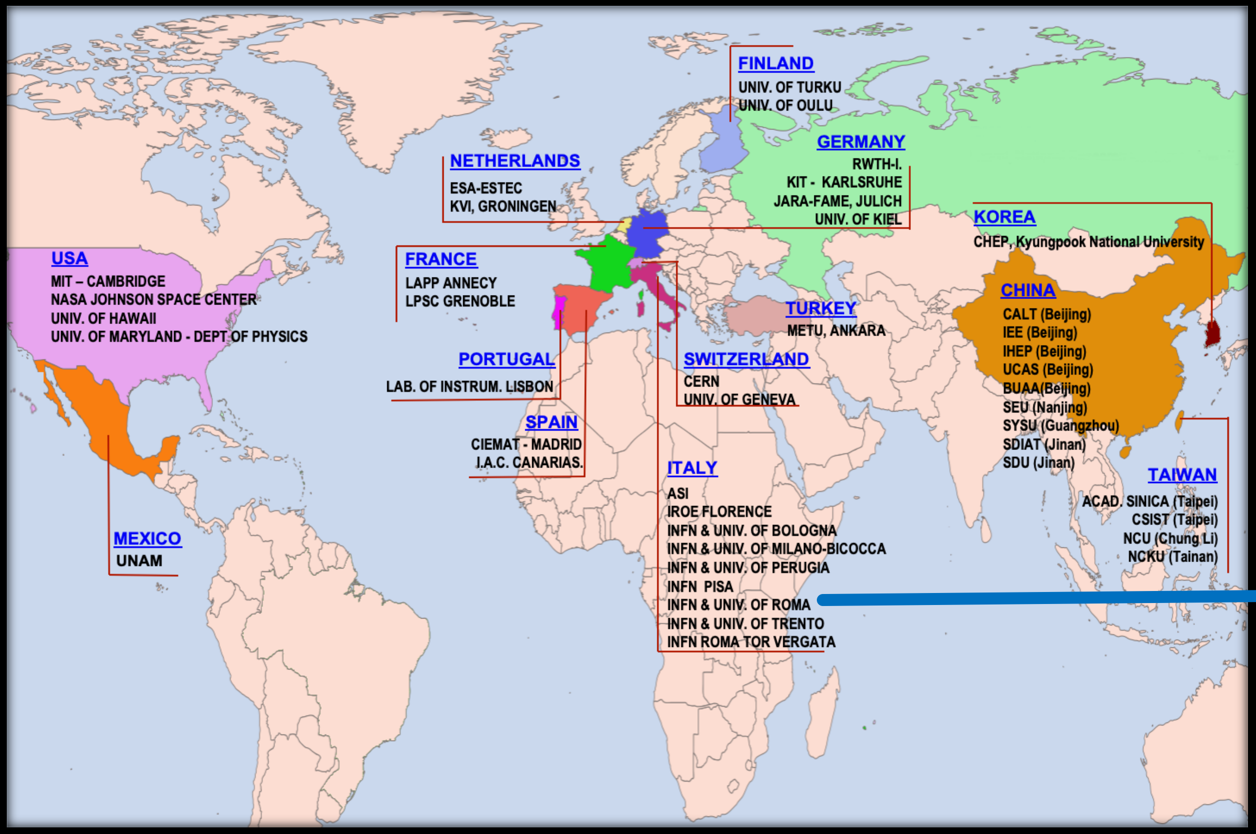
Alpha Magnetic Spectrometer (AMS)

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.

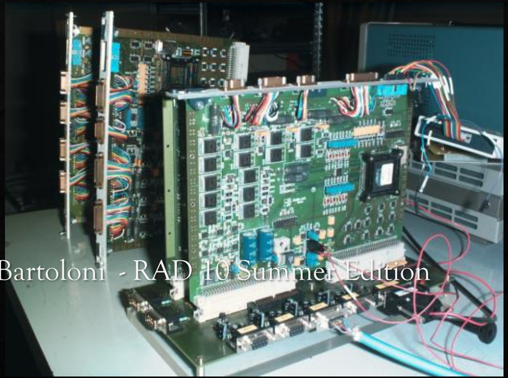
More Info in the AMS-02 webpage:
https://ams02.space

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

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

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**.

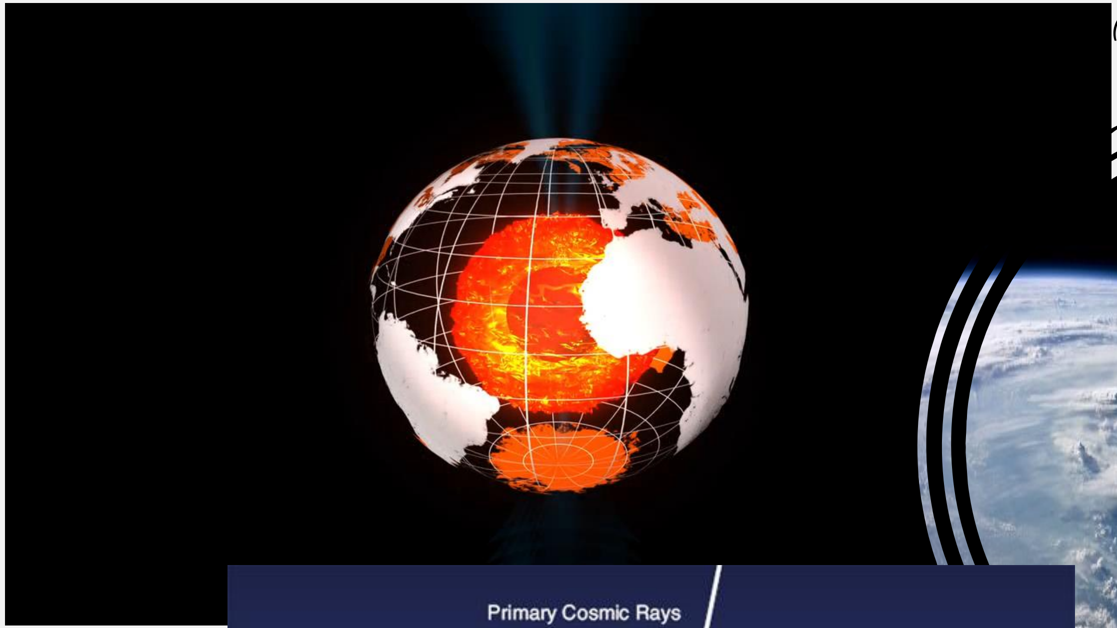
Dr. Lidia Strigari

Medical Physics Department

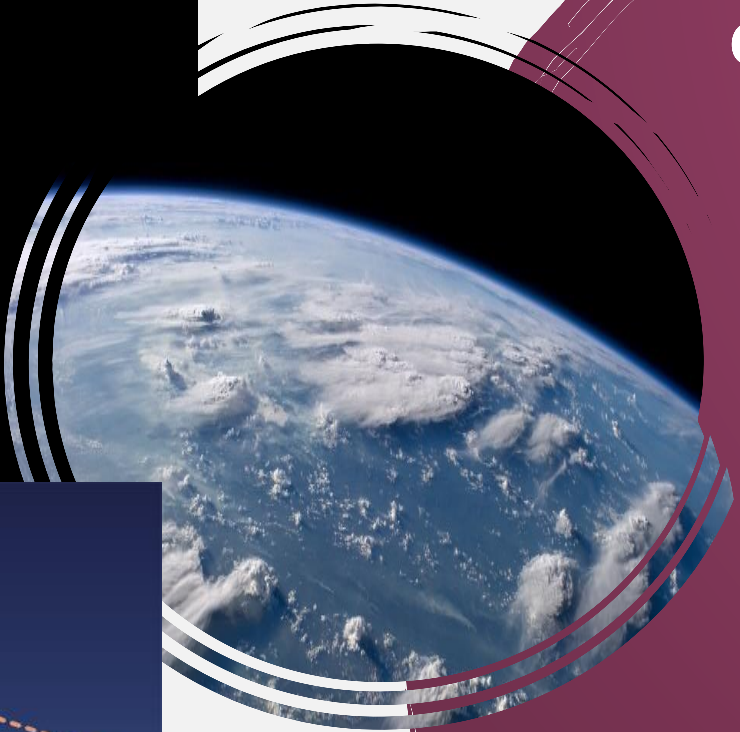
IRCCS Azienda Ospedaliero-Universitaria di Bologna, Italy

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)

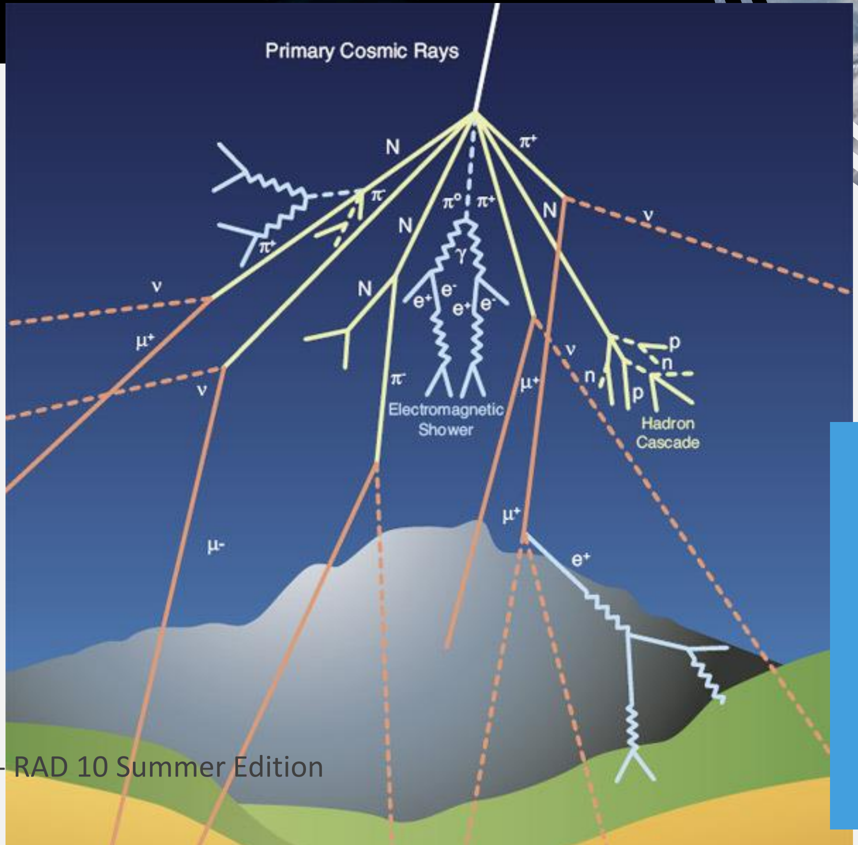


Cosmic Rays Interactions with the geo-magnetosphere

Earth is a cocoon !!!

