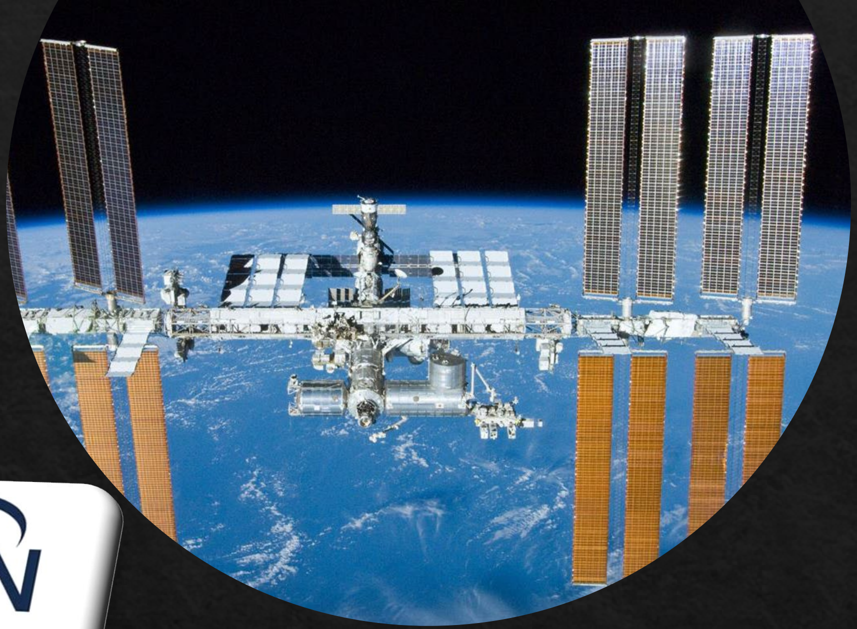
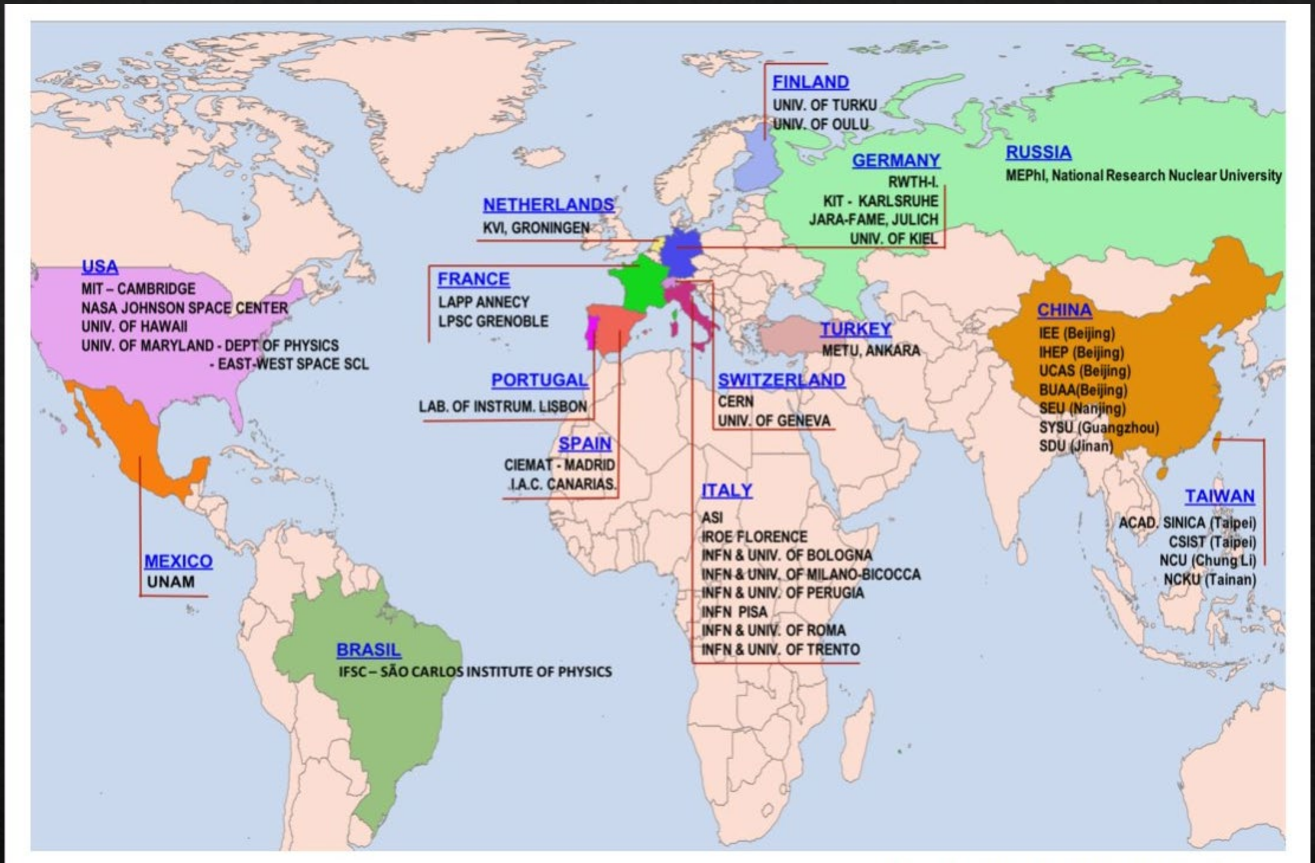


Misure di precisione di raggi cosmici con l'Alpha Magnetic Spectrometer e radiobiologia nello spazio.

Alessandro Bartoloni - INFN Roma
Lidia Strigari - Policlinico S'Orsola



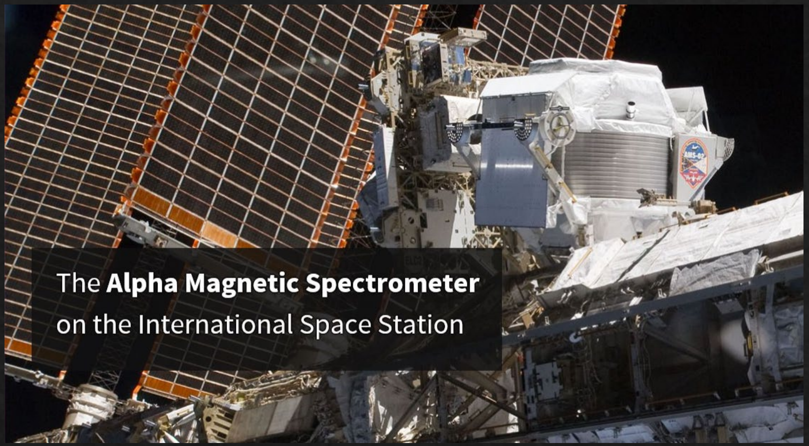
The AMS collaboration

(http://ams02.space)

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

Presents in 7 INFN department

(BO,MIB,PI,PG,RM1,RM2,TN)

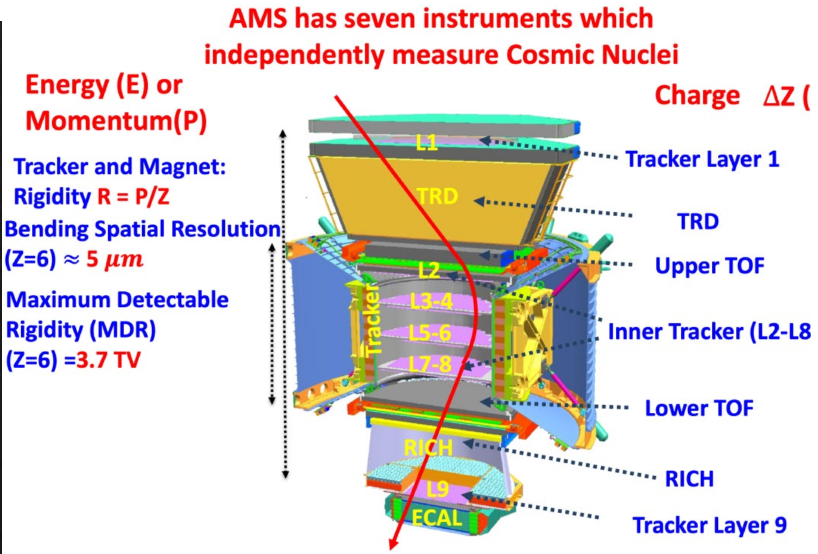


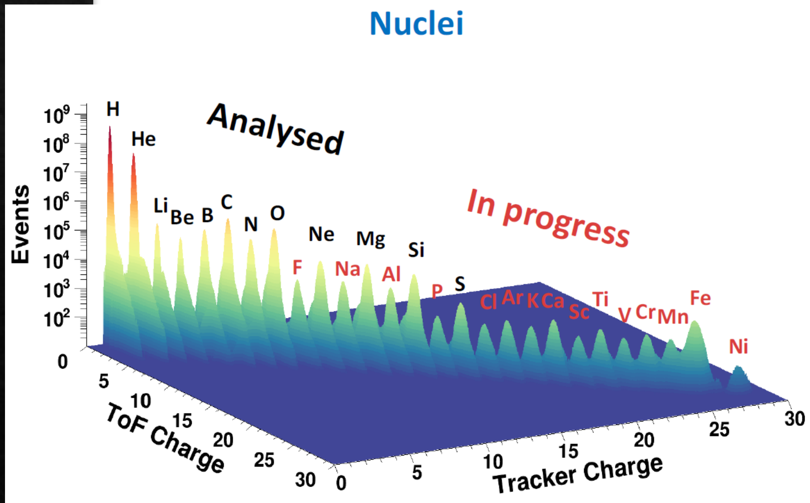
AMS in Figures

7.5 t Weight	**5×4×3 m³** Size	**0.14 T** Magnetic Field Intensity	**16/05/2011 08:56 AM EDT** Launched

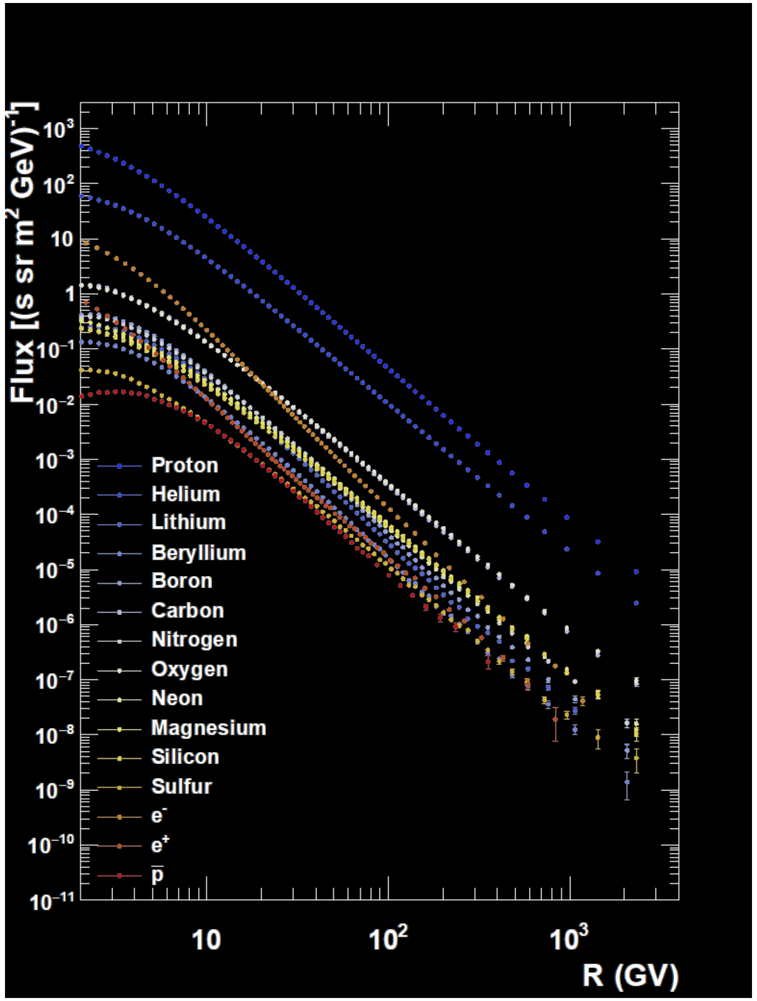
AMS02 Detector

- Multiple instruments detector
  - Tracker Layer 1
  - TRD
  - ECAL
  - Upper TOF
  - Tracker (L2-L8)
  - Lower TOF
  - RICH
  - Tracker Layer 9





AMS02 Nuclei Events (2019)



AMS02 Latest Results (Flux)

