Astroparticle Experiments to Improve the Biological Risk Assessment of Exposure to Ionizing Radiation in the Exploratory Space Missions: The research topic initiative

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Abstract

The actual and next decade will be characterized by an exponential increase in the Beyond Low Earth Orbit space exploration. In this context, a detailed space radiation field characterization will be crucial to optimize radioprotection strategies, assess the risk of the health hazard related to human space exploration, and reduce the damages potentially induced to astronauts from galactic cosmic radiation. Since the beginning of the century, many astroparticle experiments investigating the unknown universe components (e.g., dark matter, antimatter, dark energy) have collected enormous amounts of data regarding the cosmic ray (CR) components of the radiation in space. Such experiments are CR observatories, and the collected CR events contain valuable information that can enhance the space radiation field characterization. This paper will briefly present the status of the art of this research topic, and a research initiative titled "Astroparticle Experiments to Improve the Biological Risk Assessment of Exposure to Ionizing Radiation in the Exploratory Space Missions" will be introduced.

Keywords: Astroparticle Physics, Cosmic Rays, Space Radiobiology, Space Radiation, Human Space Exploration

1. Introduction

Cosmic rays (CR) approaching our planet interact with the Earth's magnetic field and atmosphere, and such interaction protects humans living on the Earth's surface. The Magnetosphere rejects most particles (99%) while the rest lose most energy going through the atmosphere before reaching the Earth's surface. Completely different is the situation in space where the CR interacting with the human body release some energy and can be dangerous for health. In this regard, this is one of the main concerns for safe space exploration as planned for the coming years by all the national space Agencies. The research on the space radiation environment and its effect on biological, mechanical, and electronic systems cover a time range of about 40 years. In 1983, J.A. Simpson published a review of galactic CRs(GCRs) elemental and isotopic composition measurements [1] highlighting fundamental GCR characteristics still relevant to space radiation effects today. Several of fundamental studies for space exploration are cited in [2, 3, 4], representing excellent overviews of research conducted over time. Moreover, NASA has an obvious and intense research focus in this area including the Space Radiation Analysis Group, developing the Space Radiation Laboratory, and supporting Space Radiation Element research projects under the Human Research Program NASA initiative. In addition, researchers such as W. Schimmerling and F.A. Cucinotta spent their careers understanding the effect of space radiation on biological systems and developing models and space radiation exposure criteria for astronauts. Nevertheless, the research on the space radiobiology represents hot topics up to date. In this context, all the different components of space radiation have been extensively studied and measured during the last decades by several astroparticle experiments operating in space, and the information contained in the data taken by such experiments are expected to improve the radiation health risk assessment (RHRA) for humans in future space missions.

2. Astroparticle Experiments in Space

In the last two decades, many astroparticle experiments have been built and deployed in space to investigate many open questions in fundamental physics and cosmology, for example, the dark matter and dark energy existence and composition or the existence of primordial antimatter. A particular class of experiments, the CR Detectors (CRD), is designed to produce a complete inventory of charged particles and nuclei in CR since the knowledge of this information is crucial to solving the above physics open

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problems.

Principal Operating Cosmic Ray Space Detectors. By now, several CRDs are doing precise and accurate measurements of CR components in the energy region from few keV to hundreds of TeV. An example of CDR in operations is The Alpha Magnetic Spectrometer(AMS-02), designed to measure high energy CRs and installed on the International Space Station(ISS). AMS-02 provides excellent particle identification capabilities and measures the charge and velocity of the traversing particle independently using different instruments The mission started in May 2011 and has been continuously operating since then with more that 200 billions cosmic ray events collected. [5]. Many are in operation now or in the recent past (e.g., the Payload for Antimatter Matter Exploration and Light-nuclei Astrophysics(PAMELA)[6], the satellite-based space mission Dark Matter Particle Explorer(DAMPE)[7], the ISS-based CALorimetric Electron Telescope(CALET)[8]).

Operations and Mesurements. The characteristics of the CDR space mission valuable for the research topic include:

- CR components identification:They can measure the light components like electrons and protons and the nuclei from the lighter (i.e.,Helium) up to heavier one (i.e.,Iron, Z=25).
- Wide Energy Measurement Range: data collected from the operating CRDs ranges from a few MeV up to hundreds of TeV.
- CR Solar Modulation: one of the most important aspects to be evaluated is the differences in IR exposition due to the interference of the solar activities and cycles with the GCR part of the space radiation. In this regard, the CRDs took data during cycles 23 and 24 and some will continue for the 25th.