Magnetosphere stops/deflects 99.9% of charged particles

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



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

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

(credit : CERN)

Origin of Space Radiation and Consequent Risk

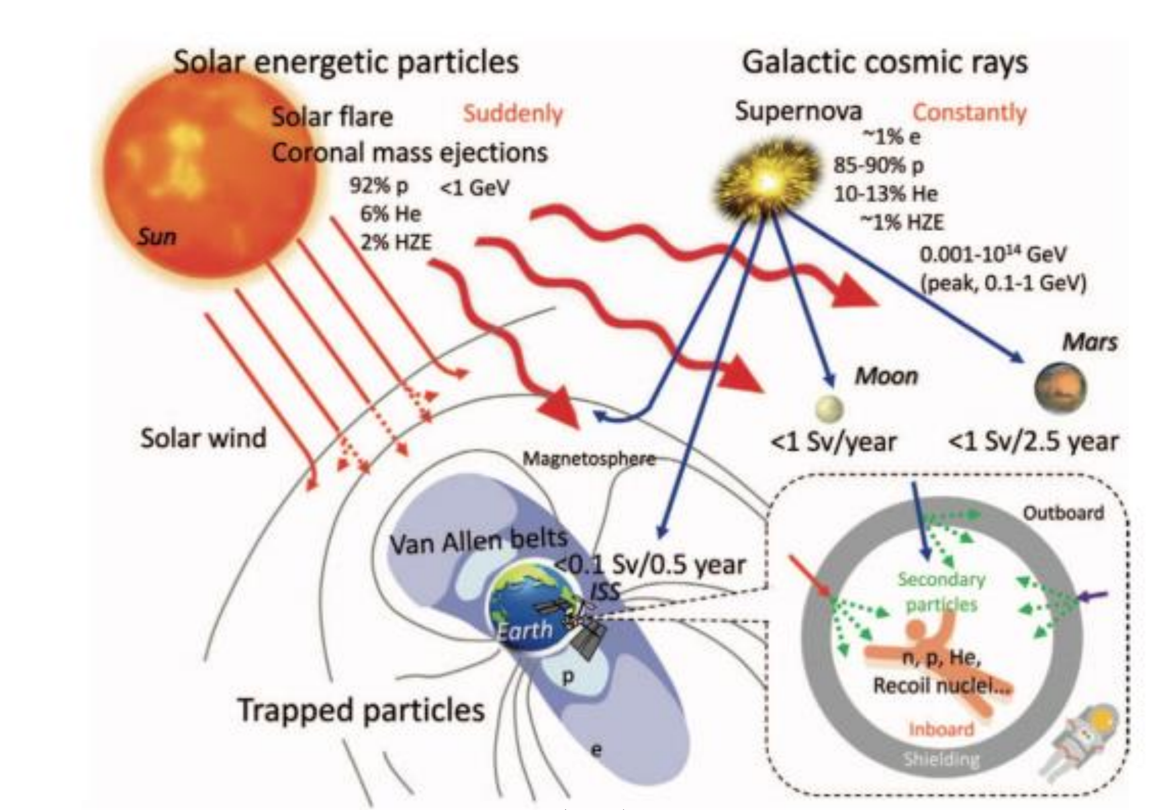
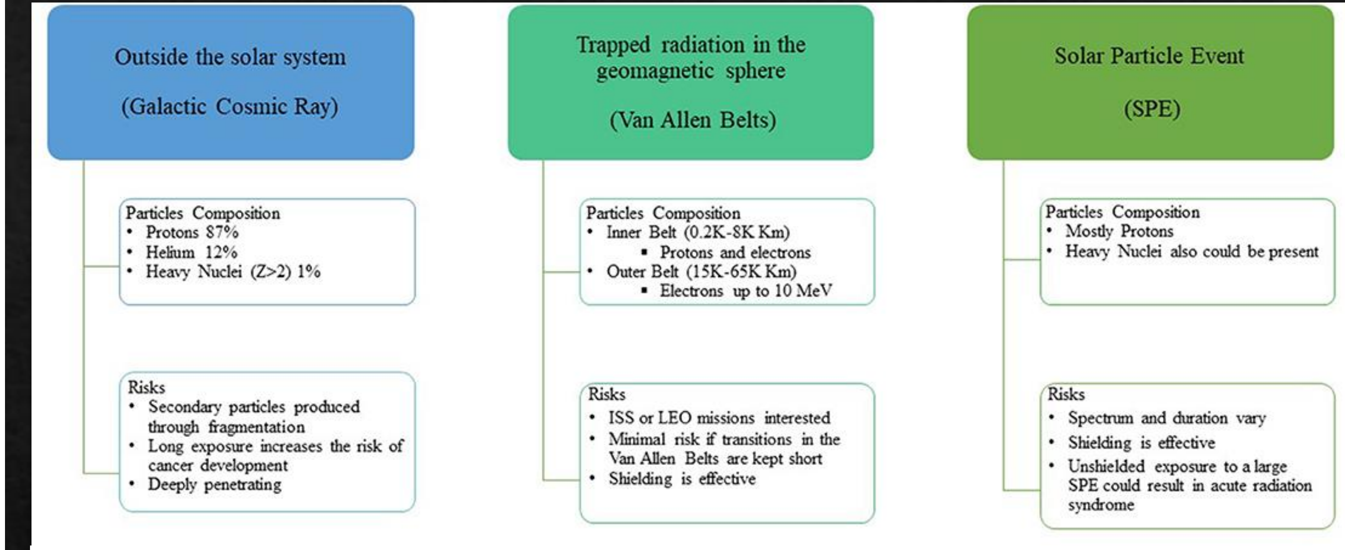


Image courtesy of European Space Agency (ESA)



From Strigari et Al Front. Public Health, 08 November 2021 | https://doi.org/10.3389/fpubh.2021.733337

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)**

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

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

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

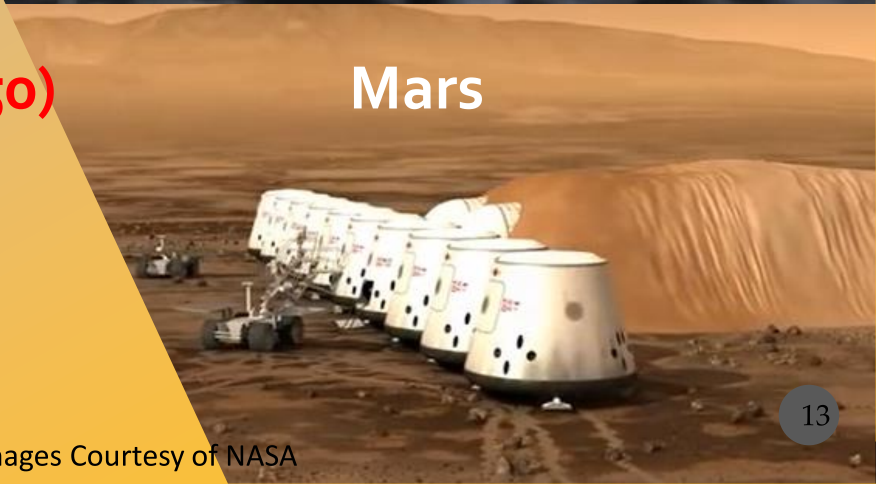
- short-term (<hours)
- acute effects (<months)
- late effects including severe toxicity

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)

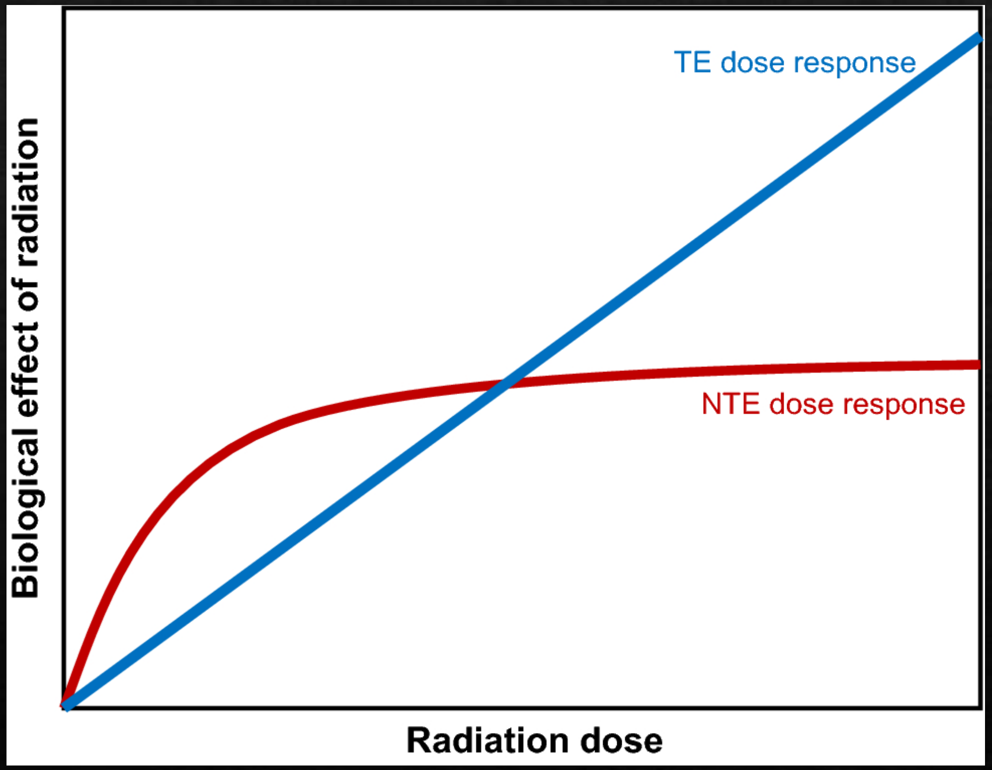


Images Courtesy of NASA

Part I: Dose Effects Relationship (DER)

Dose-Effect Relationship

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 correletion between the exposition to IR and the possible damages to the organ at risk



Dose-Effects Relationship

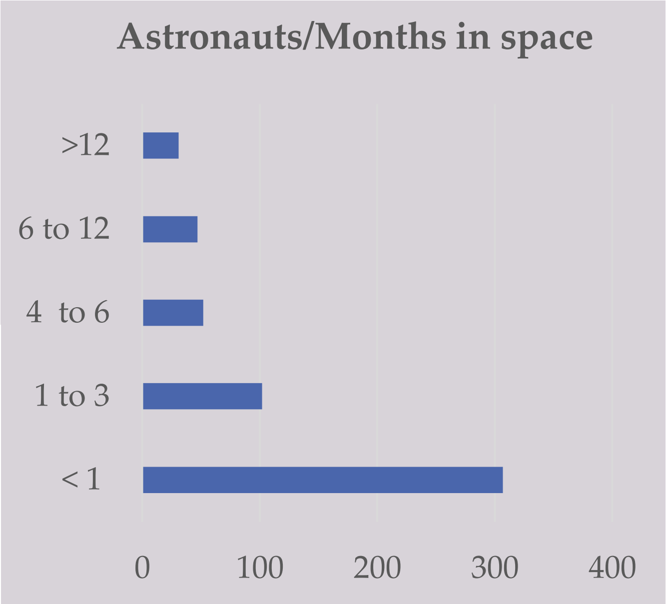
The known dose-effect relationships are based on a limited number of astronauts