Health Hazard for Astronauts

Visual Impairments

Fluid Distribution

Muscle Atrophy

Microgravity

Osteoporosis

Motion sickness

Circadian

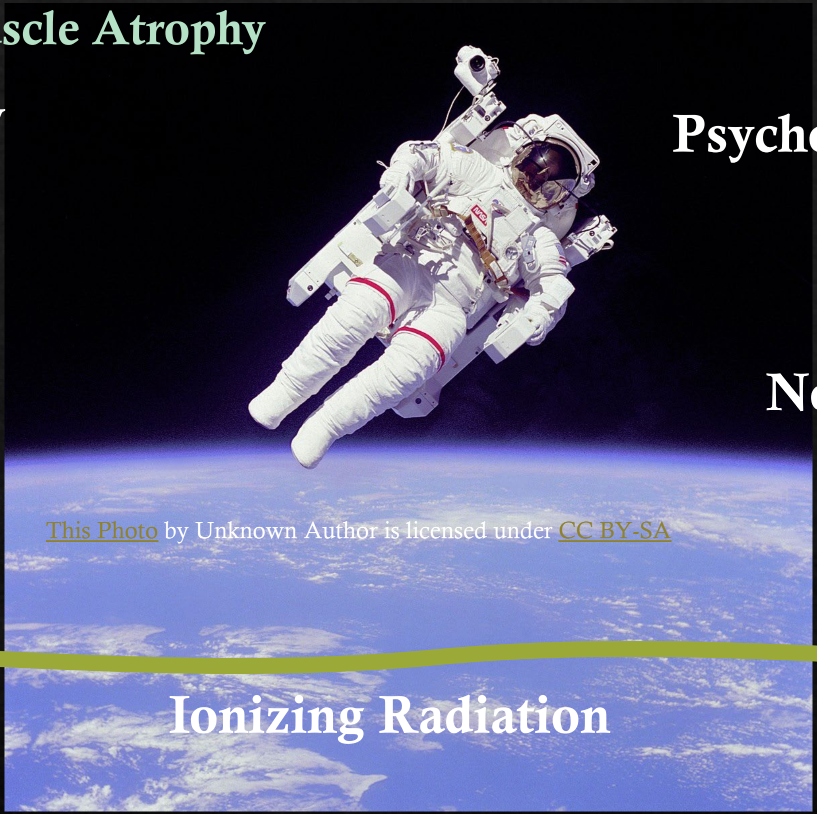
Psychological Stress

Isolation

Dietary Limitation

Noise Background

Confined Space



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Ionizing Radiation

Eye Flashes

Cardiovascular disease

Cataract

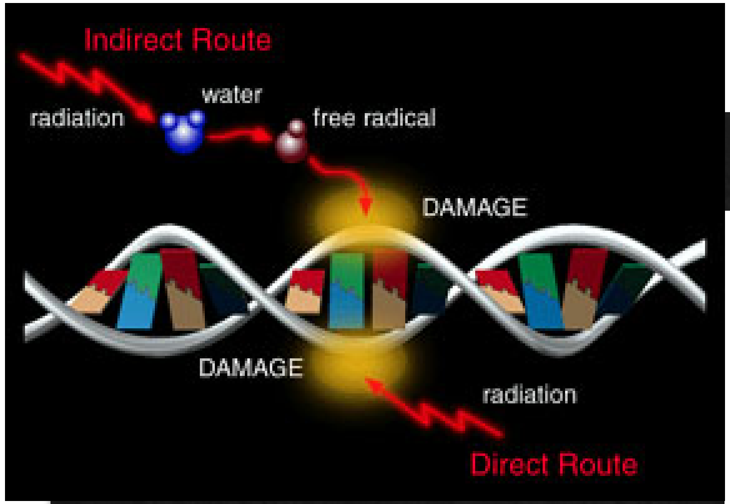
Central nervous system effects

Acute radiation syndromes

Immune dysfunction

Cancer

DNA damages from ionizing radiation



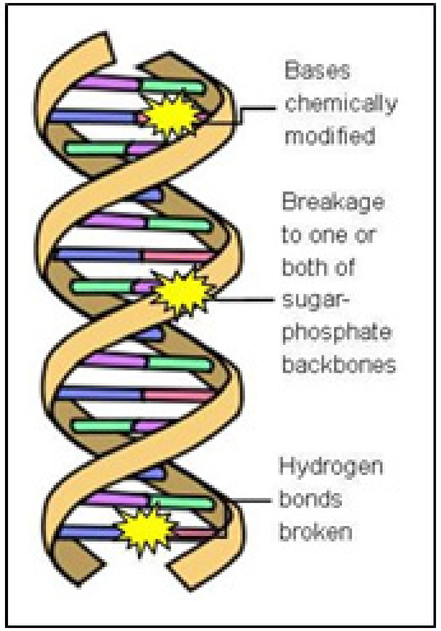
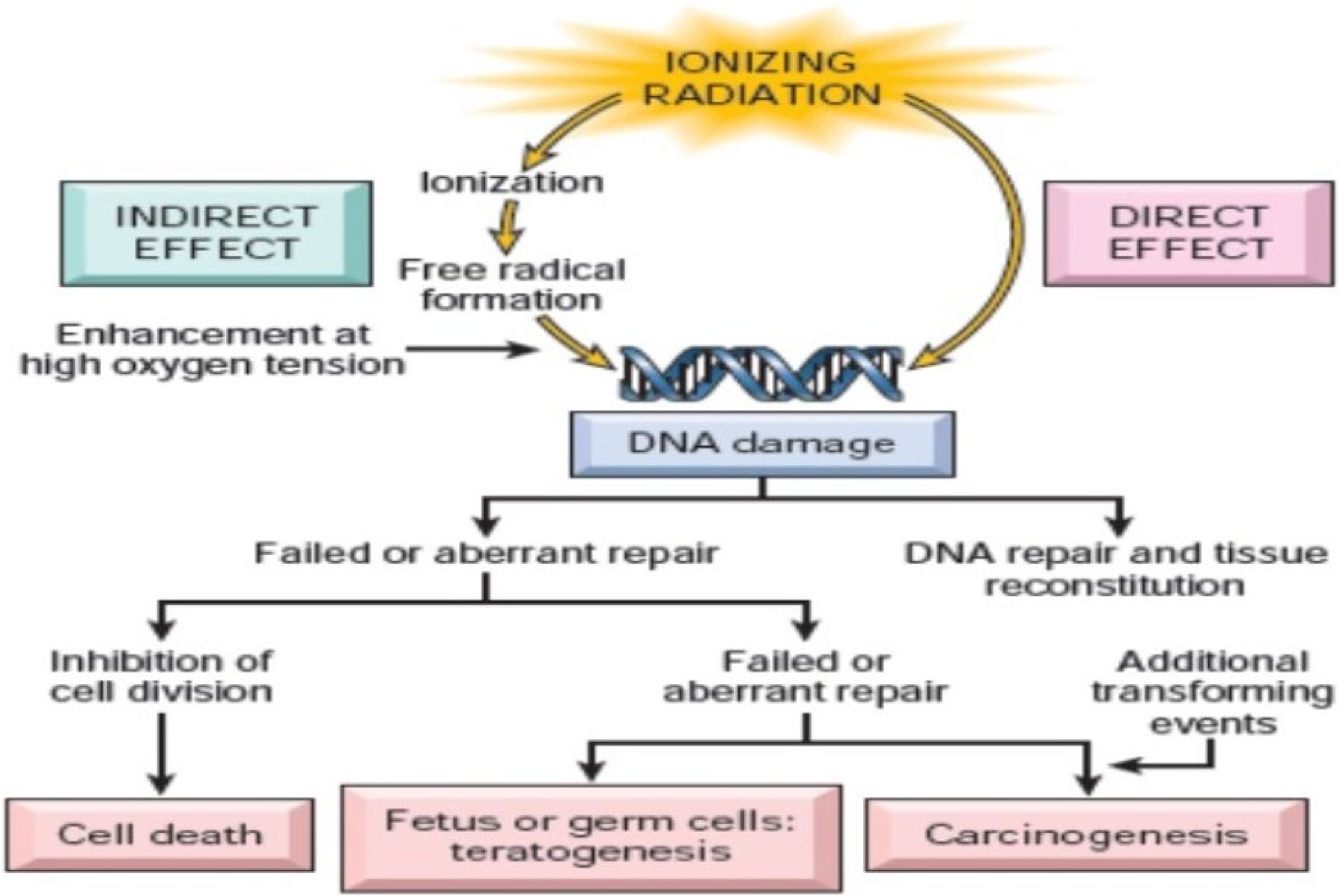
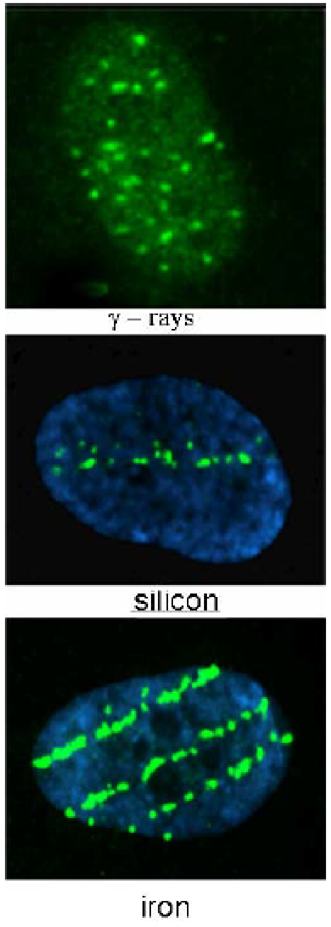
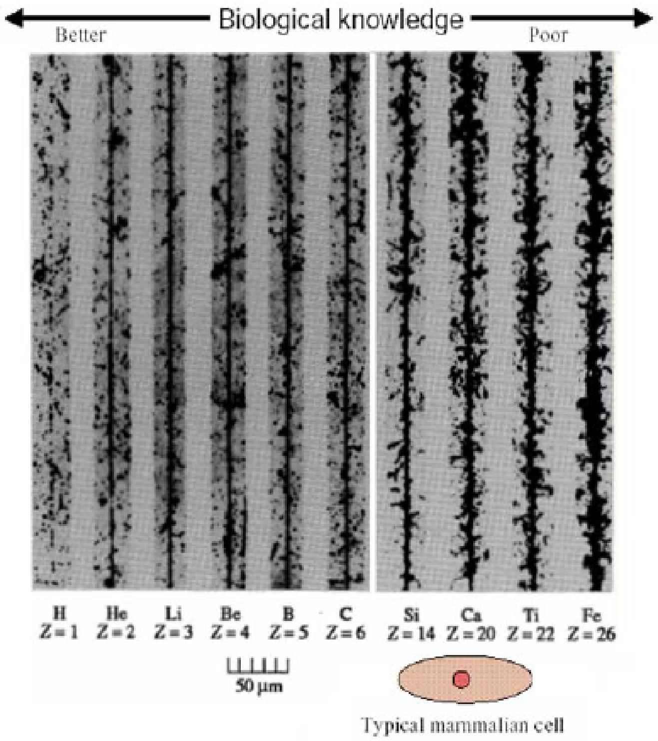


Figure 1: Potential direct effects of ionizing radiation on DNA molecules.

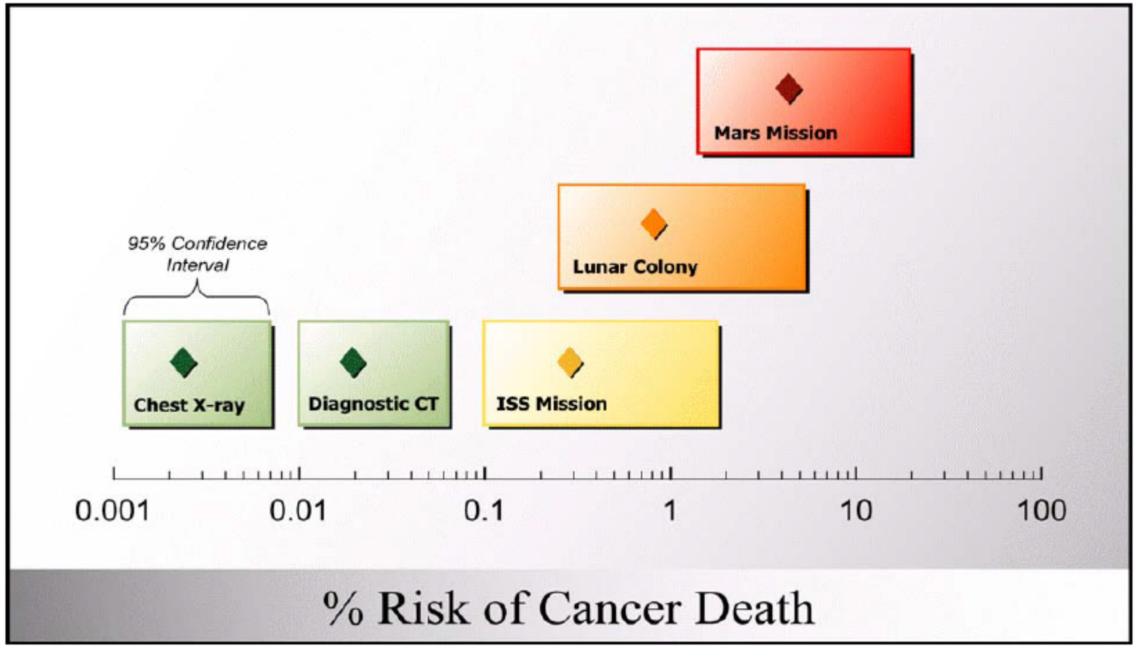


Radiation Quality





(Cucinotta, Durante 2008)[1]



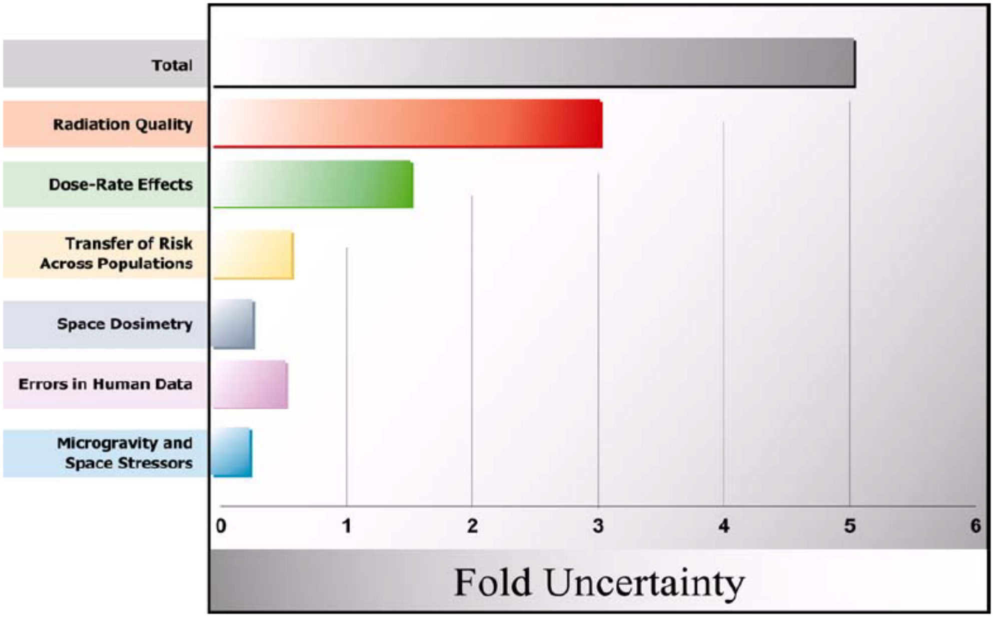
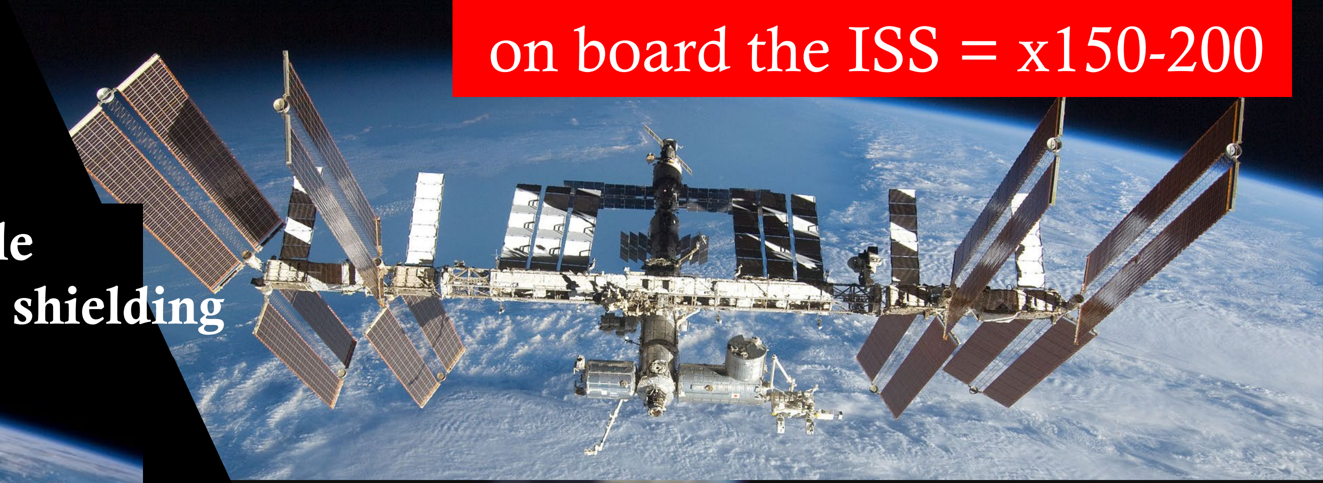


