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Bridging the Gap: Exploring AMS, Astroparticle Experiments and Space Radiobiology

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Abstract

This paper summarizes the three-year achievements of the AMS INFN Roma Sapienza research group, with a focus on their active engagement in astroparticle experiments and the exploration of the synergistic connection between astroparticle experiments and space radiobiology. Collaborating with institutions like the Medical Physics division of the IRCCS Azienda Ospedaliera-Universitaria di Bologna, they have made substantial contributions to space radiobiology projects, fostering interdisciplinary collaboration. The group's research has produced significant findings on various fronts, including the assessment of carcinogenic risks from galactic cosmic rays, with a particular emphasis on bystander effects. Additionally, the paper underscores the complementary role of astroparticle experiments in enhancing the assessment of biological risks associated with ionizing radiation exposure. Finally, the paper showcases examples of research conducted through collaboration with scientists and researchers worldwide. These illustrations offer valuable insights and highlight the interdisciplinary nature of this dynamic field.

Keywords: Human Space exploration, Space Radiation, Space Radiobiology, Monte Carlo Simulation, Astroparticle Experiments

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1 Introduction

The Earth's atmosphere along with the magnetic field around the Earth ensured that life on the planet could evolve to what we find today. Most of the cosmic particles do not reach the earth's surface because they are either deflected by the earth's magnetic field or stopped in the atmosphere. The Earth's magnetic field deflects some cosmic particles towards the Earth's poles, and the Earth's atmosphere acts like a shield of several meters of heavy metals (such as lead) against those particles. However, the situation in space is completely different, and cosmic rays are everywhere. Cosmic rays are composed of many particles including charged and uncharged particles. The energy spectrum of those particles is very wide, from less than 1 keV to hundreds of TeV [1] and beyond up to 10^20 eV[2]. Those energetic particles can interact with the body tissues of astronauts and leave a lot of energy in their bodies finally leading to the destruction of living tissue. Therefore, investigating the biological effects of those particles has particular importance.

Thanks to the astroparticle experiments that have been done or are being done so far [1-7], researchers have gained good knowledge and data about cosmic particles and their energy. This data can be used to maintain the health of astronauts against cosmic particles in future missions of space agencies for manned journeys to the Moon and Mars (Artemis exploration program), as well as long-term human stays in space. Certainly, the best method to study the effects of cosmic particles on living tissues is the experimental method (Artemis-1 mission). However, due to the high risks and expenses of such experiments, simulation methods (such as simulation of the interaction of particles with matter through the Monte Carlo technique) are the best alternative to experimental methods. In fact, the data obtained from astrophysics experiments can be defined as the input of Monte Carlo simulations, and then the effects of cosmic particles on various materials, including human body tissue, can be investigated.

2 Astro Particle experiment in space

Until now, many astroparticle experiments have been conducted to answer the fundamental questions of physics, such as the existence of dark matter and dark energy, as well as the investigation of antimatter in space. For this purpose, advanced detectors (cosmic ray detectors) have been built and deployed in space to classify cosmic rays. Since those detectors can detect different particles in a wide range of energy and record data, the information obtained is very useful for investigating the biological effects of cosmic rays on the astronauts' bodies.

The Alpha Magnetic Spectrometer (AMS-02) is a cosmic ray detector [1, 2]. It can measure high-energy particles in space. Although its main purpose is the indirect search for dark matter and dark energy. But so far, it has collected valuable data about the composition of cosmic particles and their energy, which can be used in the field of space radiobiology. The AMS02 was launched and installed on the International Space Station (ISS) in May 2011, and it is still operating. The Dark Matter Particle Explorer (DAMPE) [3], CALorimetric Electron Telescope (CALET) [4], Cosmic Ray Energetic and Mass for the International Space Station (ISS-CREAM) [5], Advanced Composition Explorer (ACE) [6], Payload for Antimatter Matter Exploration and Light-nuclei Astrophysics (PAMELA) [7], are other cosmic particle detectors that have collected and sent valuable data on cosmic rays to researchers.

3 Enabling Research at INFN ROMA AMS Research Group

The AMS research group at INFN Roma and Sapienza University has been actively involved in the AMS-02 experiment since 2001, contributing to the construction and development of key components such as the Transition Radiation Detector (TRD) and the GAS System. Following the installation of AMS-02 on the International Space Station (ISS) in 2011, the group has been engaged in data-taking and analysis at CERN. In 2017, a collaboration was formed with a medical physics research group to explore novel applications of AMS-02 data in space life sciences, space radiobiology, and dosimetry. This collaboration led to research focusing on understanding space radiation effects and dose-effect relationships, securing funding for studying data applications in radiobiology, particularly for protons, and delving into dose-effect models for space radiation exposure during exploratory space missions. [8-10].