(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 improvements

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

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

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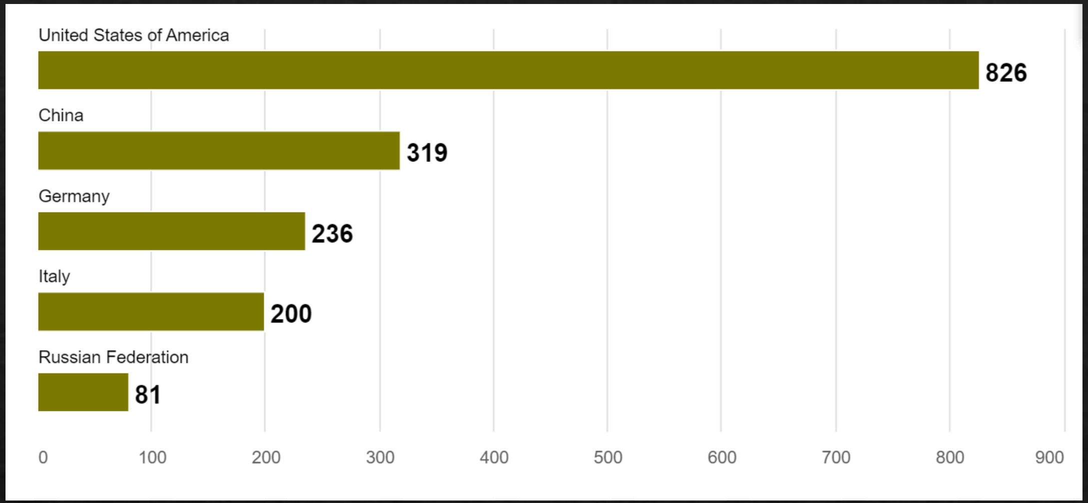
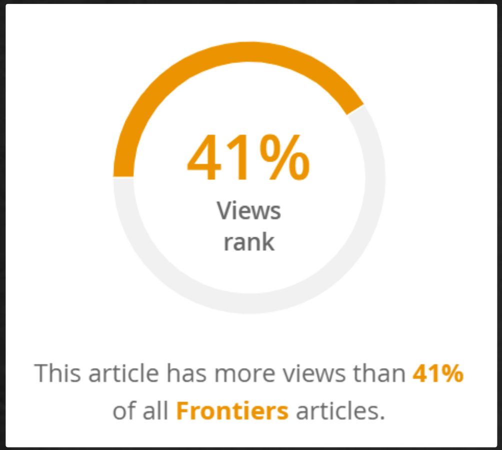
Dose-Effects Models for Space Radiobiology: An Overview on Dose-Effect Relationships

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

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.*					





Article Statistics (June 2022)

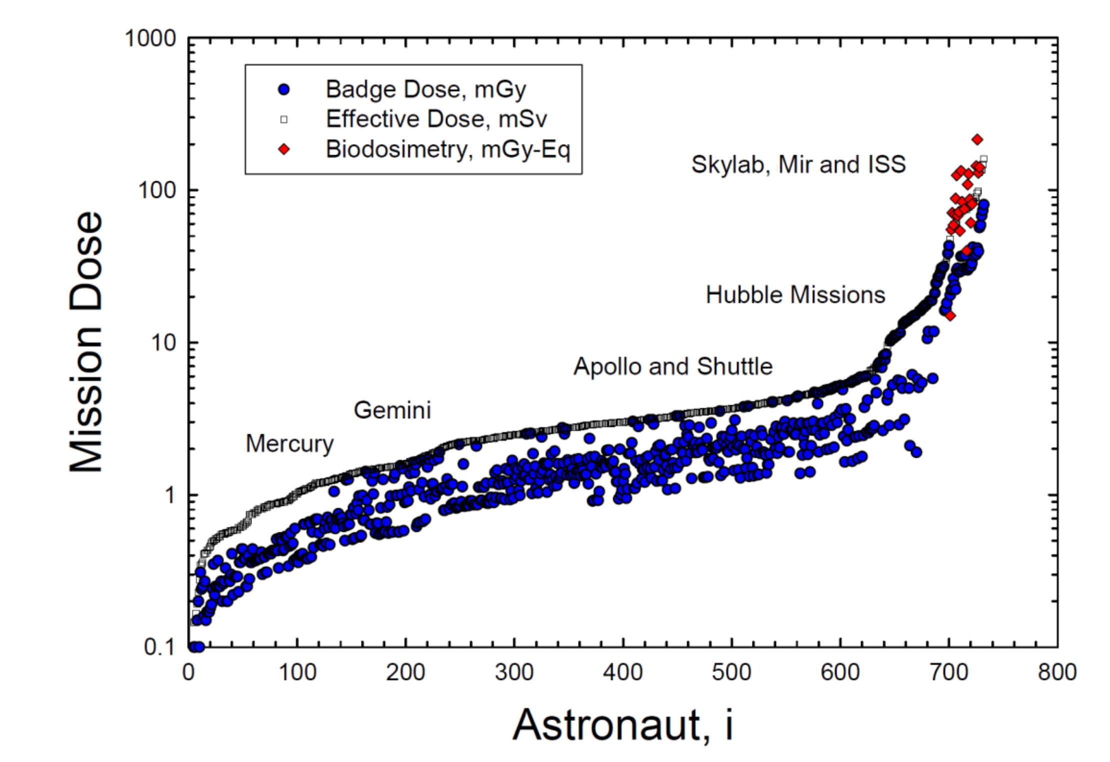
RISK for the CNS due to IR

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.

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)

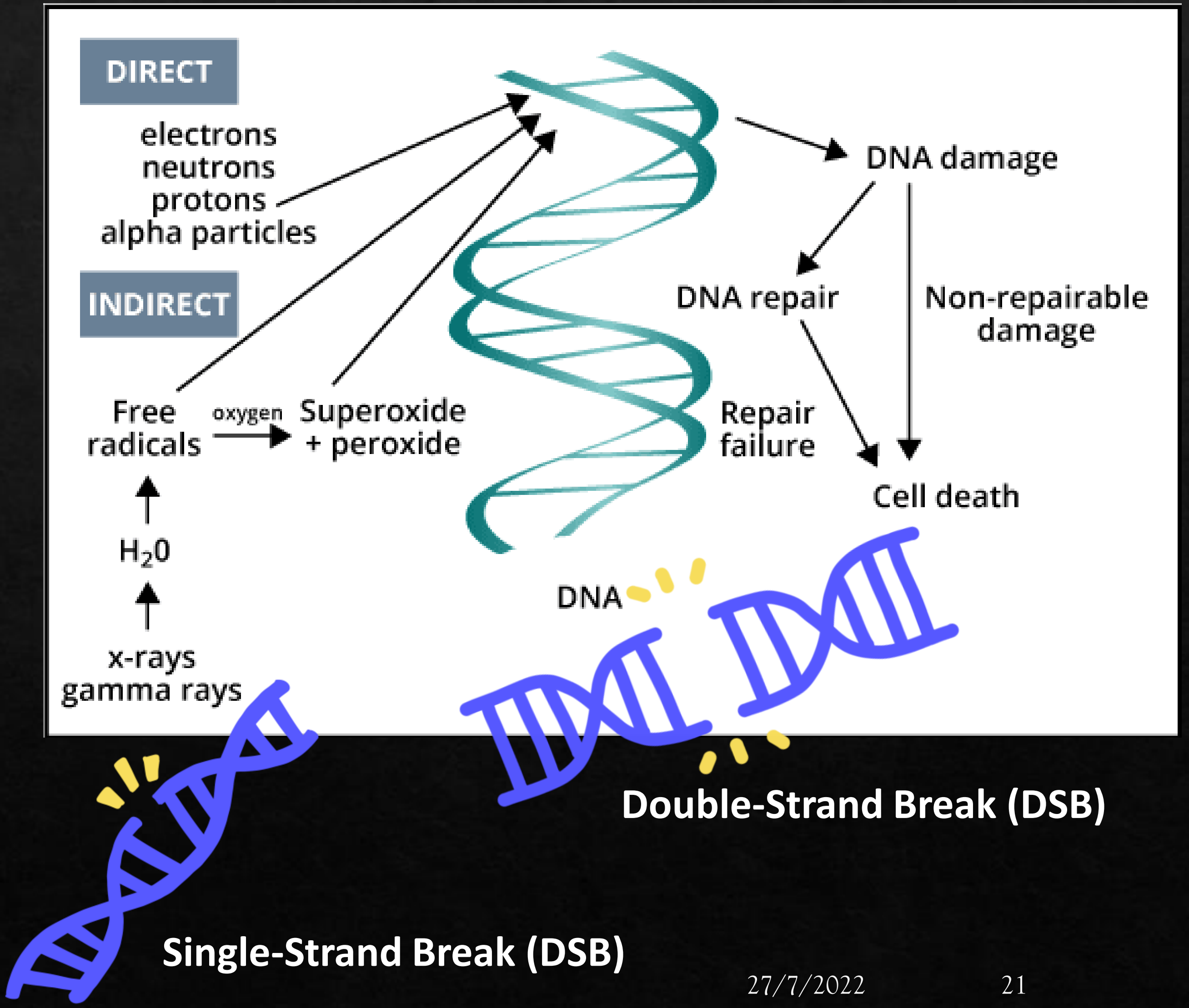


Summary of mission personnel dosimetry from all past NASA crew (Cucinotta et al. 2008).

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.

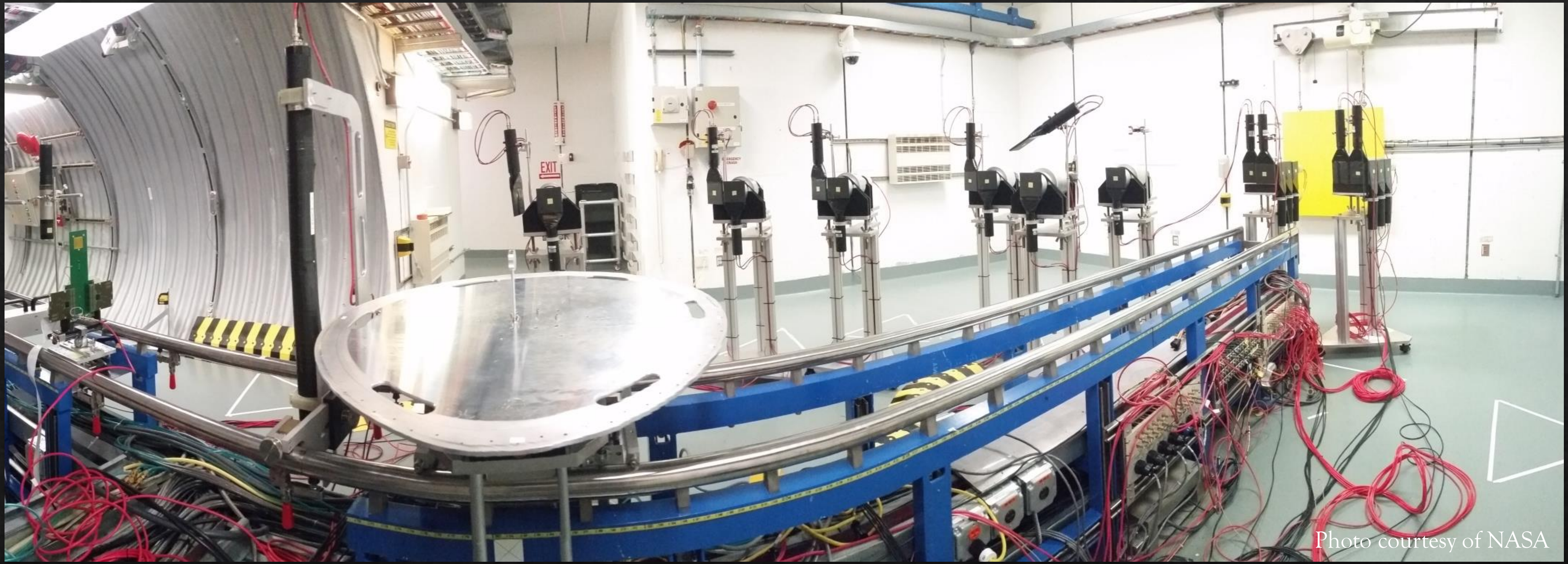


Space Radiation effects on CNS
Early vs Late

- **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**

Dose Effects Relationship for CNS



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

Microgravity effects are also to be considered.