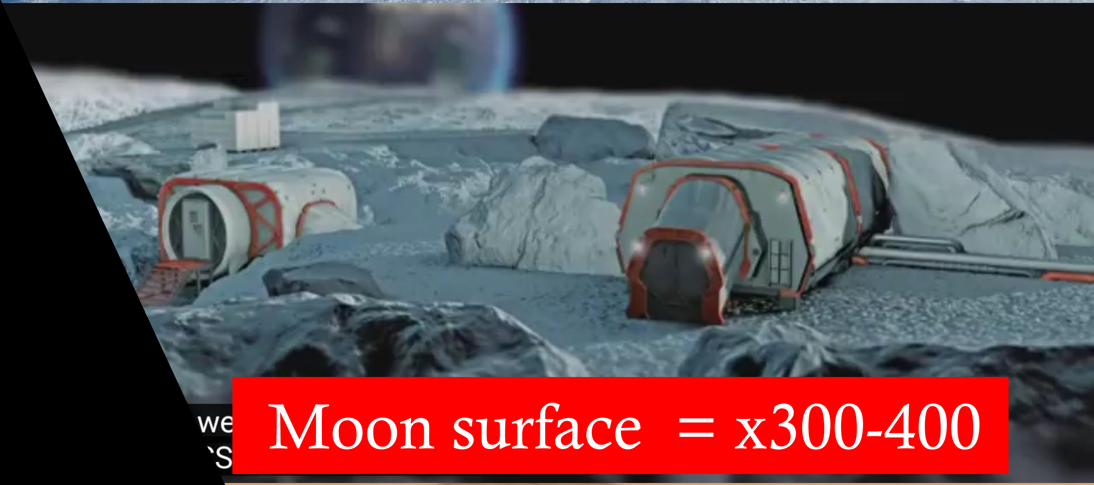
Figure 4-1. *Estimates of fold uncertainties from several factors that contribute to cancer risk estimates from space radiation exposures. The uncertainties are larger for astronauts who are in space as compared to typical exposures on Earth, as illustrated.*

Earth is a coocon:

- Magnetosphere stops 99.9% of charged particle
- Atmosphere equivalent to a 10 meter of water shielding



on board the ISS = x150-200



Moon surface = x300-400

Mars surface =x250

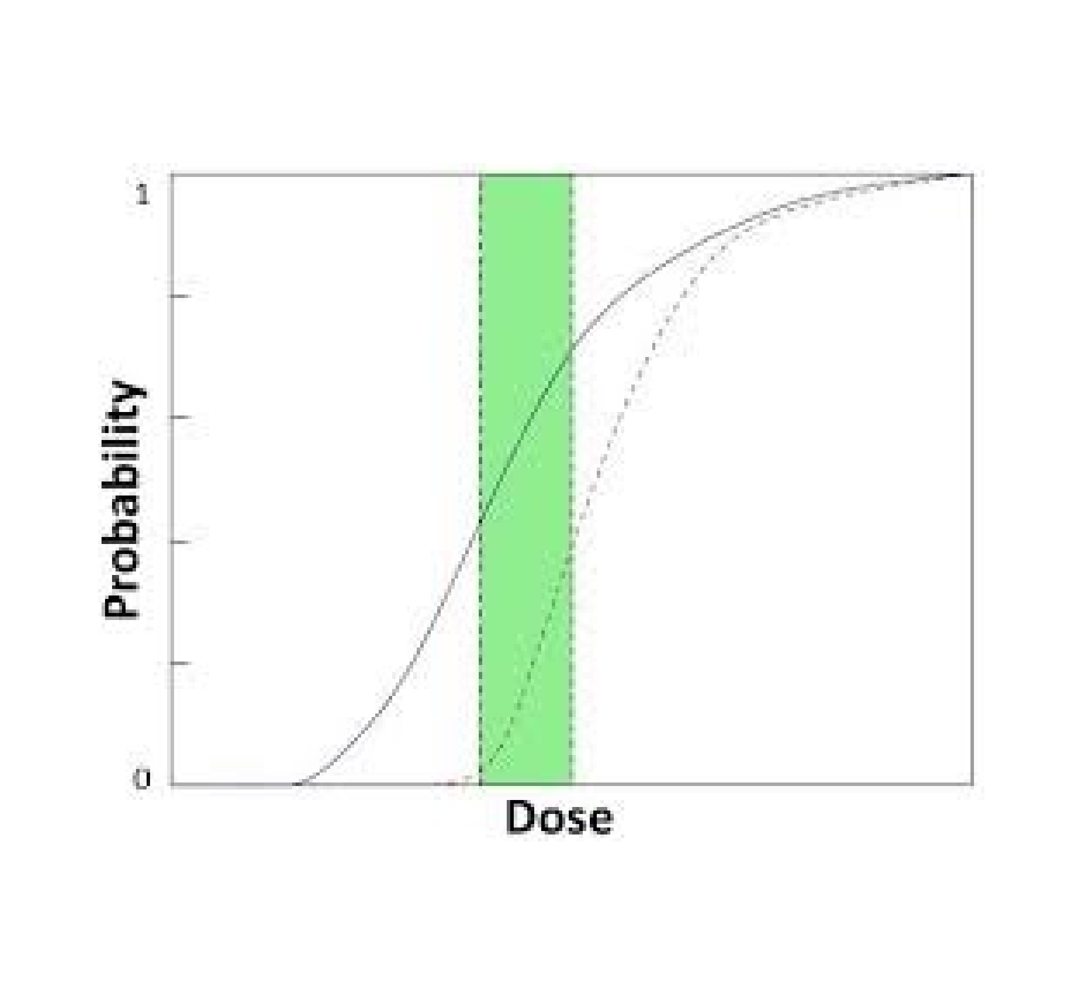
Travelling Earth to Mars = x750

By SpaceX - Falcon Heavy Demo Mission

Dose Effects models

- Describes the probability of an event (effect) depending on the amount of dose absorbed 'dose-damage' model for organ damage or development of a disease

- Knowledge of dose-effect models is an essential prerequisite for identifying and reducing risk factors from ionizing radiation associated with human exploration and colonization of the solar system.



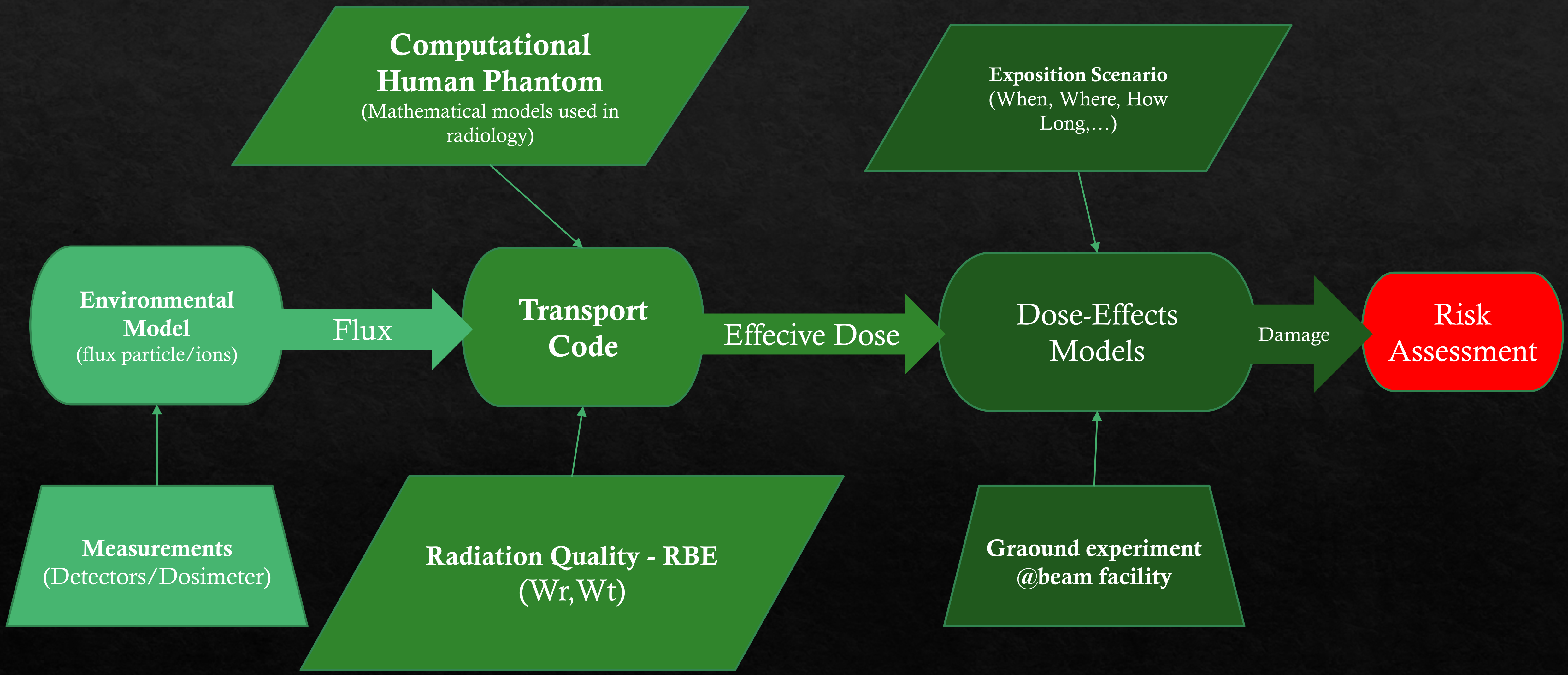
”Dose-Effects Models for space radiobiology: an overview”[1]

N. Study Reference	Model	Particles	Dose range/threshold or LET	Experimental Validation
4	Eye flashes	Light Nuclei (He,..)	LET> 5 – 10 keV/µm	Yes
7	Chromosomal aberrations	Not Identified	5 - 150 mGy	Yes
7	Cataract Risk	Not Identified	8mSv	Yes
2	CNS Risk	Not Identified	100-200 mGy	No
1	Mucositis	Heavy Nuclei (C, ..)	-	No
3	Cardiovascular disease (CVD)	Not identified	1000 mGy	In japan atomic bomb survivors
6	Cancer	Not identified	<100 mGy	Yes

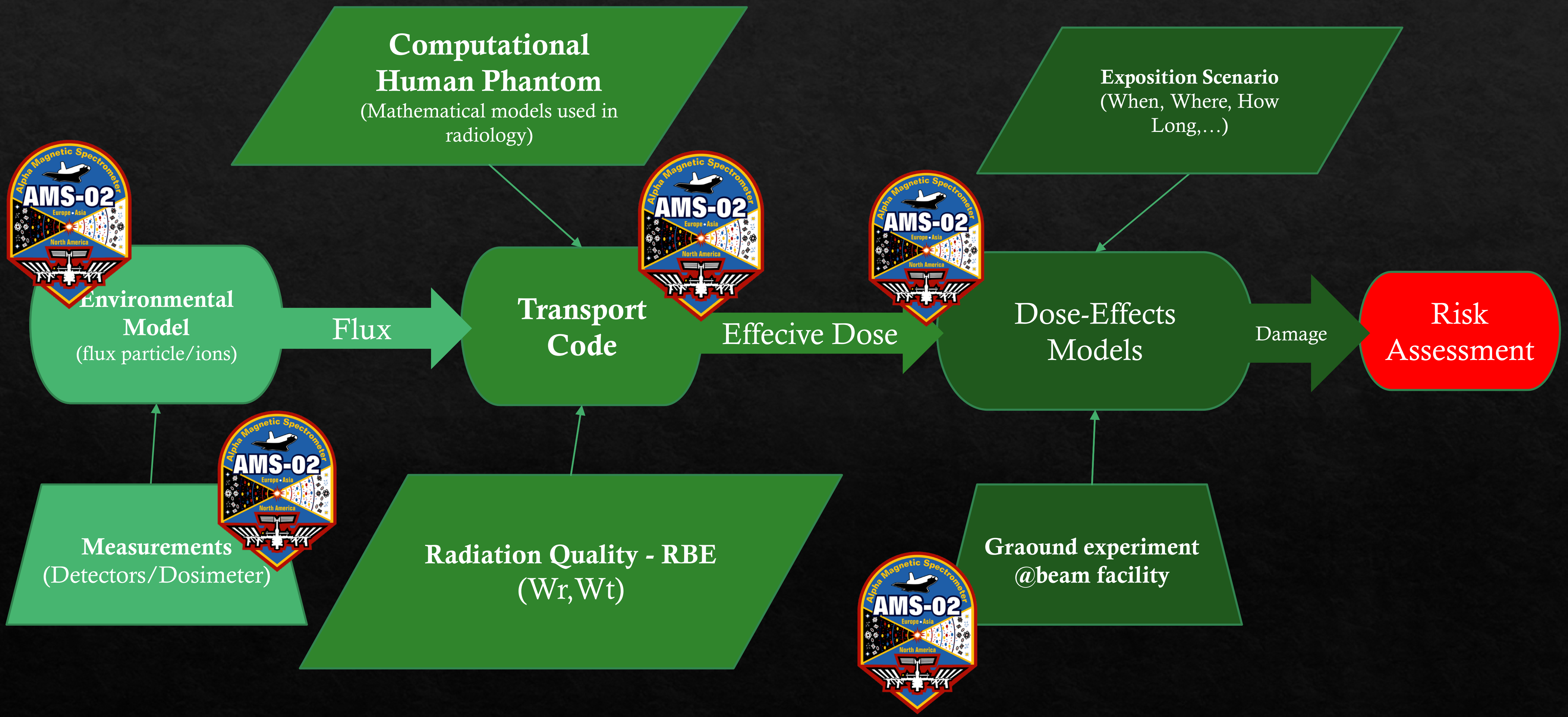
We carried out a review of the dose effect patterns derived from the biological effects observed as a result of space missions.