3.1 Non-target effects investigation

The research project aimed to introduce a novel set of tools known as "NTE-DEM" to streamline the creation of robust dose-effect models in the realm of space radiobiology. These tools were specifically designed to enhance the development of reliable models, and the initial findings from this research were partially showcased in Figure 1. The study [11] delves into the concept of "Non-target effects" while also calculating Tumor Prevalence (TP) for protons, based on the analysis of AMS data organized into kinetic energy intervals or "bins". This investigation represents a significant step forward, made possible in part by the NTE-DEM tools, in the pursuit of more accurate and trustworthy dose-effect models. The preliminary results from this endeavor underscore the consistency of anticipated outcomes, utilizing Hazard functions to evaluate TP concerning proton flux and exposure duration. Figure 1 visually encapsulates these findings, highlighting a noteworthy revelation: high-energy protons with lower linear energy transfer demand extended exposure times compared to their low-energy counterparts to attain equivalent TP values.

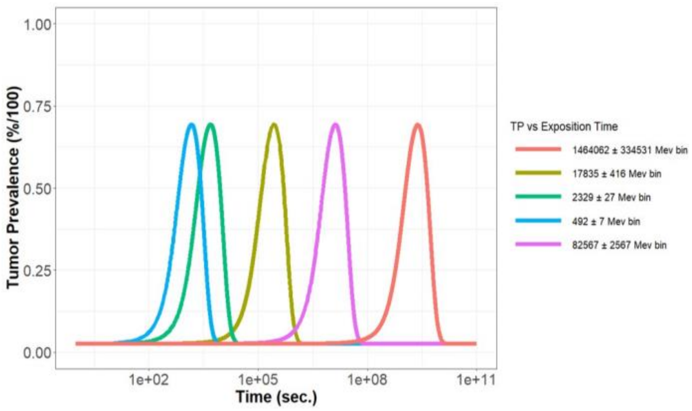

Figure 1: Tumor Prevalence vs. exposition time for GCR protons: using a single different energy bin (492.4±7 MeV to 1.46±0.335 TeV) [11].

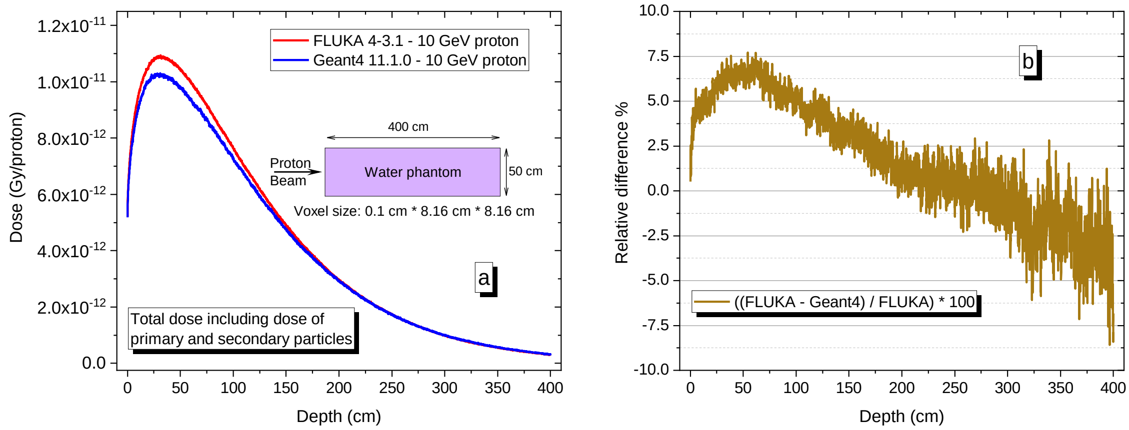

Figure 2: a) Depth dose distribution of 10 GeV protons in the water phantom by FLUKA and GEANT4, b) the relative difference between the results of FLUKA and GEANT4

3.2 Monte Carlo Codes Simulations for Space Radiobiology

Nowadays, comprehensive Monte Carlo codes (such as MCNP, FLUKA [12], GEANT4[13], and PHITS, etc) can study parameters related to radiation effects (such as total dose, effective dose, equivalent dose, linear energy transfer, buildup factor, and relative biological effectiveness, etc) on different materials (including living tissues). Due to the fact that those codes use models and cross-sections of interaction close to reality, they provide relatively reliable results to researchers. "For example, Figure 2 illustrates the depth dose distribution of 10 GeV protons in a water phantom simulated using the FLUKA and GEANT4 codes. Despite employing different models to simulate radiation-matter interactions, the results exhibit good agreement, as evident in Figures 2.a and 2.b. Using Monte Carlo simulation, the dose due to only primary particles and only secondary particles can also be obtained separately.

4 Conclusions

In contemporary space exploration, a key objective for space agencies is the exploration of the moon and Mars, with a focus on establishing sustainable, long-term human presence in space. Therefore, it is necessary to use data obtained from astroparticle experiments to investigate the effects of cosmic rays on the bodies of astronauts and crew. In addition to experimental studies on the biological effects of cosmic particles, simulation methods that are cheaper and less dangerous can also be used. Considering that good Monte Carlo codes have been developed so far, it is expected that the use of those codes to study the biological effects of cosmic rays will increase. Finally, it can be mentioned that without a complete investigation in the field of radiobiology, it will not be possible to carry out long-term manned space journeys.

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