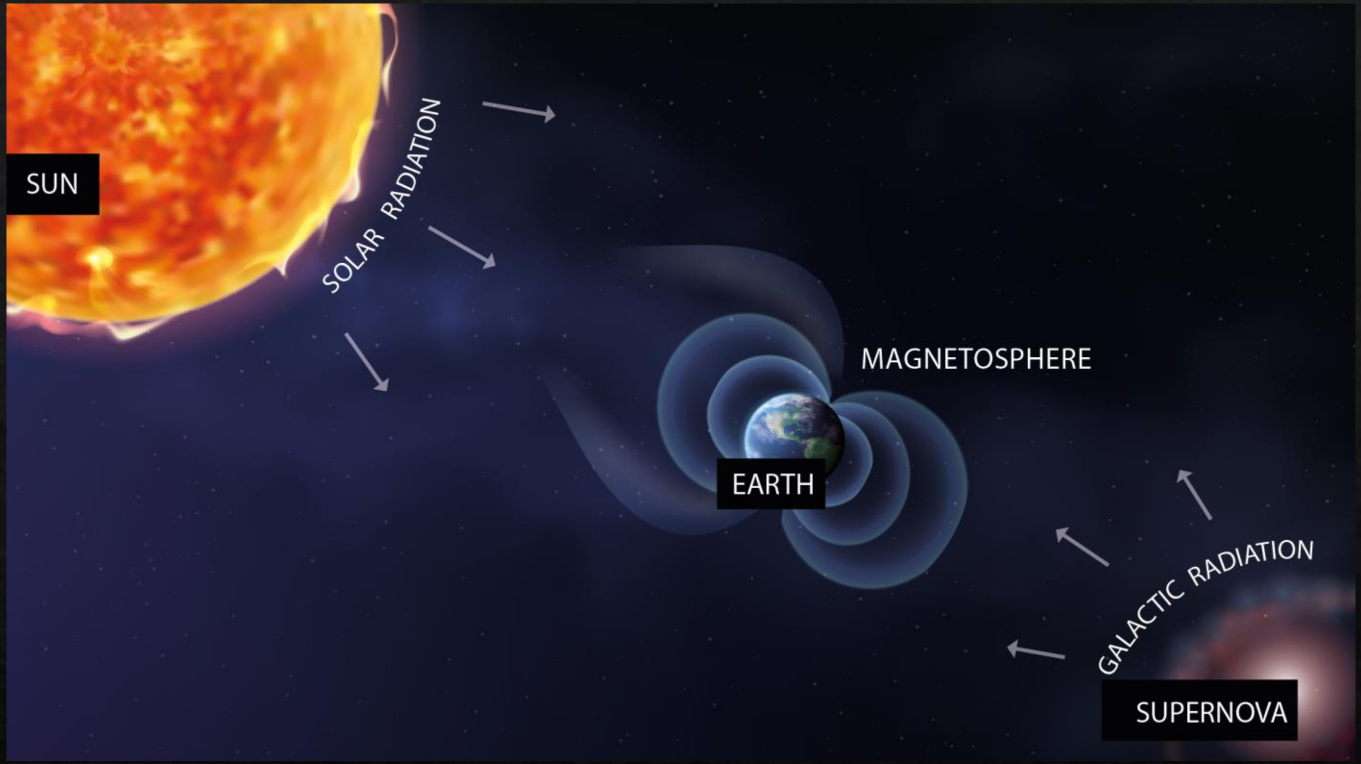


Image courtesy of IAEA

Dose effects relationship

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.
- Individual **radio susceptibility** should be considered in dose-effect models predicting the radiation-induced CNS changes.
- 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.

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

- **Computer Simulation of interactions of IR with biological matter**

  Simplified 3D neuron models with properties equivalent to realistic neuron morphology have been developed using GEANT4 to describe the effect observed in rats after a dose from 0.1 to 2 Gy delivered to the hippocampus Of note, the changes to synapses are one aspect to be considered.

- **Synergy with the Clinical Field :**

  The possible risks to astronauts chronically exposed to space radiation could prevent astronauts from performing complex executive functions which are to be deeply investigated after radiotherapy for brain cancers.

- **Mathematical Modelling** :

  Cacao E and Cucinotta FA in 2016 reported a predictive mathematical model of radiation-induced changes to neurogenesis for various radiation types after acute or fractionated irradiation, extending a mouse model of impaired neurogenesis in the hippocampal dentate gyrus after exposure to low-LET radiation to heavy ion irradiation.

- **Quantitative Meta Analysis**

  recently, the first quantitative meta-analysis of the dose-response for proton and heavy-ion rodent studies has been published based on the widely used novel object recognition test, which estimates detriments in recognition or object memory (27). The log-normal model predicts a heavy-ion dose threshold of ~0.01 Gy for novel object recognition-related cognitive detriments.

- **Radioprotectors effects in models :**

  One of the most promising ways to prevent and mitigate the acute effects of CNS and the neurocognitive impairment during long-term spaceflight is based on the use of substances (e.g., Dammarane Sapogenins)

- **Synergy with the Astroparticle experiments ….**

A synergy with Astroparticle researches

Part II : Target Effects vs Non Target Effects

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Target Effects vs. Non-Target Effects in Estimating the Carcinogenic risk due to Galactic Cosmic Rays in Exploratory Space Missions.

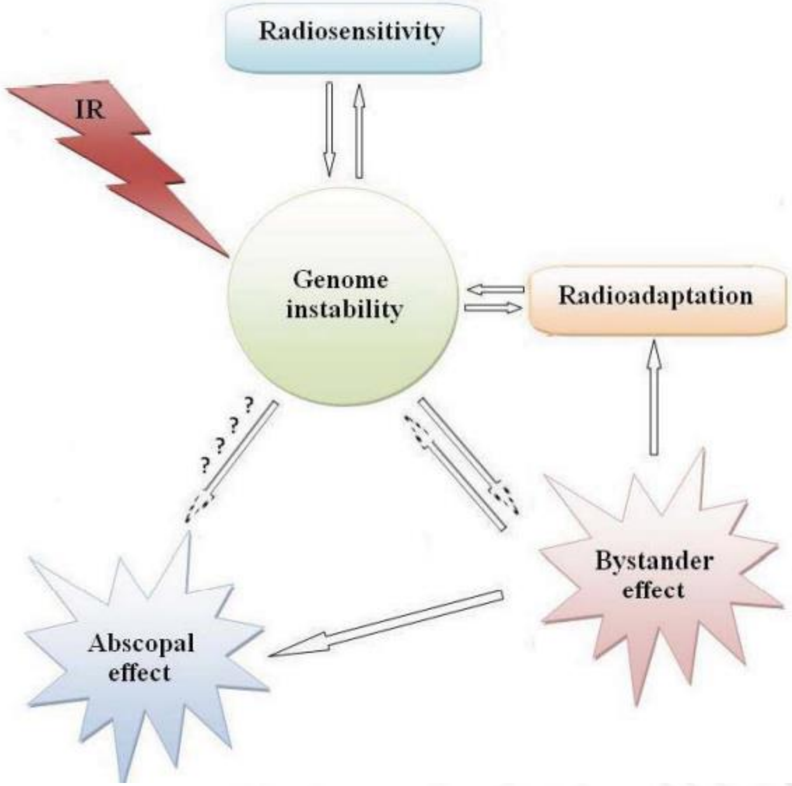
L. Strigari[1,2], A.N. Guracho[2] , A. Bartoloni[2]

1Department of Medical Physics, Istituto di Ricovero e Cura a Carattere Scientifico (IRCCS) Azienda Ospedaliero-Universitaria di Bologna, Bologna, Italy

2 Istituto Nazionale di Fisica Nucleare (INFN) Rome-Sapienza Division, Rome, Italy

Work in progress at Roma AMS group (*A.Bartoloni, A.N. Guracho, L.Strigari*)

- "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"



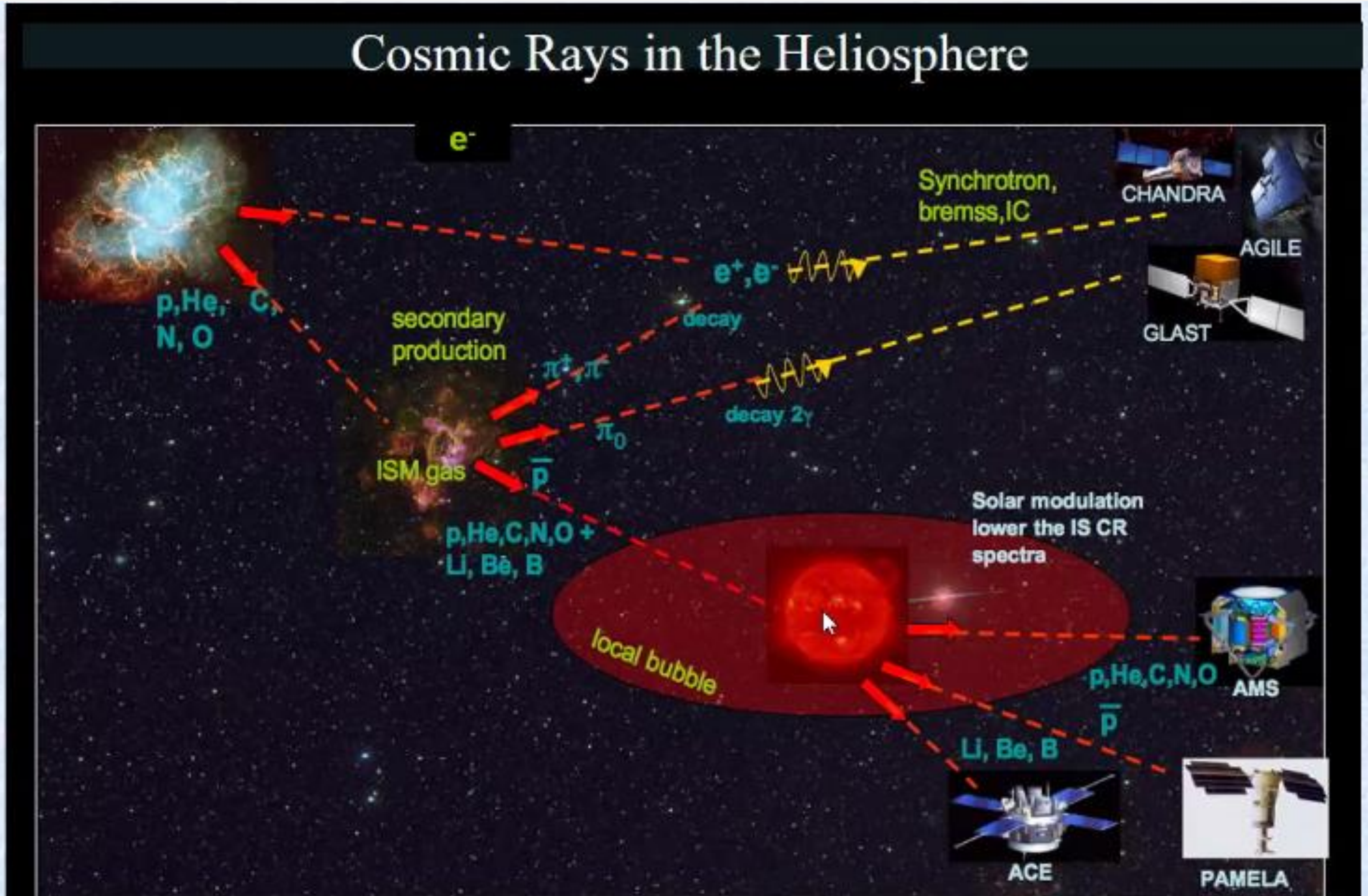
Non-Targeted Effects Models Predict Significantly Higher Mars Mission Cancer Risk than Targeted Effects Models