Many of the effects occur at doses of hundreds of mGy and are typical doses of diagnostic investigations so a synergy between knowledge arising from clinical trials and those of Space Radiobiology is desirable to increase the robustness and prediction of current models.

«Research plans in Europe for radiation health hazard assessment in exploratory space missions», Life Sciences in Space Research (2019)[2]



Potentialities of AMS02 in the research plan context



Un esempio di «GCR sensitivity analysis» - Slaba2014[3]

Radiation Type	Energy WR (ICRP 60)
x-rays, gamma rays, beta particles, muons	1
neutrons (< 1 MeV)	$2.5 + 18.2.0e^{-[\ln(2E)]2/6}$
neutrons (1 - 50 MeV)	$5.0 + 17.0e^{-[\ln(2E)]2/6}$
neutrons (> 50 MeV)	$2.5 + 3.25e^{-[\ln(0.04E)]2/6}$
protons, charged pions	2
alpha particles, nuclear fission products, heavy nuclei	20

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

Table 1: Tissue weighting factors according to ICRP 103 (ICRP 2007)

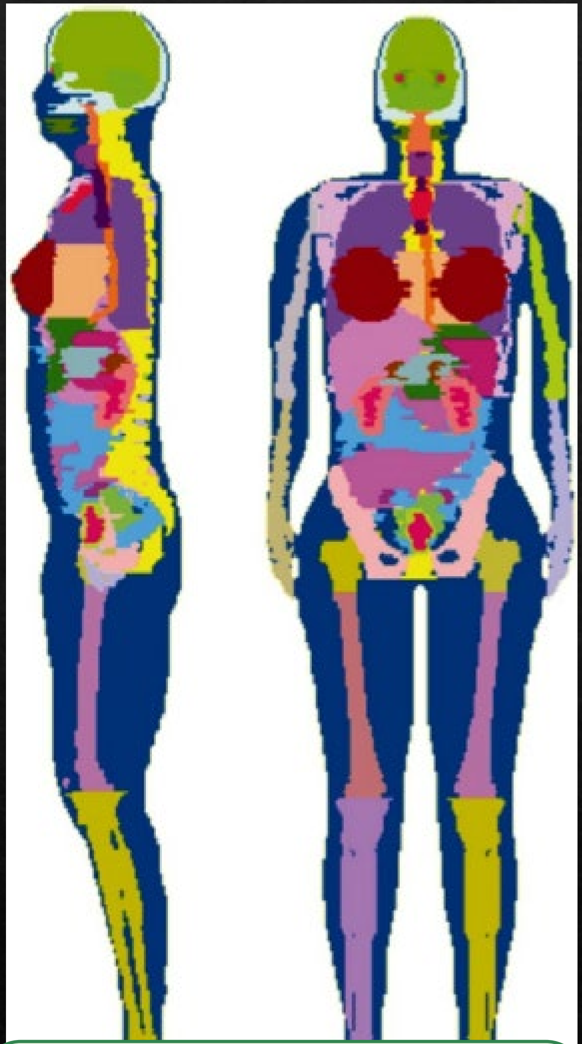
Tissue	Tissue weighting factor wT	ΣwT
Bone-marrow (red), colon, lung, stomach, breast, remaining tissues(*)	0.12	0.72
Gonads	0.08	0.08
Bladder, oesophagus, liver, thyroid	0.04	0.16
Bone surface, brain, salivary glands, skin	0.01	0.04
	Total	**1.00**

(*) Remaining tissues: Adrenals, extrathoracic region, gall bladder, heart, kidneys, lymphatic nodes, muscle, oral mucosa, pancreas, prostate (♂), small intestine, spleen, thymus, uterus/cervix (♀).

"The Badhwar-O'Neill galactic cosmic ray (GCR) model has been revised to model all balloon and satellite GCR measurements since 1955. This includes the newer 1997-2010 Advanced Composition Explorer (ACE) measurements and spans six solar cycles.

….

The GCR spectrum is needed by radiation health physicists for astronauts exposures on deep space missions"

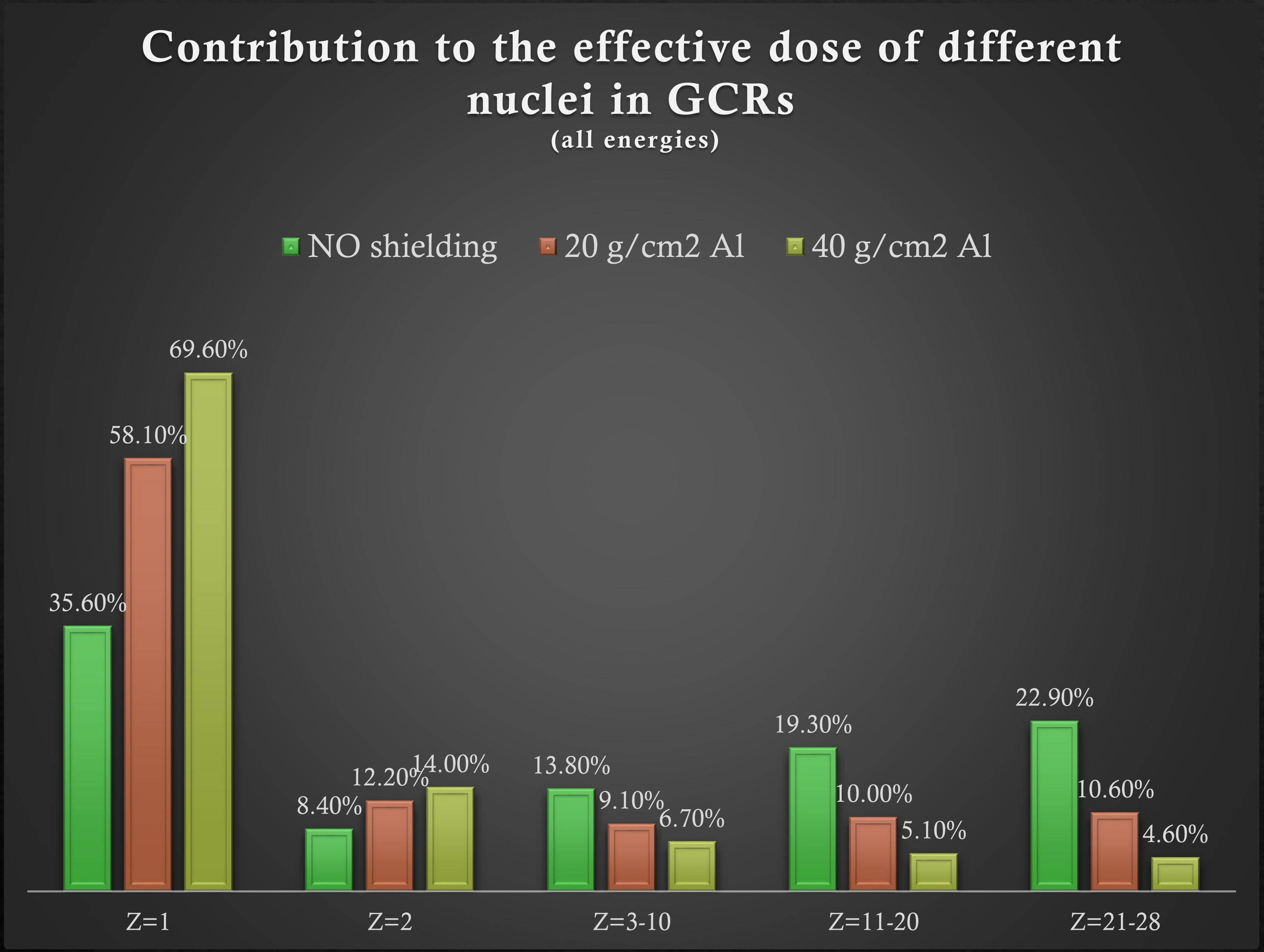


FAX model built using 151 CT images recorded from a female patient, corresponding to indication in ICRP 89

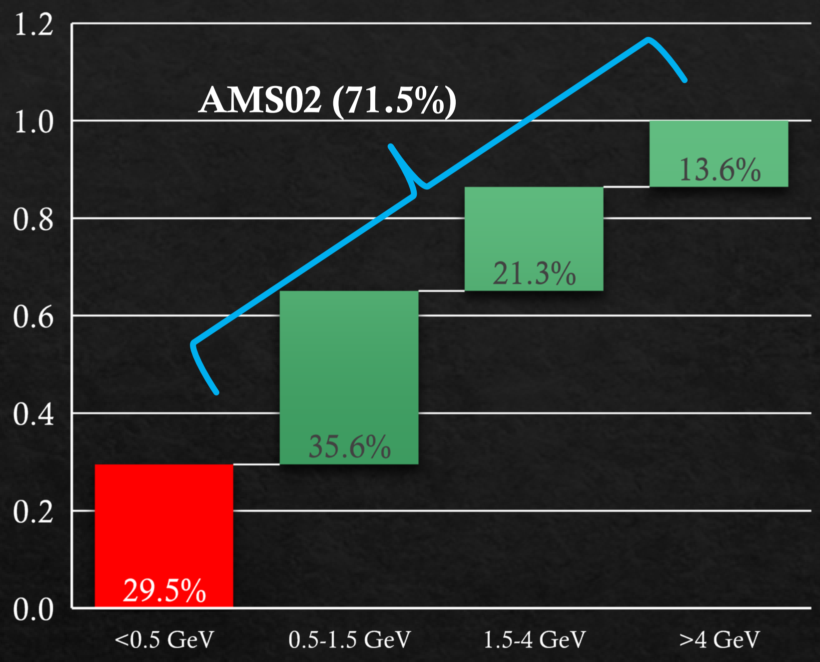
AMS02 is able to measure 100% of the particles and heavy ions of interest

As the thickness of the protective shielding increases (in the Aluminum study) the heavier ions are stopped and the contribution of the lighter ones becomes prevalent.

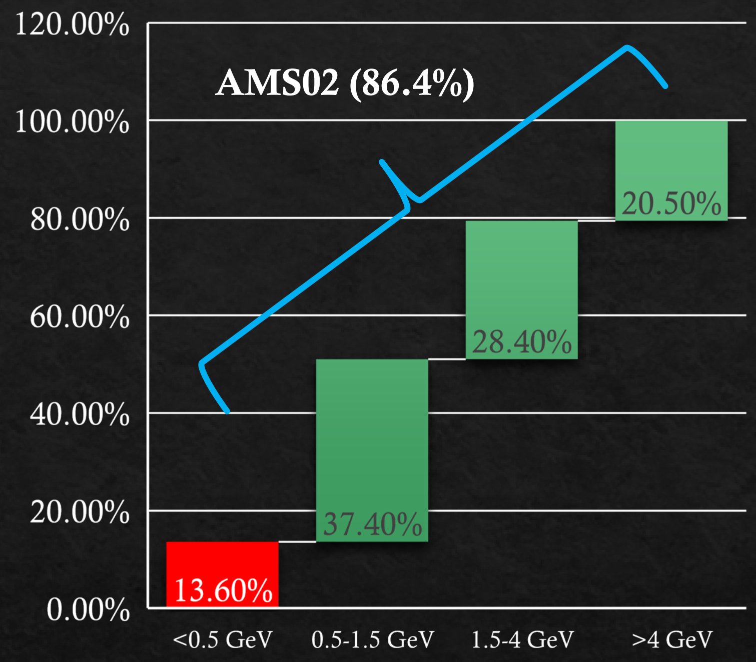
Protons contribute for 50% of the effective dose



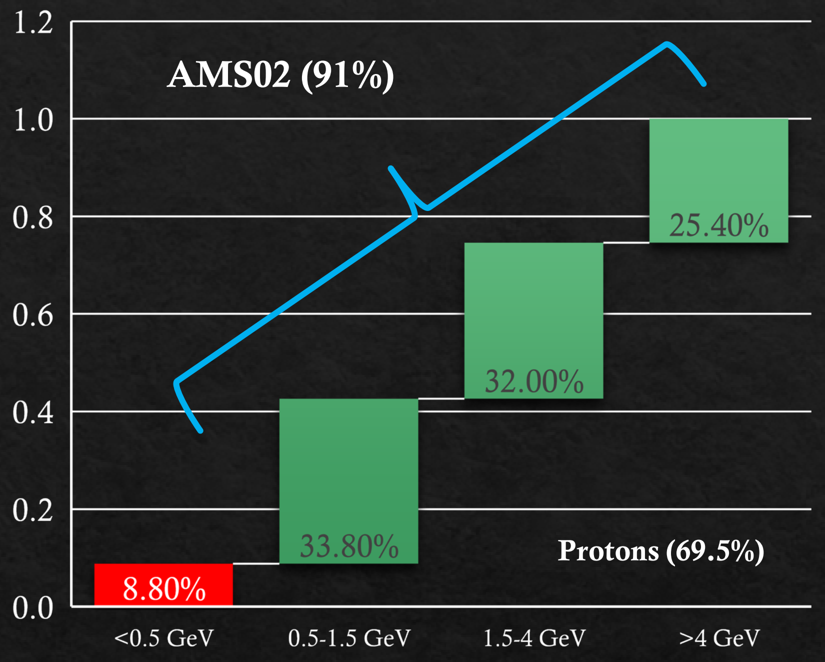
Dati elaborati da (Slaba2014)