3. Improve the Radiation Health Risk Assesment for Humans in Space Missions

Since 2018, the INFN Roma Sapienza AMS group has collaborated with researchers and scientists to investigate the possibilities of using the CRD to improve the RHRA 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, and National Space Agencies). We have many studies [9, 10, 11] on the capabilities and possibilities in that direction, especially regarding the AMS02 and also we identify many opportunities for improvement [12] and in particular:

- Environmental Model Characterization: Current environmental model used in the risk assessment process are based on a subset of the CR spectrum poor in the information of CR components of energy > 1GeV due to limited information collected in the past years. This affects the accuracy and precision of the risk assessment potentially underestimating the actual damage. Indeed, space radiation for LET greater than several keV/micron causes more serious damage than low-LET radiation to living cell/tissues. Many successful CRD space missions are collecting crucial data in the last decade and they will continue in the years. These data have an unprecedented precision on the spectrum and LET distribution of charged particle fluxes that compose the CRs. This precision is essential for improving the space risk assessment models thanks to the capability of monitoring the CR fluxes and their variation over time (including the frequency and duration of solar events).
- Effective Dose Evaluation: Measurements only of absorbed doses, by passive dosimeters, are insufficient for investigating biological effects or assessing radiation risk for astronauts. Dose equivalents need to consider the whole LET distributions, their QFs (up to 30), and RBE of high-LET particles constituting the space radiation environment. So the CRDs data could be used to complete the absorbed dose measurements related to the installation site/area
- Transport Code Validation: Based on more detailed information, Monte Carlo (MC) simulation code can be further implemented to better describe the interaction with the matter of GCR environments thanks to the improvement of accuracy of cross sections at high energy of elementary particles (electrons, protons), light and heavy nuclei (Helium to Iron and beyond). The implementation of transport code at these energies allows predicting the particle interactions with the known geometries of installed detectors. Moreover, MC codes can be used for designing ad hoc shielding of spacecrafts and space landers.
- Space Exposition Scenario Dose Computation: MC codes can be implemented to calculate the dose and so predict/describe the effects of GCR particles interacting with cells, tissues/organs and astronauts, which can be modeled as geometries with increasing details and complexities. The CRDs data could be used as input of the MC codes for determining the absorbed dose in the forecast exposition scenario (e.g lunar gateway/lander or spacecrafts).

among the others tha AMS Roma Sapienza group focused his research on the space radiobiology dose-effects model as one of the most important and promising research fields for possible collaborations[13] [14].

4. The Research Topic Initiative

While progressing in the research activity raised the awareness that to make progress in such a field it was re-

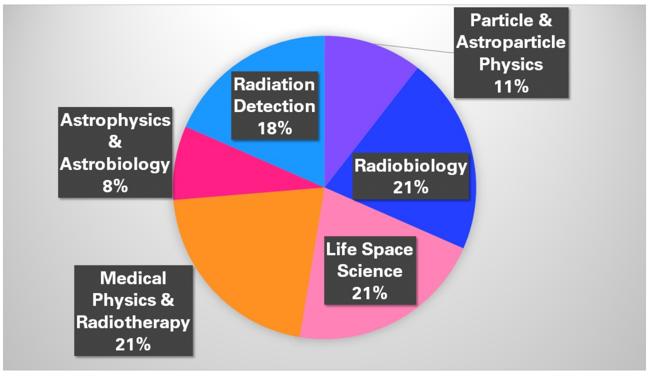

Figure 1: Expected Contributors divided per research areas

quired 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 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". We created a research topic editorial board 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. Fig.1 shows the distribution of research areas of expected contributors that manifested interest in participating during the first six months of the initiative (November 2021- May 2022). Other details on the topic and instructions to take part are in the research topic web page[15].

5. Acknowledgement

We gratefully acknowledge the strong support from the AMS collaboration, from the INFN Scientific Committee 2 and from the Italian Space Agency (ASI) within the agreement ASI-INFN n. 2019-19-HH.0.

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