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

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)

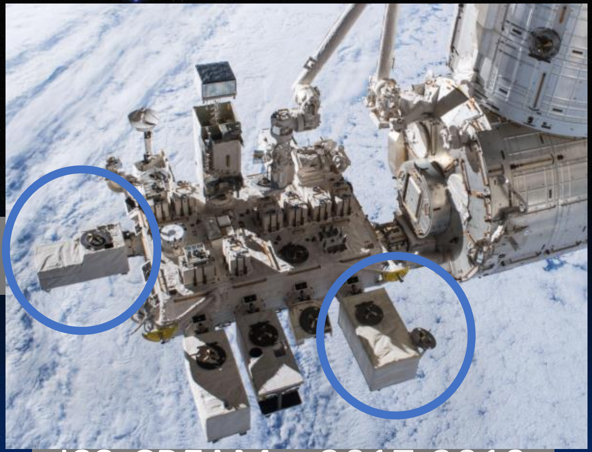
Principal Operating Cosmic Ray Space Detectors

International Space Station based

Satellite Based

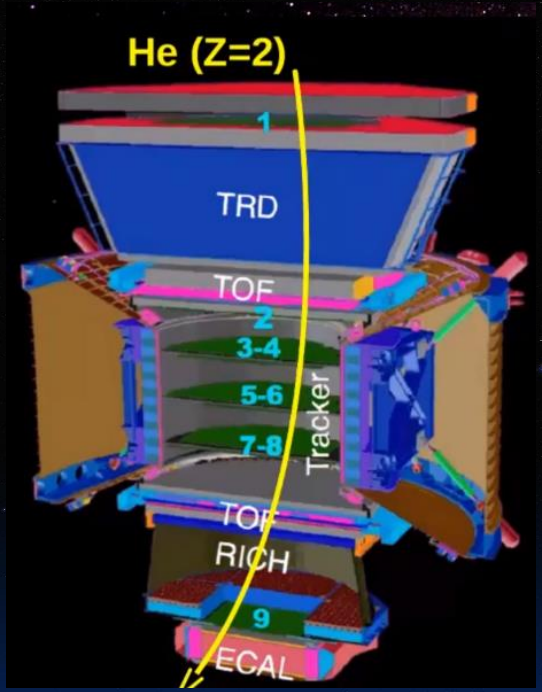
an ensemble of instruments each one designed to capture and measure the cosmic ray particles