No Shielding

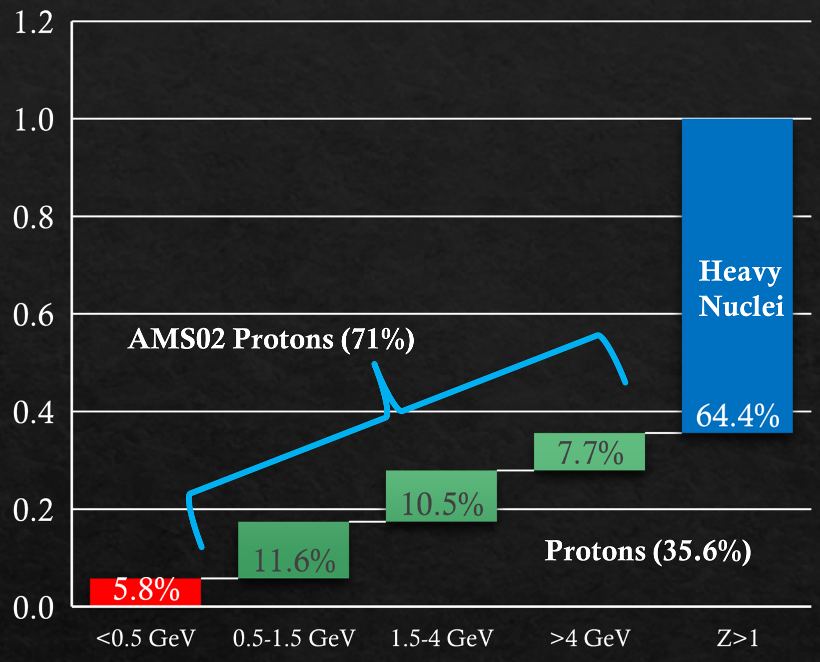


Al Shielding 20g/cm2

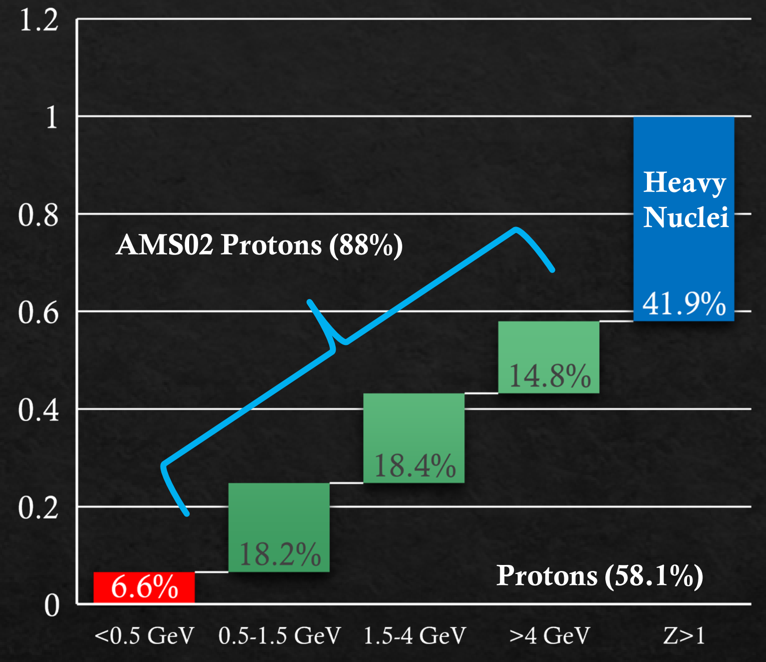


Al Shielding 40g/cm2

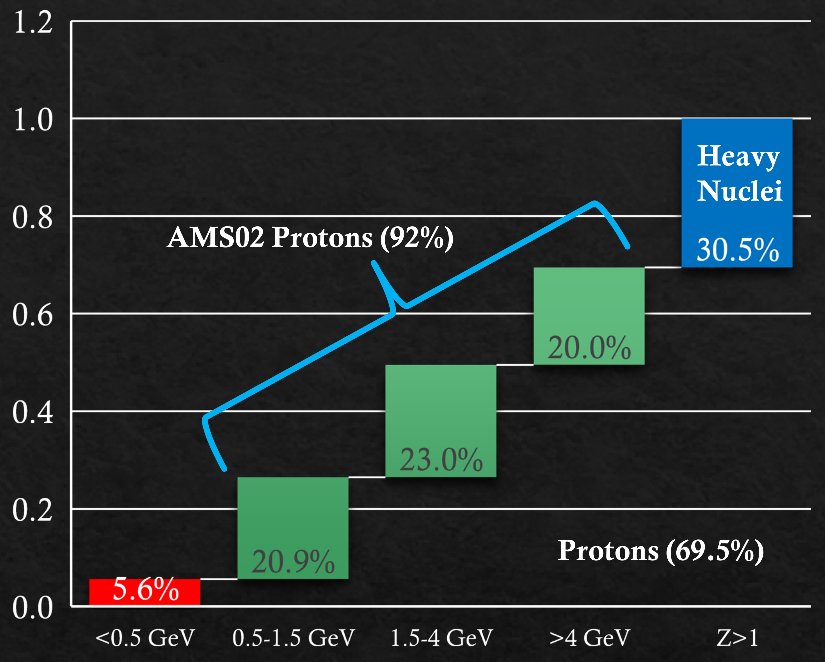
AMS02 measures the flux and properties of most GCRs charged particles that contribute to the effective dose



No Shielding



Al Shielding 20g/cm2



Al Shielding 40g/cm2

AMS02 measures the flux and properties of most protons
that contribute to the effective dose

Dati elaborati da (Slaba2014)

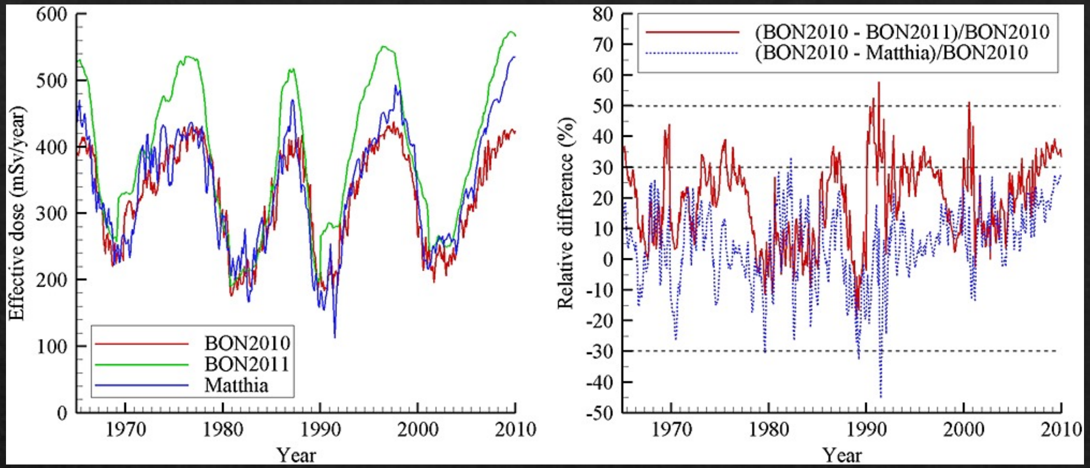
Conclusions

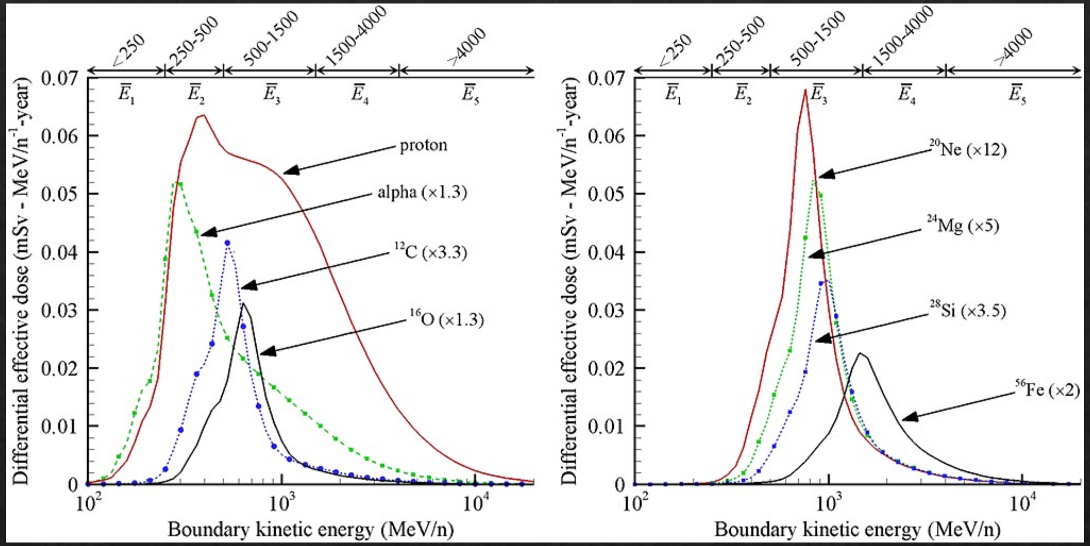
- AMS02 is able to measure all the components of GCRs, and other phenomena (SPE,..) that can be harmful to human health in its space exploration activities.
- The energy range covered by AMS02 allows to measure a large part of the contribution of RI to the effective dose is the measures can be used to improve the effect dose models and therefore the different aspects of the risk assessment process of the effects of Useful to optimize future space missions.

References

1. A. Bartoloni , L.Strigari "Dose-Effects Models for space radiobiology: an overview" to be published (2019)
2. L.Walsh et al , «Research plans in Europe for radiation health hazard assessment in exploratory space missions», Life Sciences in Space Research (2019)
3. Slaba, T. Blatting,S. «GCR environmental models I: Sensitivity analysis for GCR environments», Space Weather 12, (2014)
4. O'Neill, P. «Badhwar-O'Neill 2010 Galactic Cosmic Ray Flux Model—Revised», IEEE Transactions on Nuclear Science (2010)
5. Kramer, R. et al. "All about FAX: A female adult voXel phantom for Monte Carlo calculation in radiation protection dosimetry", Phys Med Biol, 49, 5203, (2004)
6. Wilson, J et al. «Transport Methods and Interactions for Space Radiations, NASA Ref. Pub. 1257 (1991)