AMS02 – 2011



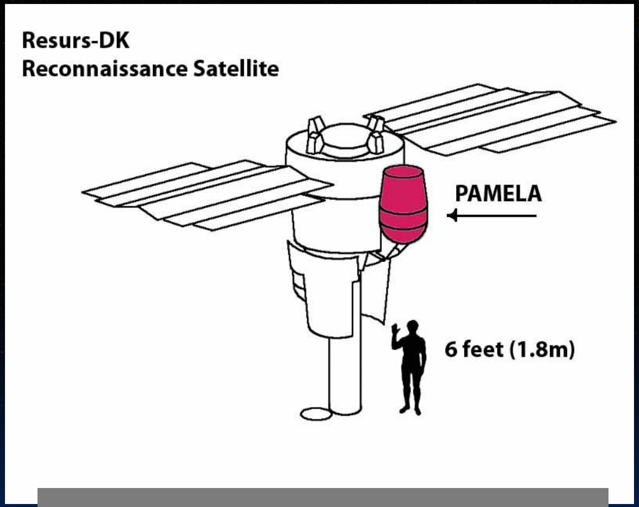
CALET - 2015

ISS-CREAM – 2017-2019



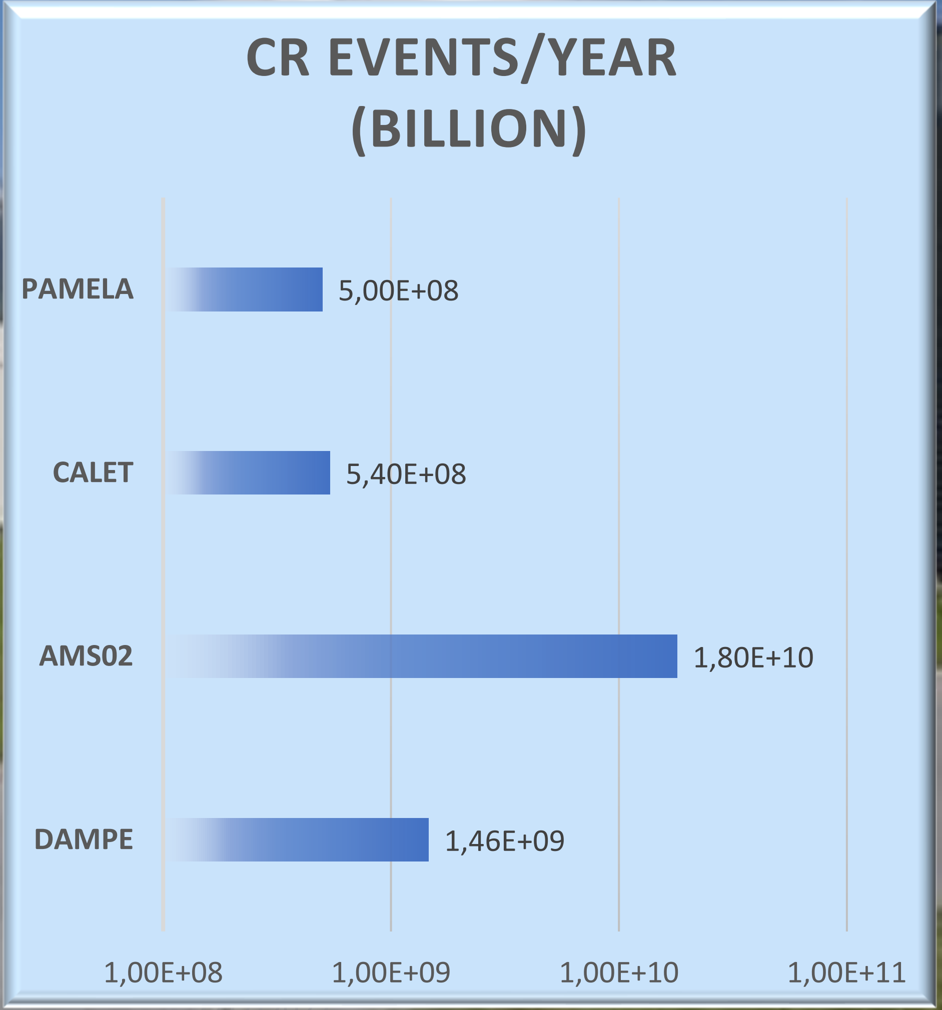
ACE - 1997

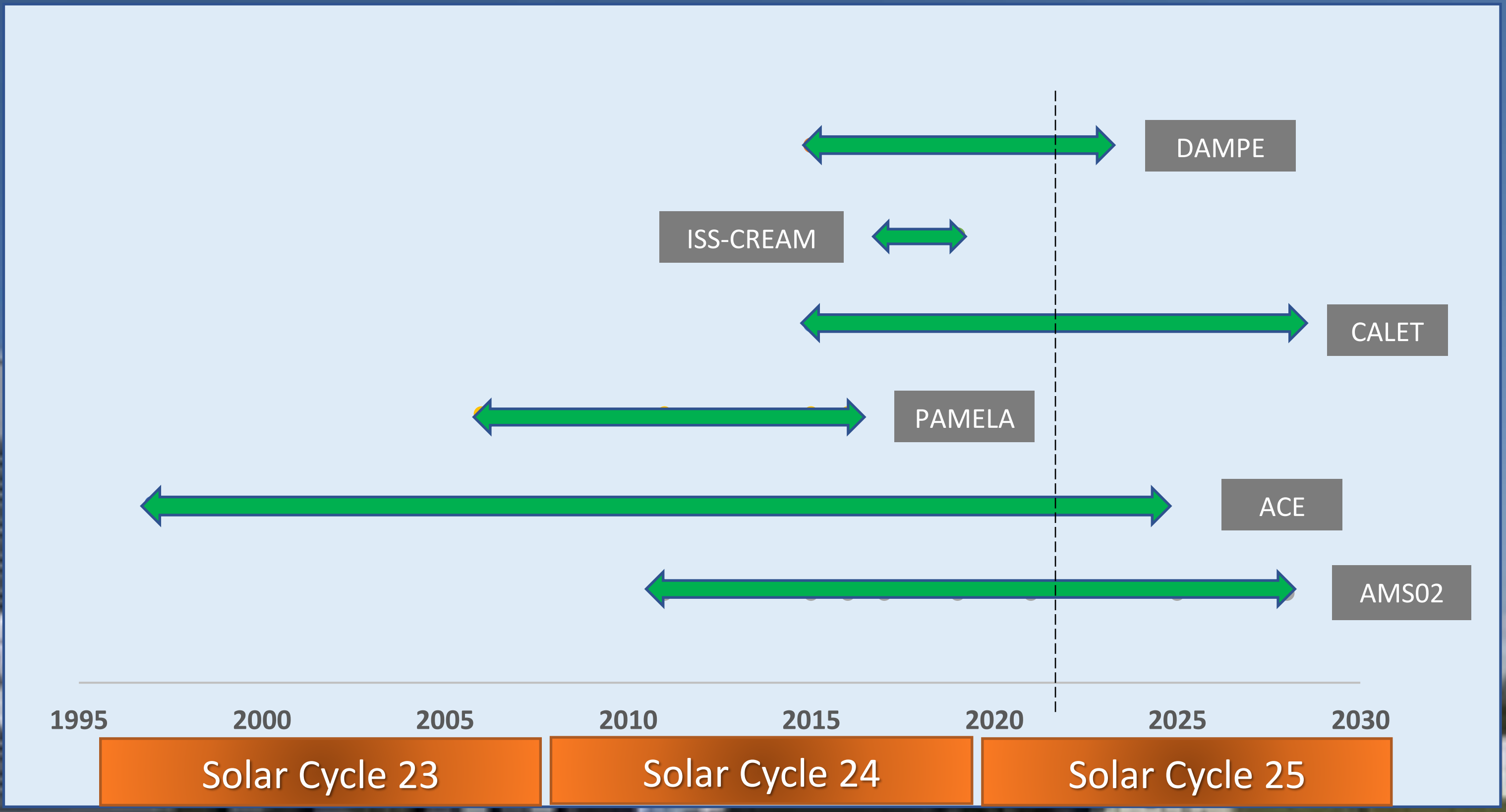
DAMPE - 2017



PAMELA – 2006-2016

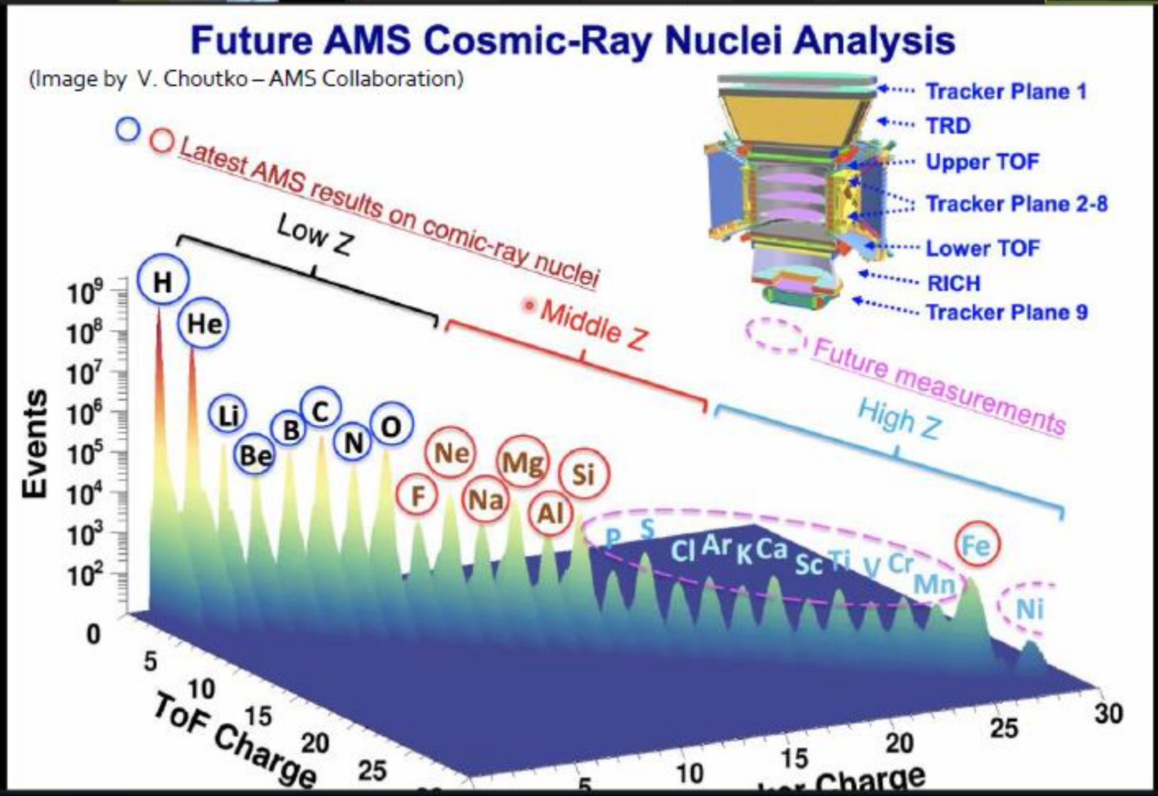
Missions Operations





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



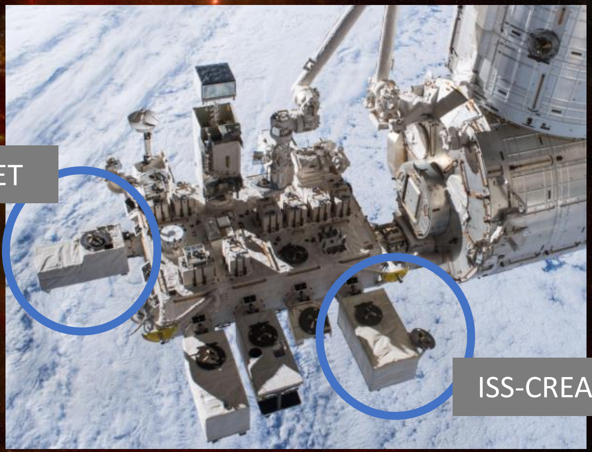
Properties of Iron Primary Cosmic Rays: Results from the Alpha Magnetic Spectrometer
AMS Collaboration • M. Aguilar (Madrid, CIEMAT) et al. (Jan 29, 2021)
Published in: *Phys.Rev.Lett.* 126 (2021) 4, 041104

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 - **5GeV-100TeV**

DAMPE

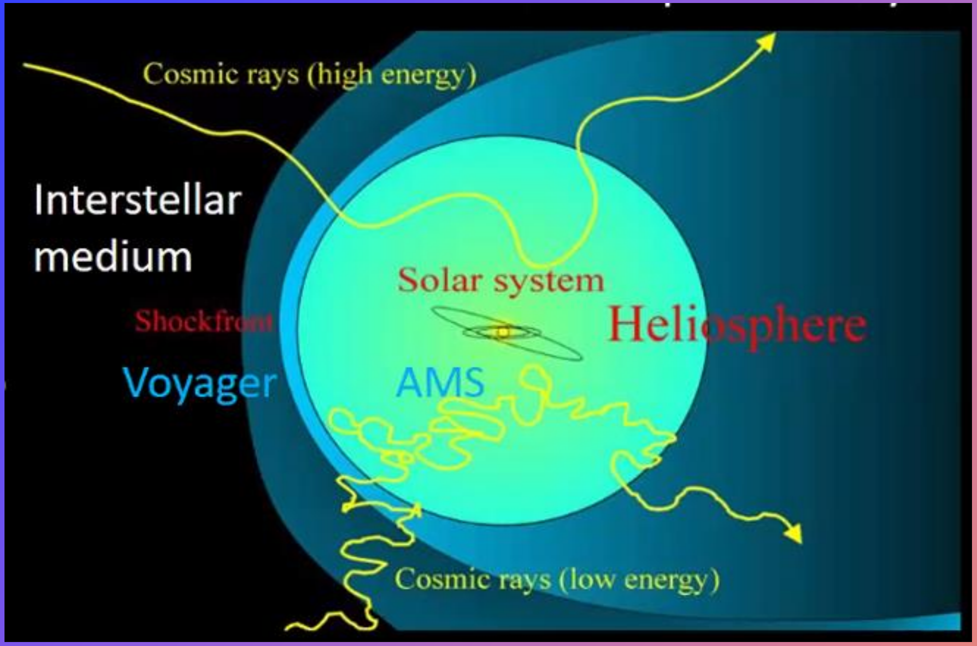
ACE

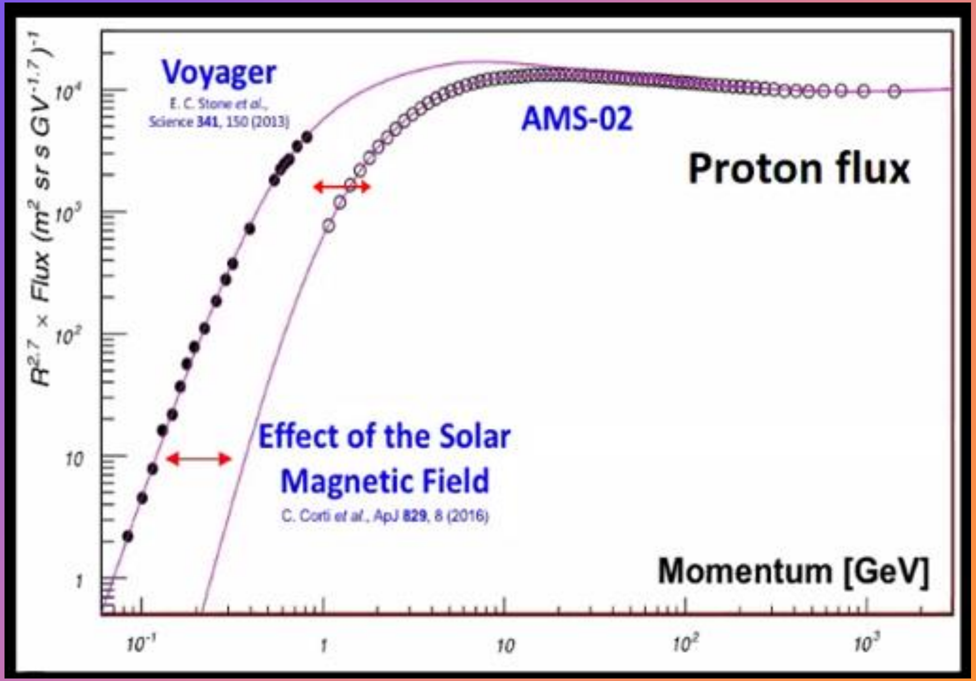
50 – 500 MeV

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 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

NTE in Tumor Prevalence (TP) of HGT in rodent model

- ***Prevalence*** is the number of people/cell with a specific disease or condition in each population at a specific time. This measure includes both newly diagnosed and pre-existing cases of the disease.

- **Tumor prevalence (TP)** is described by a Hazard function, H, which is dependent on radiation type for γ-rays or particles with charge number Z and kinetic energy per atomic mass unit (u), E and fluence F, the energy per unit area contained in the particles with which a cell is irradiated

TP$= \mathbf{1 - e^{-H(Z,E,F)}}$

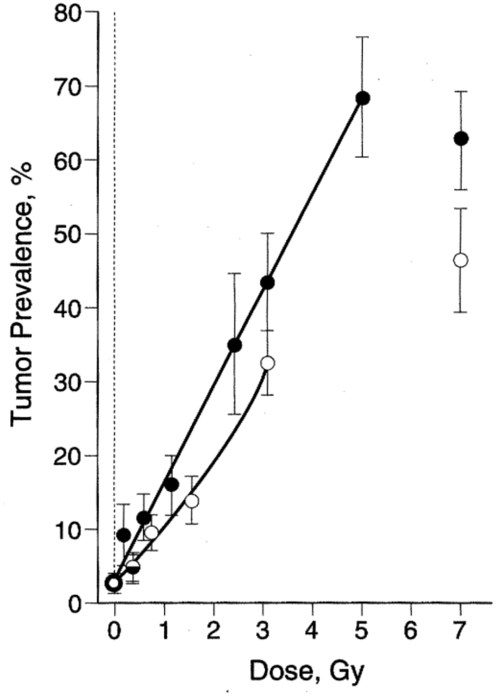


FIG. 1. Tumor prevalence for mice irradiated with 228*A* MeV helium ions (●) in the plateau of the Bragg curve, or ^{60}Co γ rays (○). The mice received pituitary isografts. The curve is the fitted regression. The error bars indicate the standard deviation of the prevalence.

Tumorigenic Potential of High-Z, High-LET Charged-Particle Radiations

E. L. Alpen; P. Powers-Risius; S. B. Curtis; R. DeGuzman

Radiat Res (1993) 136 (3): 382–391.

https://doi.org/10.2307/3578551

Hazard Functions for Gamma & Target Effects (TE)

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

Hazard Function for Tumor Prevalence:

For γ-rays we used the following form for the Hazard function:

$$\mathbf{H}_{\gamma} = \mathbf{H}_0 + [\alpha_{\gamma}\mathbf{D} + \beta_{\gamma}\mathbf{D}^2] * \mathbf{S}(\mathbf{D})$$

Where, **H0** represents the background prevalence (D=0)

αγ and **βγ** are the linear and quadratic coefficient with dose Induction terms, and **S(D)** the cell survival probability.

For particles it is considered a track structure model that extrapolates to low doses (or low fluence) the functional form used in the NASA cancer risk assessment.

$$\boldsymbol{H_{TE}(Z,E,F)} = [\boldsymbol{H_0} + \Sigma F + \beta D^2] * \boldsymbol{S}$$

Hazard Function for Non-Target Effects (NTE)

The NTE model assumes a non-linear type response in addition to the linear dose term at low doses.

$$\boldsymbol{H_{NTE}(Z,E,F)} = [\boldsymbol{H_0} + \Sigma F + \beta D^2 + \boldsymbol{\eta}] * \boldsymbol{S}$$

the η function that represents the NTE contribution, which is parameterized as a function of LET, *L* by:

$$\eta = \eta_0 L e^{-\eta_1 L}[1 - e^{-N_{Bys}}]$$

Models to evaluate the NTE contributions using the AMS data

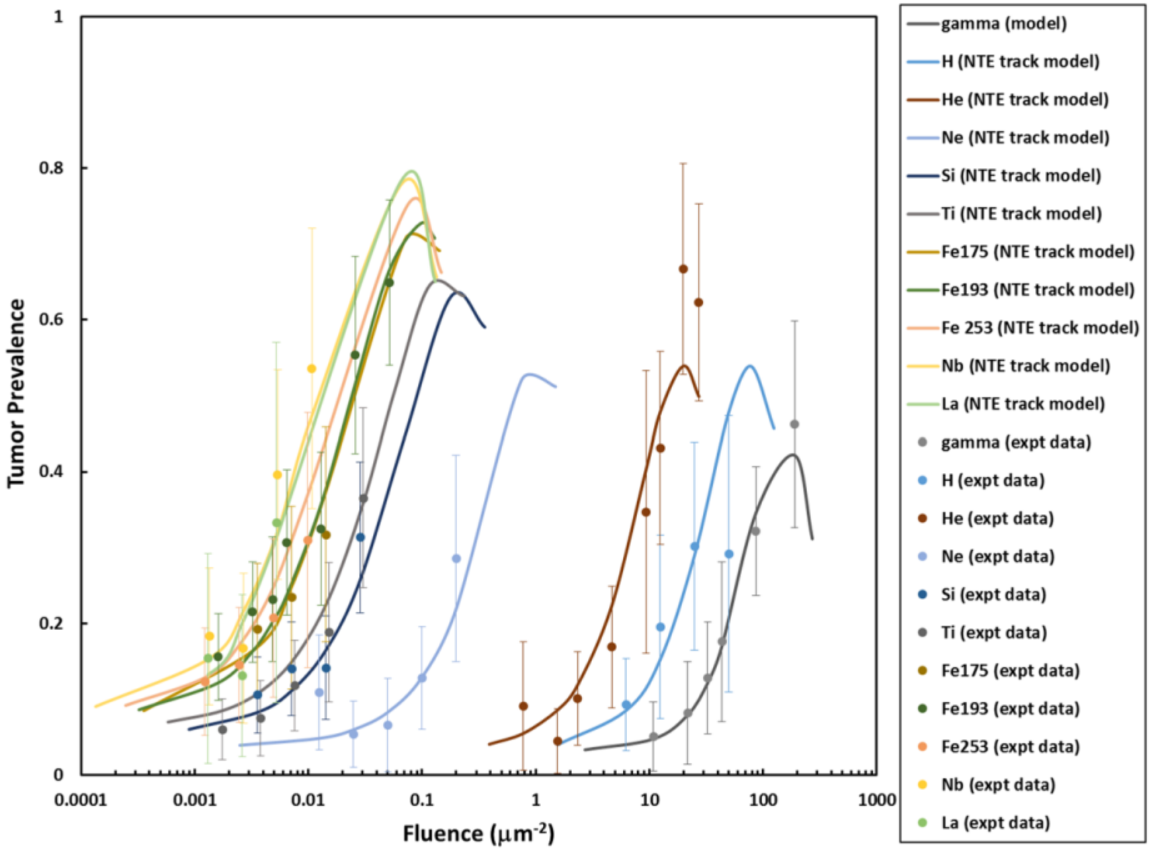


Figure 3. Comparison of the non-targeted effects (NTE) model of the percent Harderian gland tumor prevalence versus particle fluence to experiments of Alpen *et al.*[12, 13] and Chang *et al.*[14]. Error bars represent standard errors in the experiments.

Tool for NTE components evaluation

Tumor Prevalence (TP)

- Endpoint Exp Data :Harderian Gland Tumor
- Cells Survival Probability Models Library
- R-Script Coding

+

Input

- background prevalence H0, linear gamma induction and quadratic gamma induction
- absorbed dose interval (default 0-1000 Gray)
- selecting appropriate CSP models

=

Output

- Calculating the Tumor prevalence with different models
- Plot: Cell Survival probability function, Tumor prevalence (TP)

Tumor Prevalence (TP)

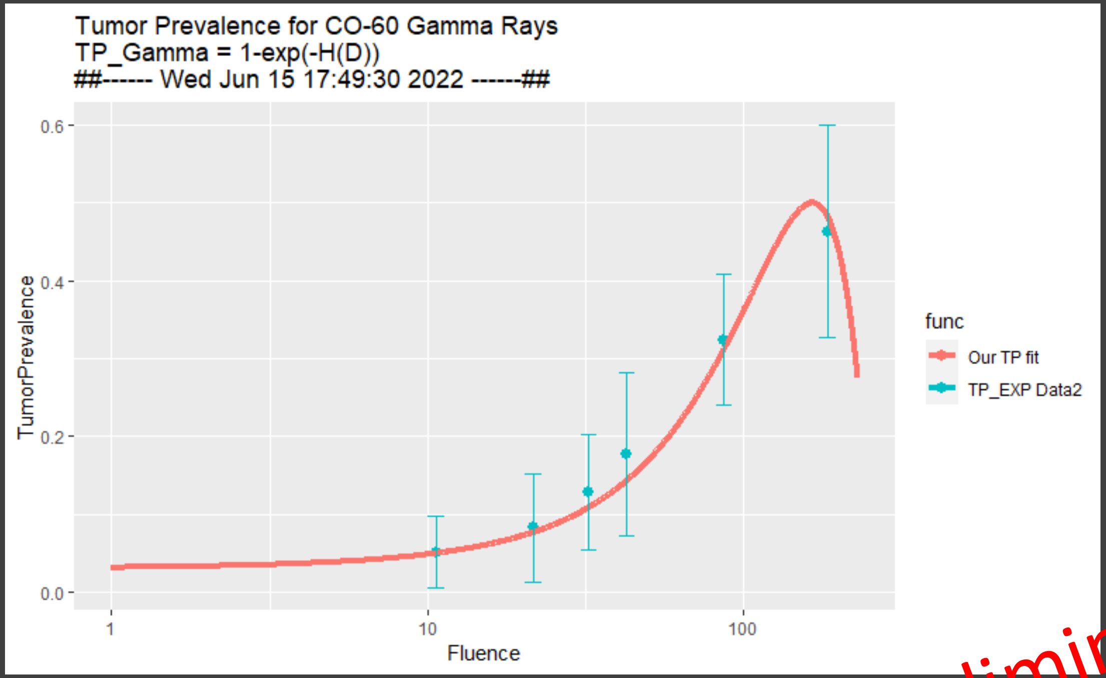
- *Experimental Data taken from Alpen et al 1997*
- *60-Co Gamma Source*
- *Ions according to the table 1*
- *Exposition time in between 60 sec. to 120 sec.*
- *Range in water are max.*
- *LET precision is few % of the vales.*
- *Irradiation field is 3 x 5 cm^2.*

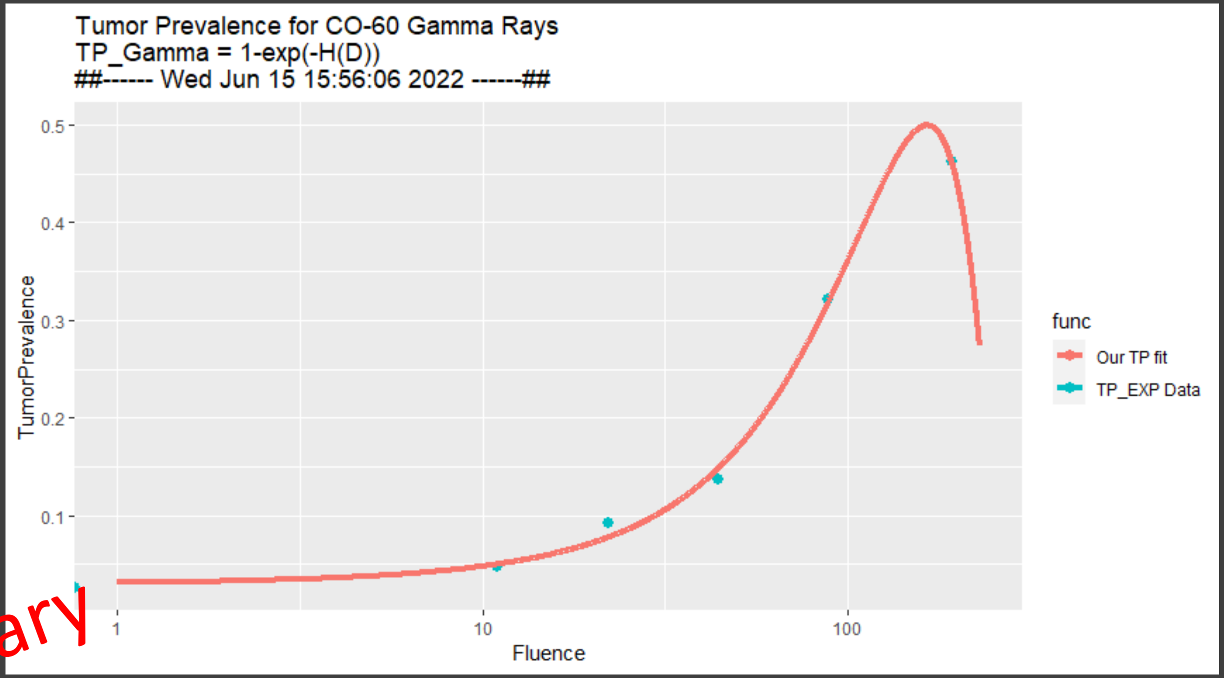
TABLE I

Nominal Energies, LET_∞,[a] and Maximum Ranges in Water

Ion	Energy (A MeV)	Entrance LET_∞ (keV/μm)	Range in water (cm)
Hydrogen, $^{1}_{1}H$	250	0.4	35
Helium, $^{4}_{2}He$	228	1.6	26
Neon, $^{20}_{10}Ne$	670	25	31
Iron, $^{56}_{26}Fe$	600	193	9.7
Iron, $^{56}_{26}Fe$	350	253	2.5
Niobium, $^{93}_{43}Nb$	600	464	4.8

[a] The values are for dose-averaged LET; however, at the zero absorber position in the plateau region of the Bragg curve, dose-averaged LET and track-averaged LET are essentially the same.