Backup Slide



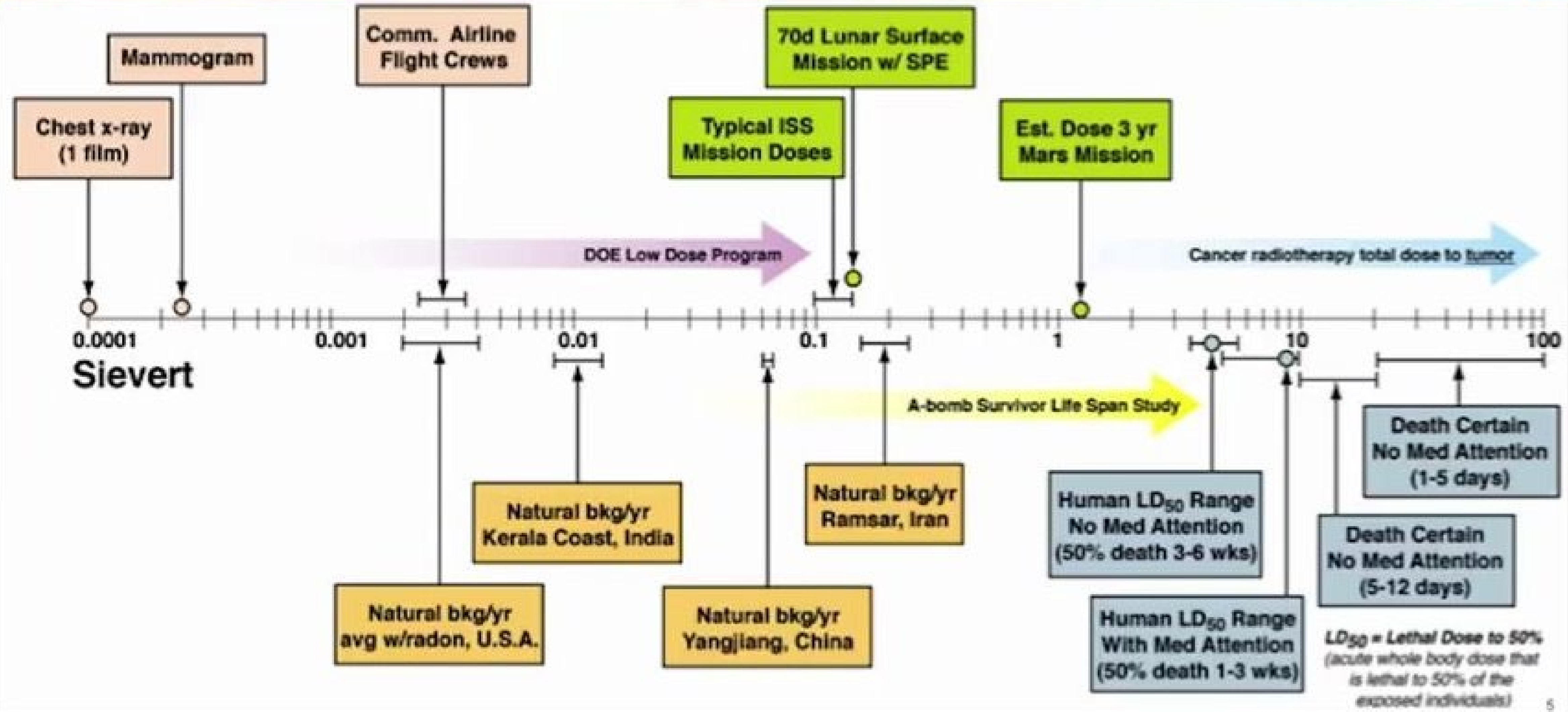


$$h_Z(E_B) \equiv \frac{\partial}{\partial EB} \mathrm{H}_Z\,(E > EB)$$

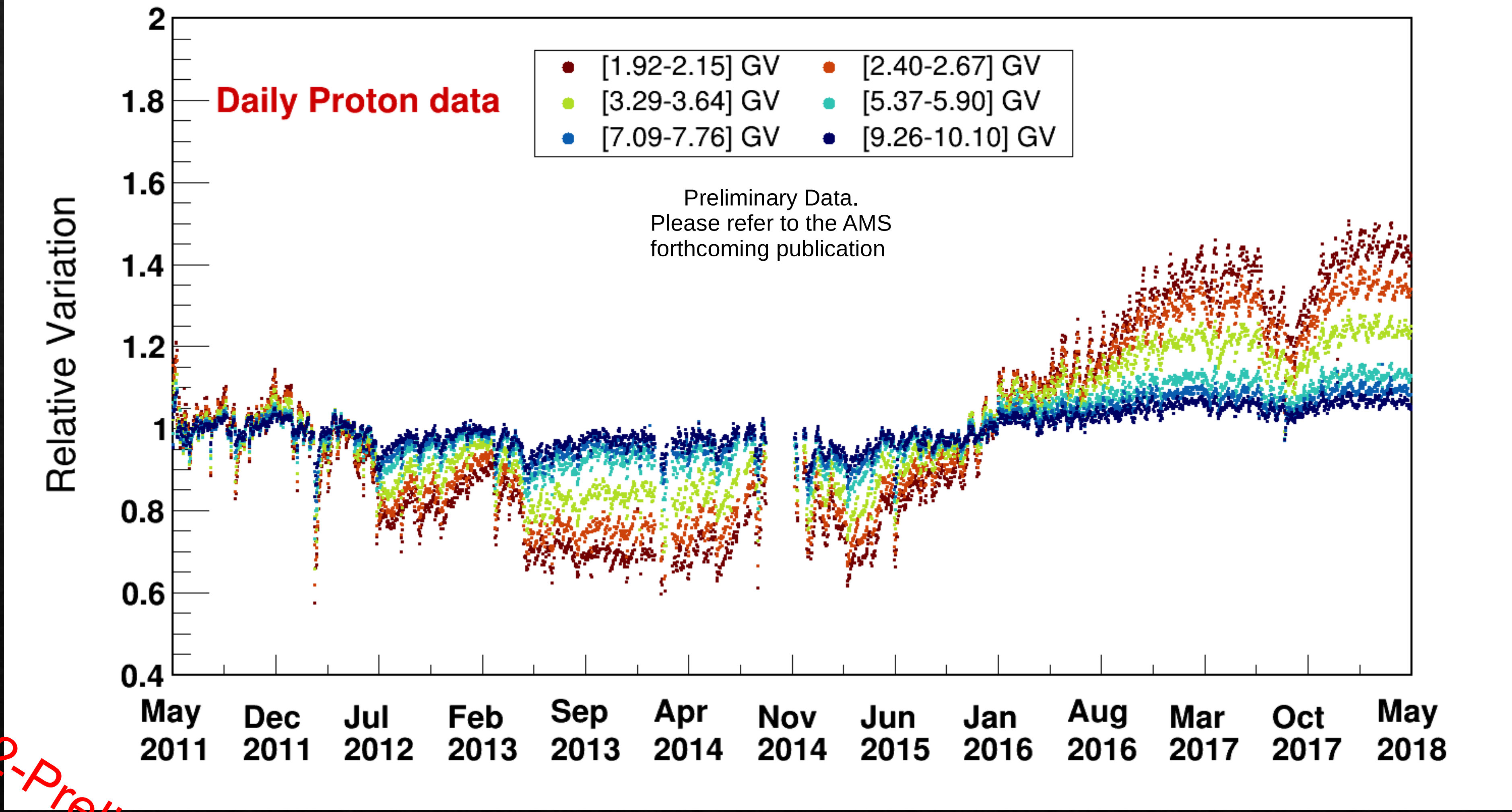
Differential Effective dose

Cumulative Effective dose rate

Space Radiation Exposure in Context



Variazioni giornaliere del flusso dei protoni Maggio 2011- Maggio 2018

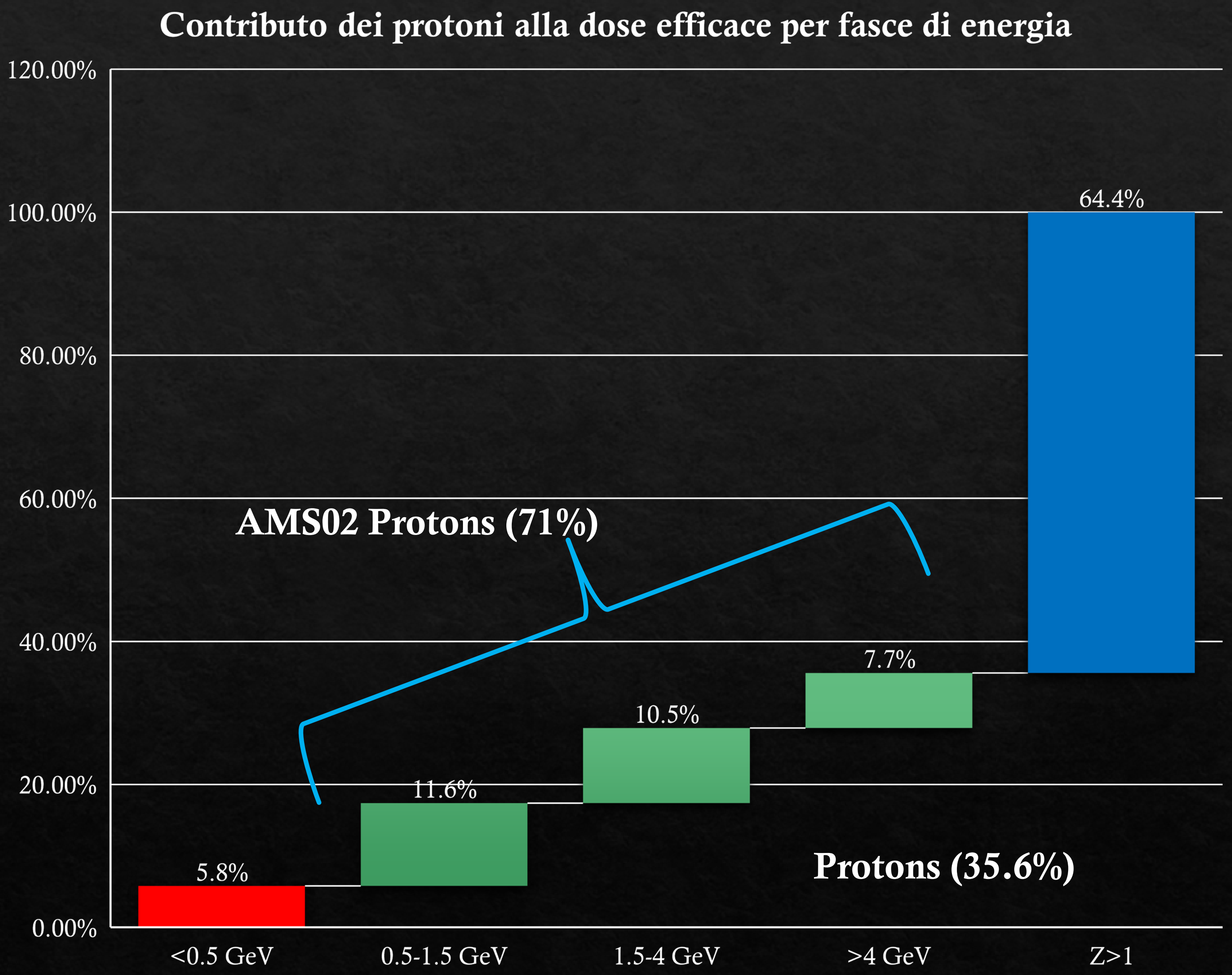


AMS02-Preliminare

Dose efficace dovuti ai GCR sensibilità rispetto alle diverse particelle ed energie

- **No Shielding**
- **Solar Minimum**

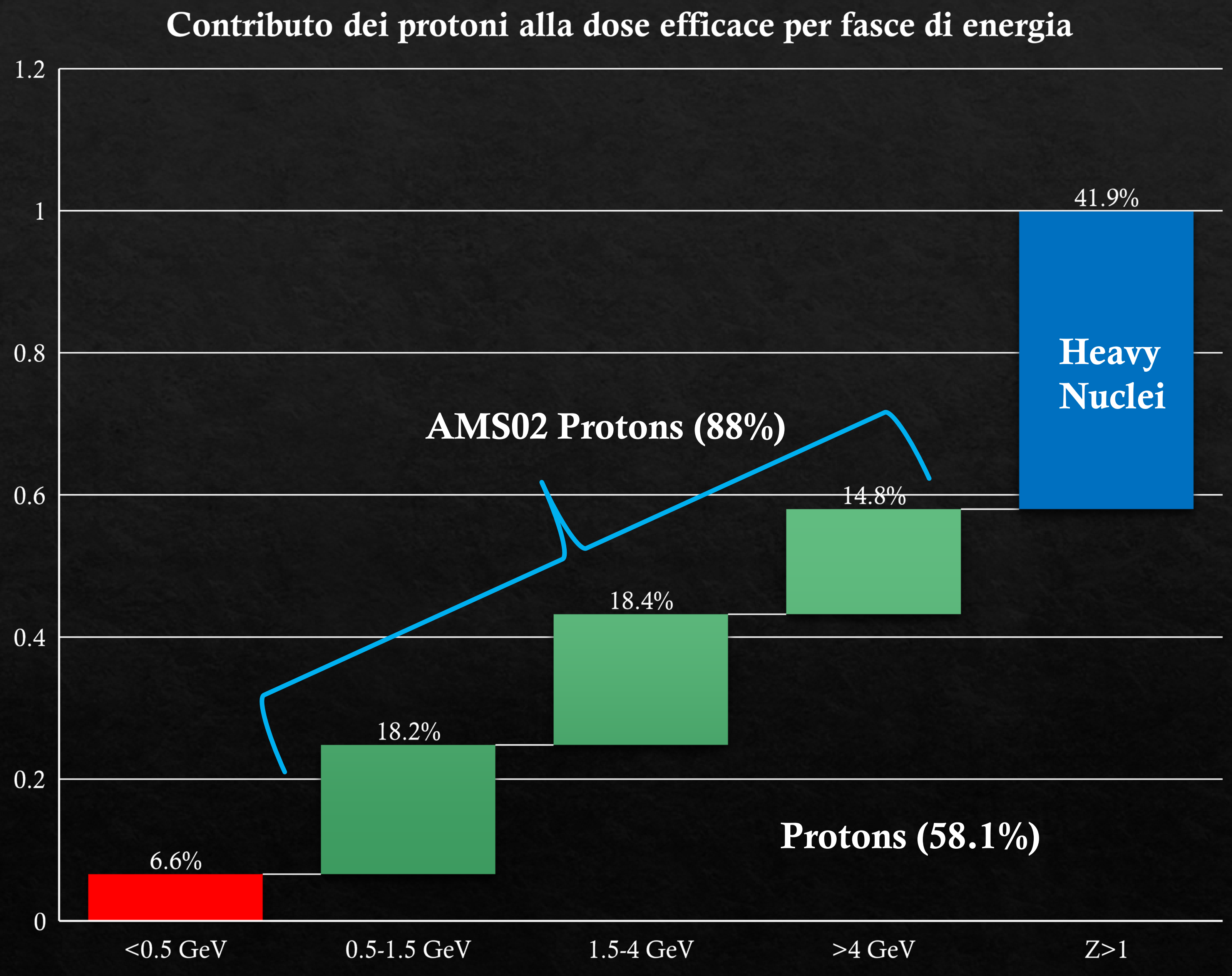
AMS02 permette di misurare il 71% dei protoni che contribuiscono alla dose efficace



Dose efficace dovuti ai GCR sensibilità rispetto alle diverse particelle ed energie

- Aluminum Shielding 20g/cm2
- Solar Minimum

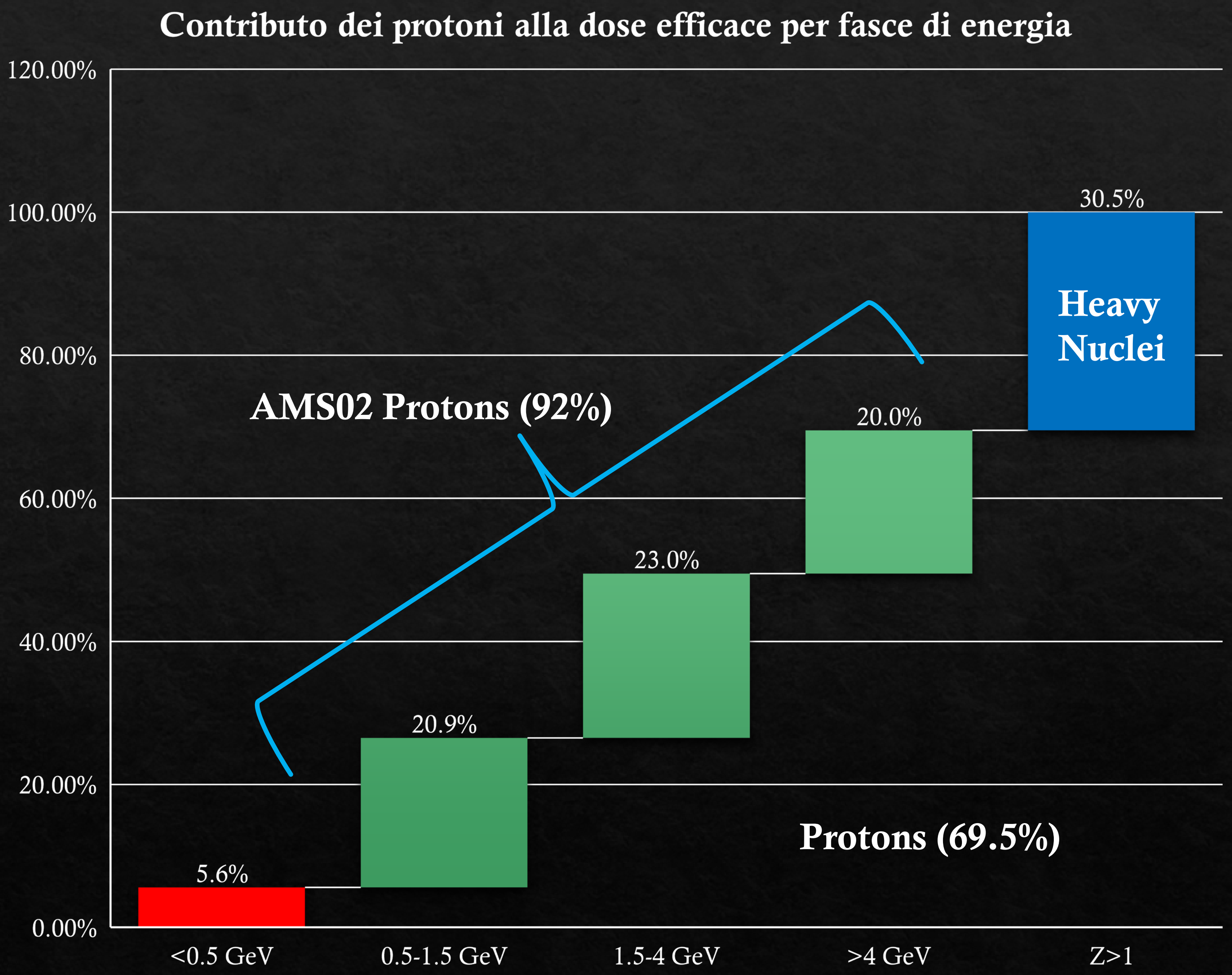
AMS02 permette di misurare l’88% dei protoni che contribuiscono alla dose efficace

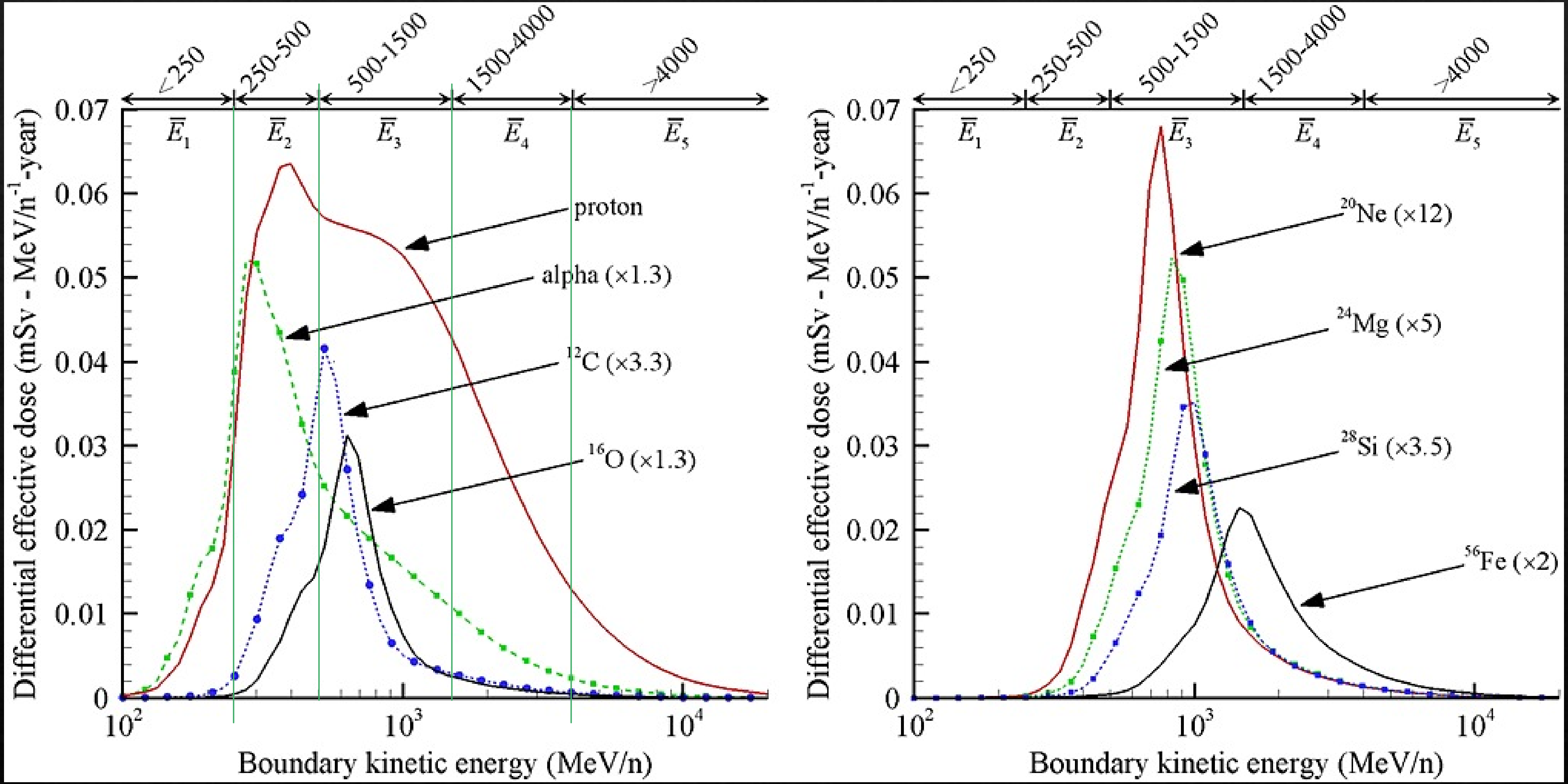


Dose efficace dovuti ai GCR sensibilità rispetto alle diverse particelle ed energie

- Aluminum Shielding 40g/cm2 Aluminum
- Solar Minimum

AMS02 permette di misurare il 92% dei protoni che contribuiscono alla dose efficace





<250
250-500
500-1500
1500-4000
>4000
$\overline{E}_1$
$\overline{E}_2$
$\overline{E}_3$
$\overline{E}_4$
$\overline{E}_5$
proton
alpha (×1.3)
^{12}C (×3.3)
^{16}O (×1.3)
^{20}Ne (×12)
^{24}Mg (×5)
^{28}Si (×3.5)
^{56}Fe (×2)
Differential effective dose (mSv - MeV/n^{-1}-year)
Boundary kinetic energy (MeV/n)
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
10^2
10^3
10^4

FAX phantom

- The International Commission on Radiological Protection (ICRP) has created a task group on dose calculations, which, among other objectives, should replace the currently used mathematical MIRD phantoms by voxel phantoms. Voxel phantoms are based on digital images recorded from scanning of real persons by computed tomography or magnetic resonance imaging (MRI). Compared to the mathematical MIRD phantoms, voxel phantoms are true to the natural representations of a human body. Connected to a radiation transport code, voxel phantoms serve as virtual humans for which equivalent dose to organs and tissues from exposure to ionizing radiation can be calculated. The principal database for the construction of the FAX (Female Adult voXel) phantom consisted of 151 CT images recorded from scanning of trunk and head of a female patient, whose body weight and height were close to the corresponding data recommended by the ICRP in Publication 89. All 22 organs and tissues at risk, except for the red bone marrow and the osteogenic cells on the endosteal surface of bone ('bone surface'), have been segmented manually with a technique recently developed at the Departamento de Energia Nuclear of the UFPE in Recife, Brazil. After segmentation the volumes of the organs and tissues have been adjusted to agree with the organ and tissue masses recommended by ICRP for the Reference Adult Female in Publication 89. Comparisons have been made with the organ and tissue masses of the mathematical EVA phantom, as well as with the corresponding data for other female voxel phantoms. The three-dimensional matrix of the segmented images has eventually been connected to the EGS4 Monte Carlo code. Effective dose conversion coefficients have been calculated for exposures to photons, and compared to data determined for the mathematical MIRD-type phantoms, as well as for other voxel phantoms.

Misure di precisione di raggi cosmici con l'Alpha Magnetic Spectrometer e radiobiologia nello spazio.

Abstract

«L'esperimento Alpha Magnetic Spectrometer (AMS) è operativo sulla stazione spaziale internazionale (ISS) dal 2011.

In tale periodo di presa dati, sono stati acquisiti più di 135 miliardi di raggi cosmici misurandone le caratteristiche con una precisione mai raggiunta fino ad ora.

Tali misure costituiscono un punto di riferimento per la soluzione dei problemi di fisica fondamentale e cosmologia attualmente aperti.

Nella comunicazione verrà mostrato come tali informazioni siano anche cruciali per un corretta comprensione dei fenomeni radiobiologici che sono osservati nello spazio al fine di migliorare la costruzione dei modelli dose-risposta.

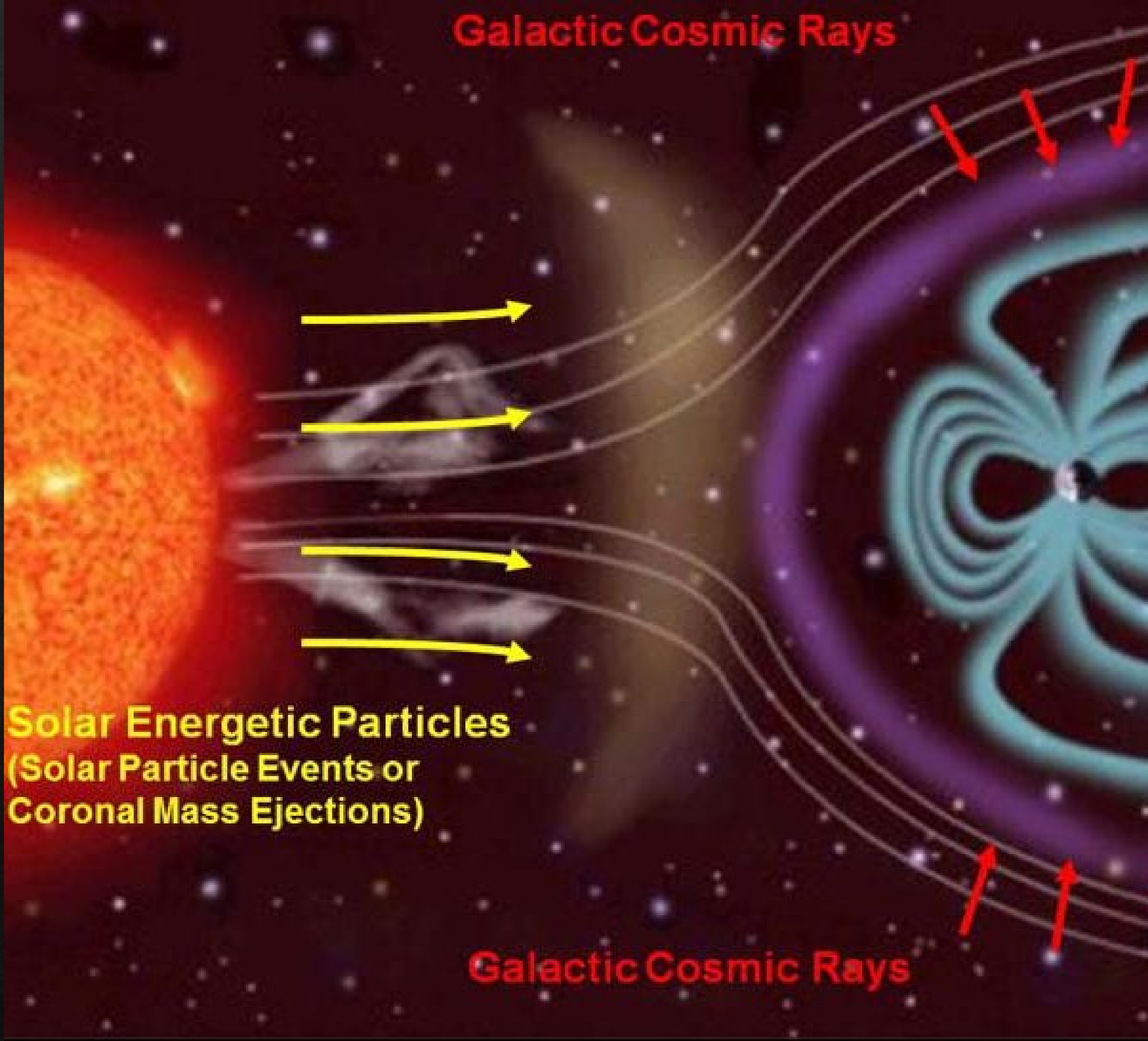
Tale conoscenza è un prerequisito essenziale per individuare e ridurre i fattori di rischio da radiazioni ionizzanti associati all'esplorazione ed alla colonizzazione del sistema solare da parte dell'uomo.»

Radiazioni Ionizzanti nel Sistema Solare

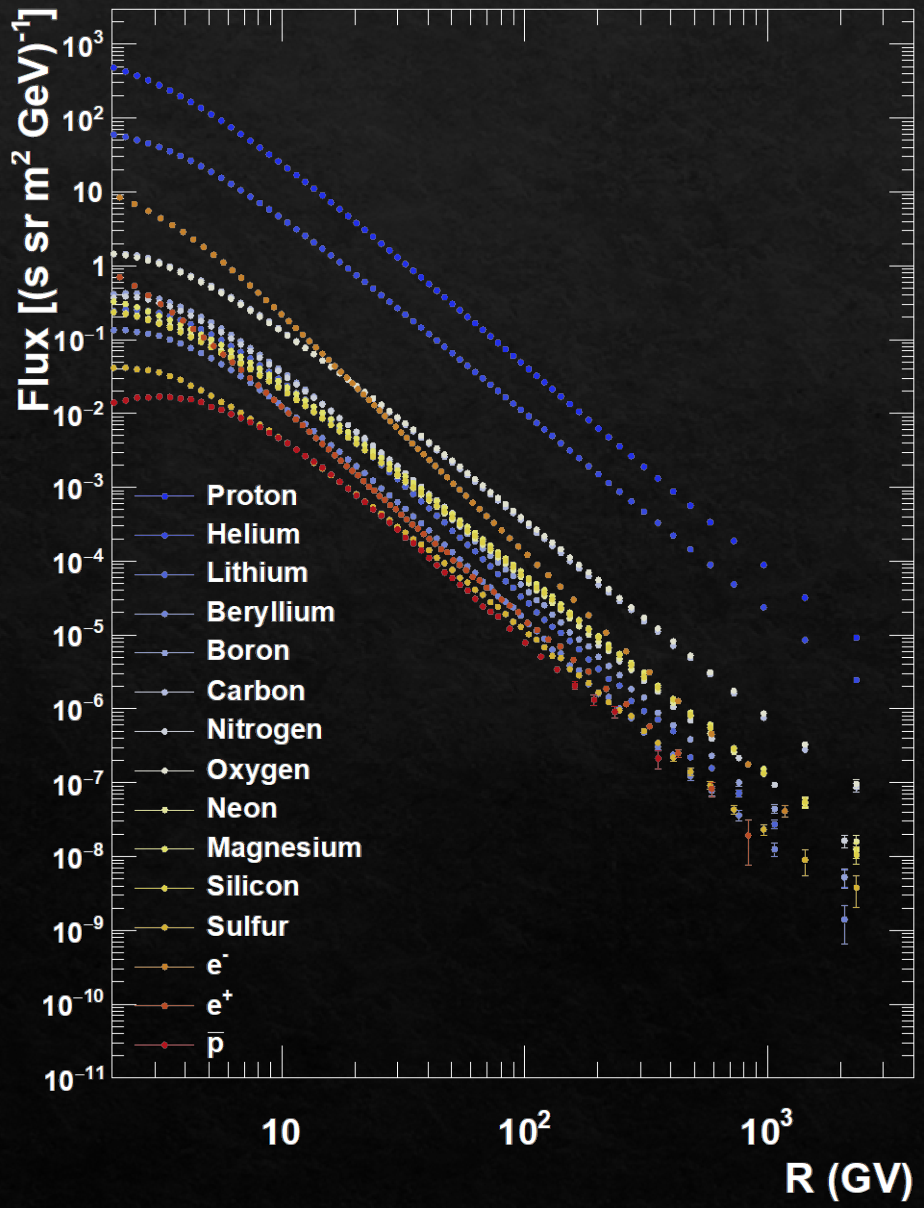
- **Particelle di origine solare**
  - Protoni di bassa-media energia (CME)
  - SPE di spettro e durata variabile
  - Shielding efficace