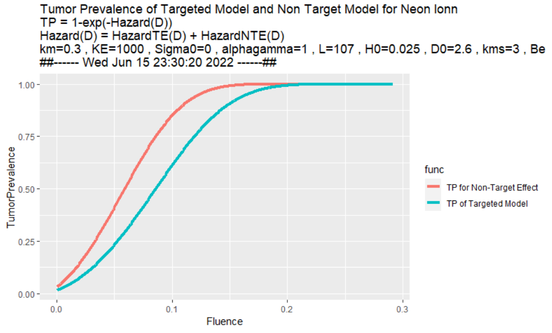


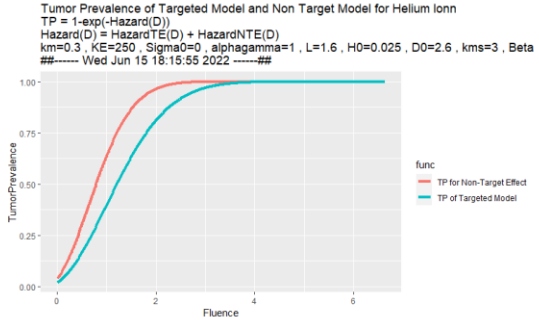


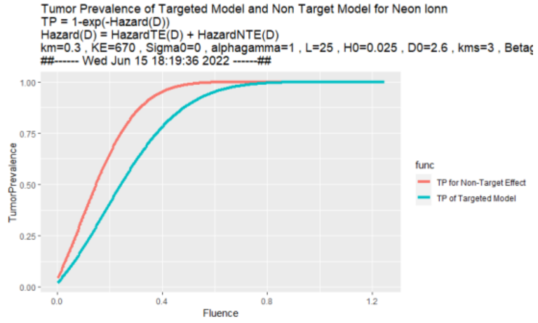
Preliminary

Gamma Rays

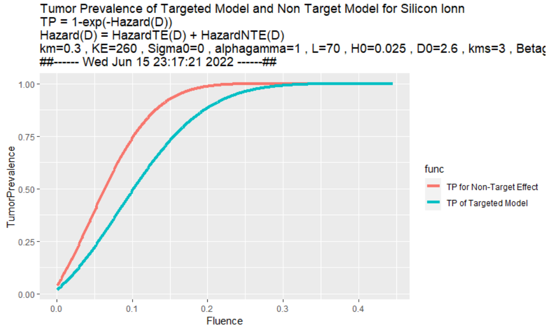
- $\mathbf{TP} = \mathbf{1} - e^{-H(Z,E,F)}$
- $\mathbf{H_\gamma = H_0 + [\alpha_\gamma D + \beta_\gamma D^2] S(D)}$

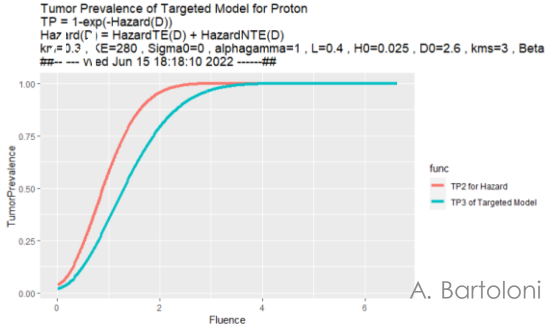






Preliminary



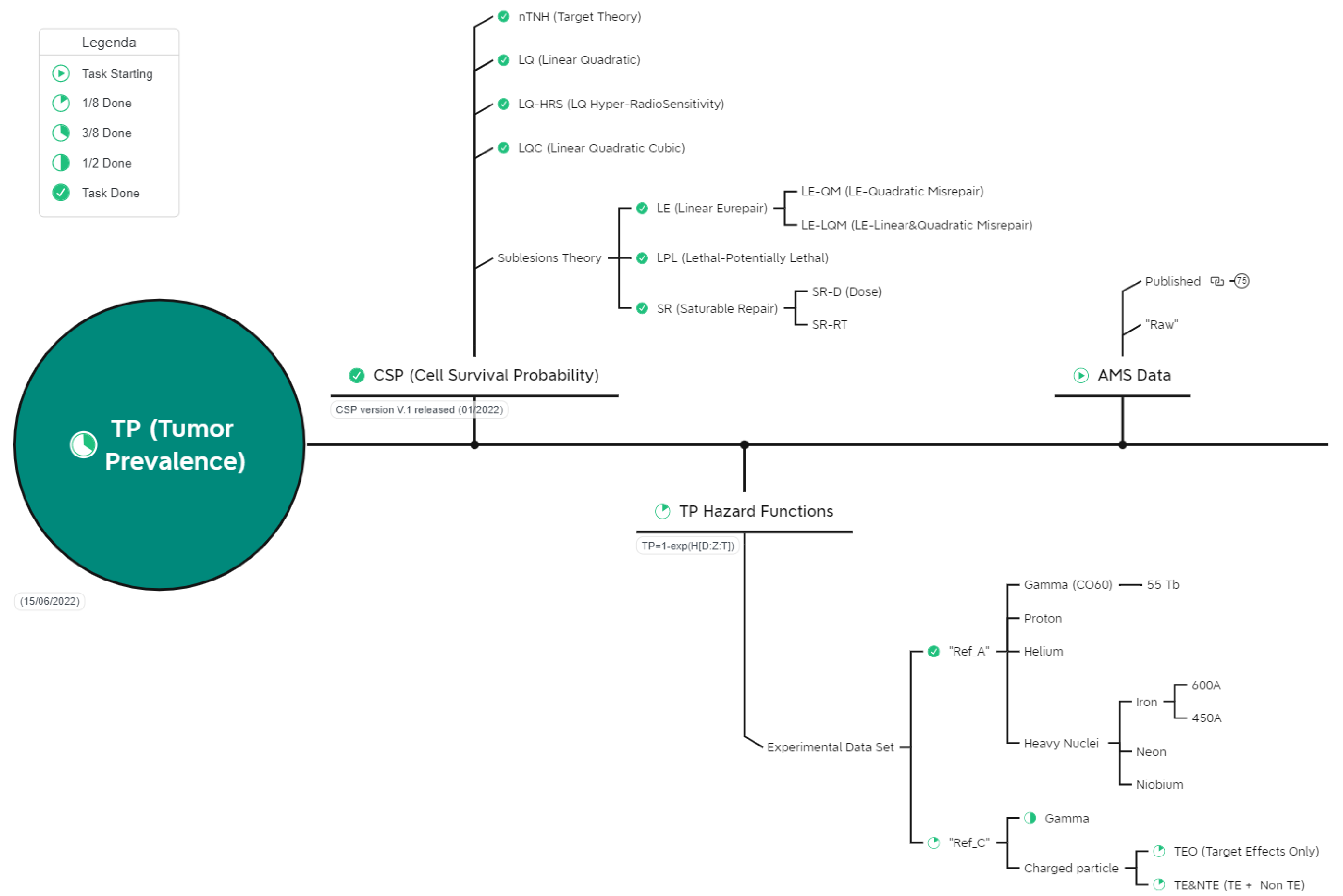


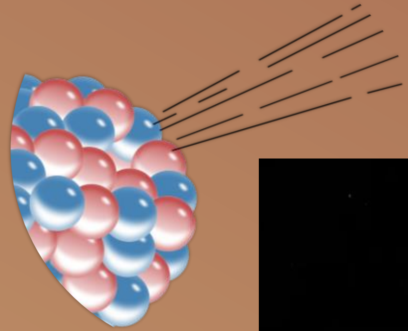
TE vs NTE

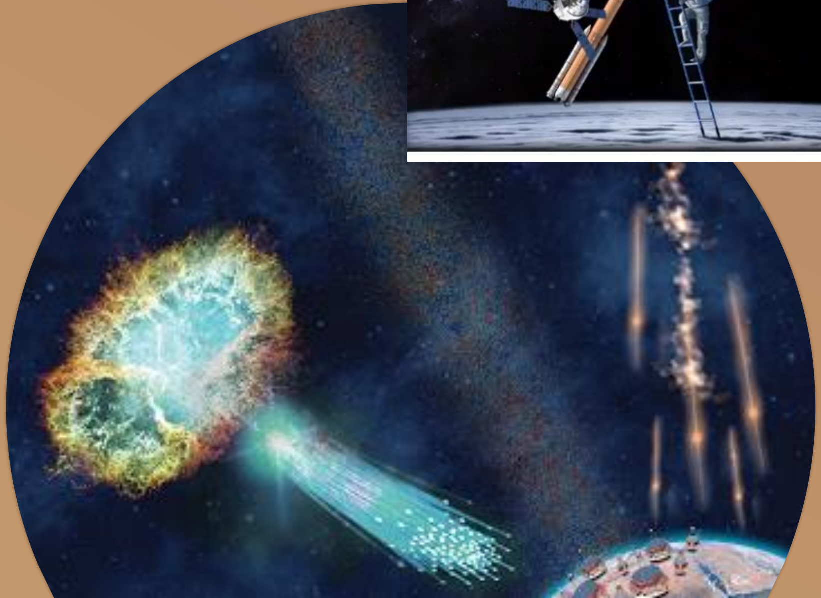
In the plots the percentage of tumors prevalence is used to investigate the effects of Non-Target Effects (NTE) in predictions of chronic GCR exposure risk.

The expected contribution of the NTE is an increase of radiation risk 2-fold higher compared to a TE model.

detrimental effects of ionizing radiation are not restricted only in the irradiated cells but also to non-irradiated bystanders or even distant cells manifesting various biological effects.


Legenda
Task Starting
1/8 Done
3/8 Done
1/2 Done
Task Done
TP (Tumor Prevalence)
(15/06/2022)
CSP (Cell Survival Probability)
CSP version V.1 released (01/2022)
nTNH (Target Theory)
LQ (Linear Quadratic)
LQ-HRS (LQ Hyper-RadioSensitivity)
LQC (Linear Quadratic Cubic)
Sublesions Theory
LE (Linear Eurepair)
LE-QM (LE-Quadratic Misrepair)
LE-LQM (LE-Linear&Quadratic Misrepair)
LPL (Lethal-Potentially Lethal)
SR (Saturable Repair)
SR-D (Dose)
SR-RT
AMS Data
Published
"Raw"
TP Hazard Functions
TP=1-exp(H[D:Z:T])
Experimental Data Set
"Ref_A"
Gamma (CO60)
55 Tb
Proton
Helium
Heavy Nuclei
Iron
600A
450A
Neon
Niobium
"Ref_C"
Gamma
Charged particle
TEO (Target Effects Only)
TE&NTE (TE + Non TE)





THANKS FOR THE ATTENTION !

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Workshops on Radiation Monitoring for the International Space Station

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Or visit the web page 25thWRMISS

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Belgian Nuclear Research Centre

UMONS
Université de Mons

25th WRMISS in Mons, Belgium

September 6 -8, 2022

Local Organizing Team:

Patrice Mégret (University of Mons)

Mariline Mura (University of Mons)

Olivier Van Hoey (Belgian Nuclear Research Center SCK CEN)

Part I references

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[3] " Cucinotta F., et al Non Targeted Effects Models Predict Significantly Higher Mars Mission cancer Risk than Targeted Effects Models"

BACKUP SLIDE