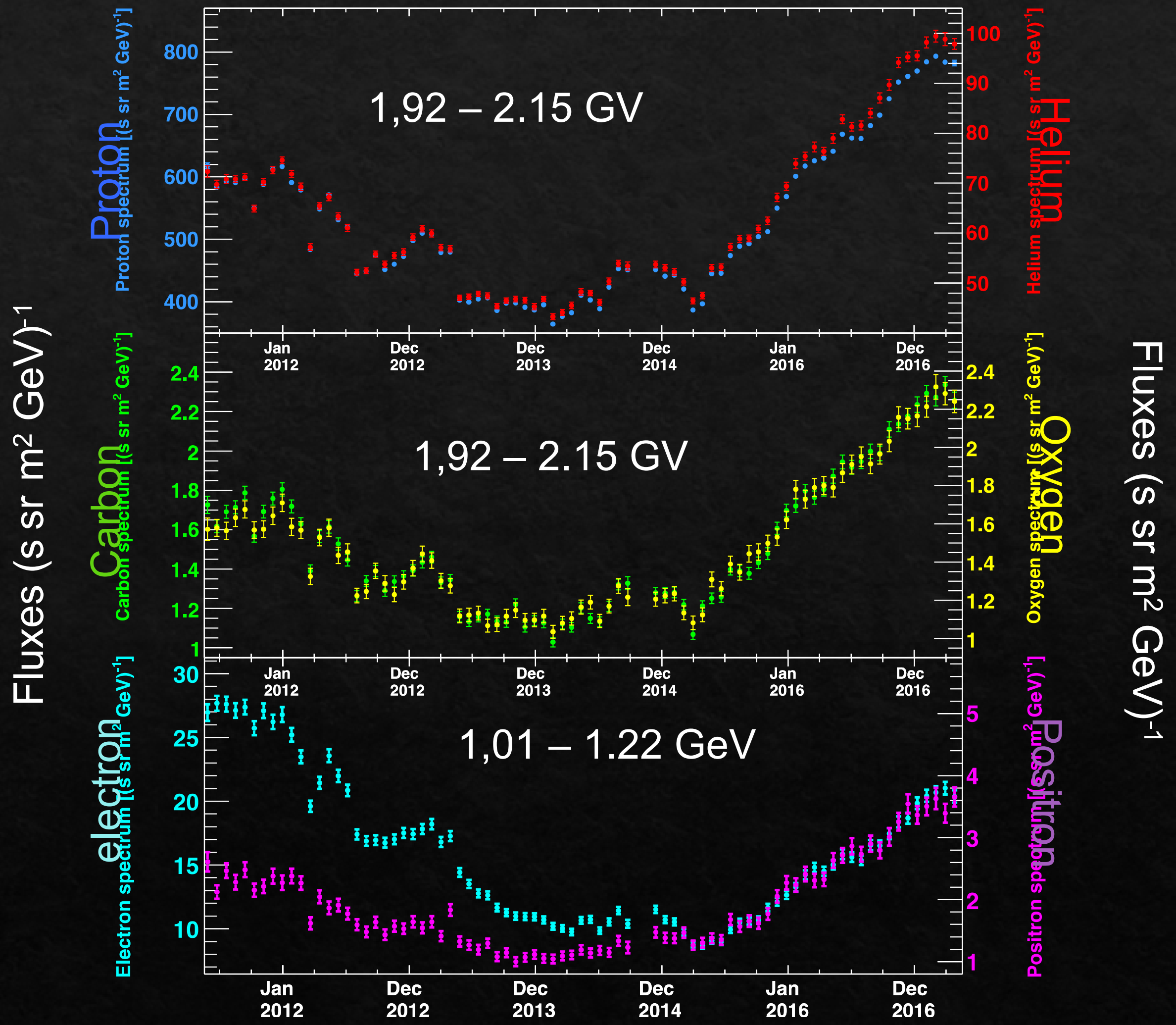
- **Particelle intrappolate nel campo magnetico terrestre (fasce di Van Allen)**
  - Fascia interna (1000-6000 Km)
    - Elettroni e Protoni
    - Bassa e Media Energia (KeV-MeV)
  - Fascia Esterna (12000-65000 Km)
    - Elettroni

- **Raggi cosmici di origine galattica**
  - Multiparticella
    - Protoni , Elettroni , Ioni Pesanti
  - Sempre presenti
  - Medie –Alte Energie (MeV-TeV)
  - Shielding non efficace



Misure di raggi cosmici con AMS
Ultimi risultati





Data collected by AMS

Particles

- Electrons and positrons
- Protons and antiprotons
- Deuterium and different He isotopes
- Heavy Nuclei

Measured Quantities

- Kinetic Energy
- Momentum
- Charge
- Rigidity

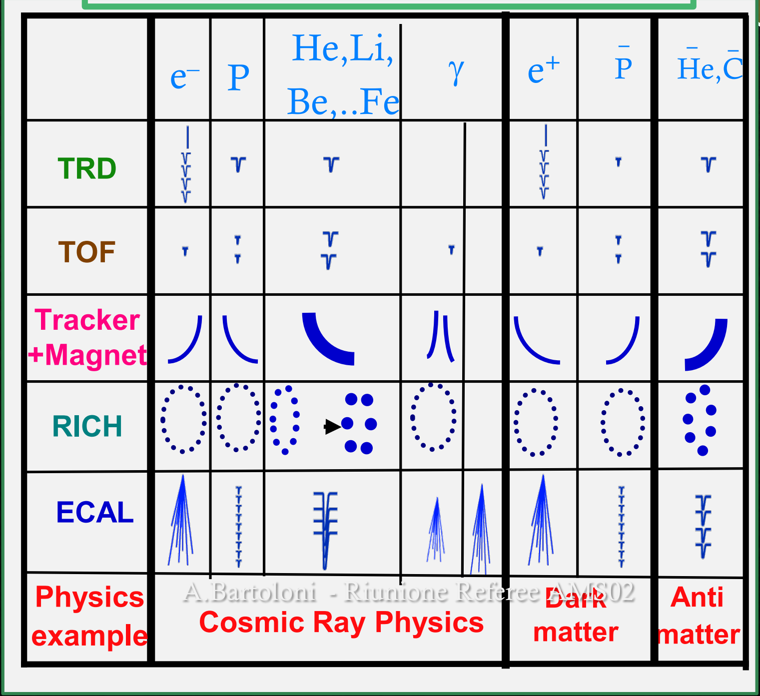
Position

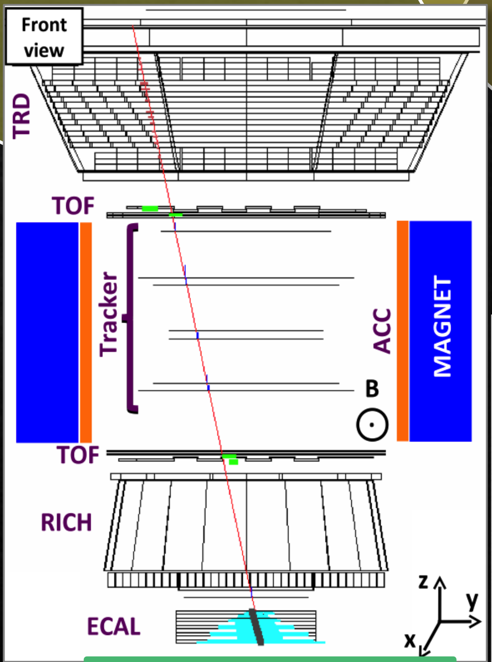
- International Space Station is in the Low Earth Orbit, approx. 400 Km of altitude
- Approx 15 orbit each day (74 minutes)
- AMS measure cosmic ray coming from any direction
- Also measuring in the South Atlantic Anomaly zone (SAA)

Time

- Operative since May 2011, h24 365day/year
- Possibility to reconstruct the variation in time of CR composition
- Approved to run until 2024
- Possibility to monitor CR for an entire solar magnetic activity cycle (11 years)

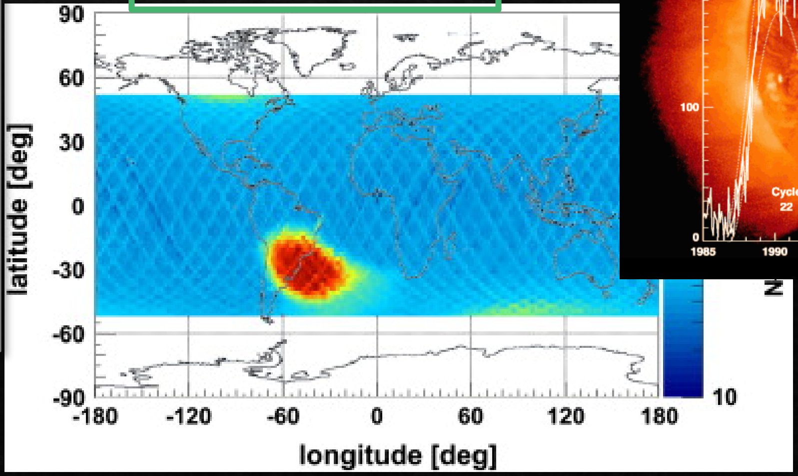
Particles signatures in AMS sub-detectors

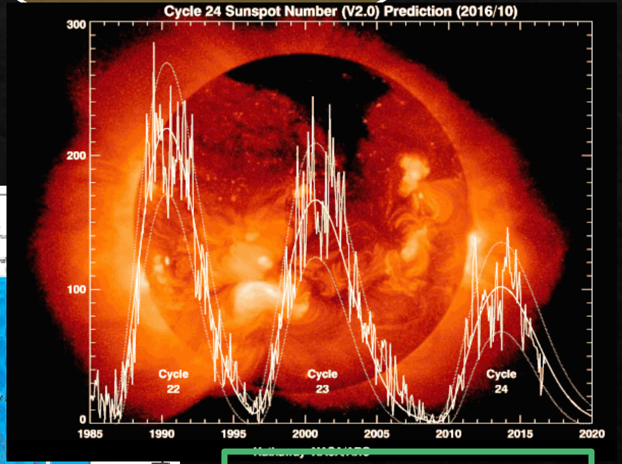




Signature of a 4GeV electron in AMS detector

AMS orbits coverage





Solar Magnetic activity cycles (1985-2020)

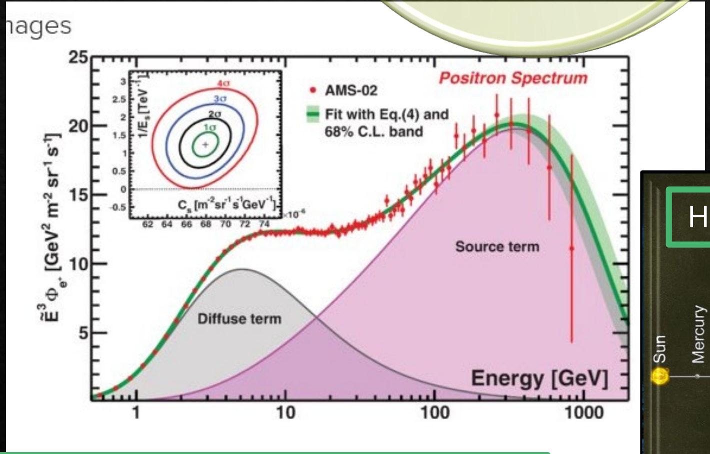
AMS Cosmic rays "Data" contains information crucial for research in different fields…

Fundamental Physics
- Indirect Dark Matter Search
- Direct Antimatter Search
- Cosmic Ray propagation modelling
- Galactic Sources
- Exotic particles search

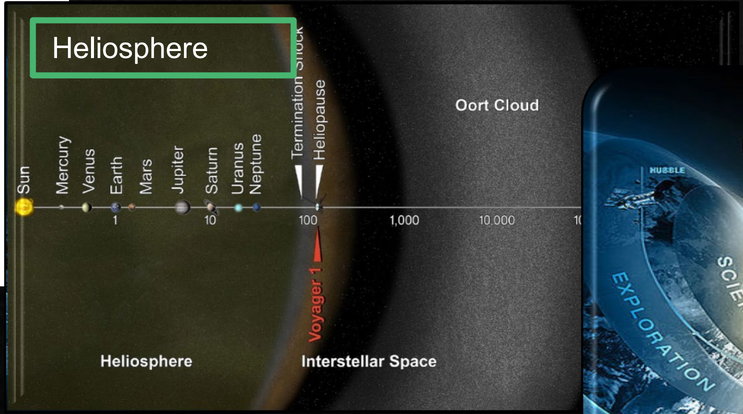
Solar Physics
- Heliosphere properties
- Cosmic Ray solar modulation
- Solar Flares predictions and monitoring

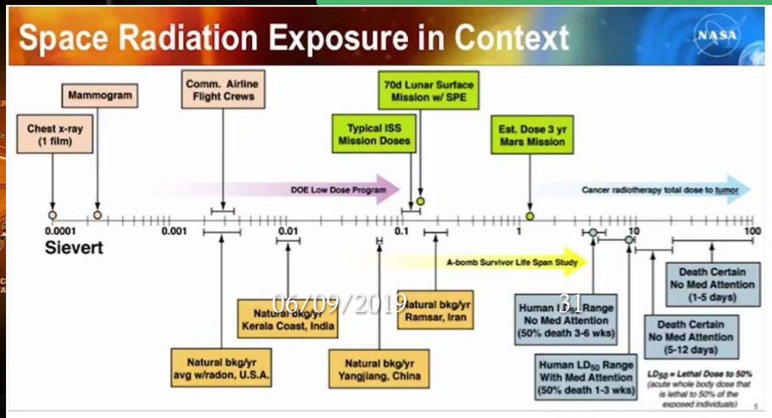
Human Space Exploration
- Earth Magnetosphere
- Missions to Moon and Mars
- Spacecraft shielding design

Space Radiation
- Space Radiobiology
- Daily Life applications
  - Biology, Medicine



Since 2013 AMS collaboration reports an excess in the cosmic ray positron spectrum that could derive by annihilation of dark matter particles (latest results in figure - 2019)





There are similarities between the ionizing radiation doses uses in clinical purposes in medicine (i.e radiotherapy, …) and the one absorbed from astronauts in space due to exposure to charged particles

Definizione di dose (ICRP)

- **Dose assorbita** (Gray)
  - Quantità fisica pari all'energia assorbita da un materiale irraggiato da una sorgente di RI esterna
- **Dose Equivalente** (Sievert)
  - E' utilizzata per misurare l'effetto biologico delle RI , ed introduce dei pesi che tengono conto del tipo di radiazione (Radiation Quality)
  - E' una quantità calcolata a partire dalla dose assorbita
  - Per ciascun tipo di radiazione si calcola il contributo che viene poi sommato
- **Dose Efficace** (Sievert)
  - E' utilizzata per distinguere l'effetto biologico biologico sui singoli tessuti e/o organi
  - E' una quantità calcolata a partire dalla dose Equivalente
  - In caso di valutazione per l'intero corpo la Dose Efficace coincide con quella Equivalente