Advancing Readiness for Deep Space Exploration: Status and Developments by the Alpha Magnetic Spectrometer Group

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Abstract

The AMS group is pioneering high-precision ionizing radiation (IR) dose-effect models to accurately predict the biological effects of IR on human health during space missions. These models are essential for understanding the risks associated with radiation exposure and developing protective measures for astronauts. In addition to dose-effect modelling, the AMS group is actively evaluating existing Monte Carlo-based codes such as FLUKA and GEANT4. The aim is to compare these codes' behaviors when applied to typical radiobiological simulations of space radiation. This evaluation is crucial for identifying the strengths and limitations of these tools and ensuring their accuracy and reliability in predicting the effects

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of space radiation on human health. The research also addresses the significant impact of solar flares and radiation on human health, presenting key challenges for deep space missions. Understanding these effects is critical for ensuring the safety of astronauts and developing effective mitigation strategies. Furthermore, the presentation will discuss the ongoing development of an ontology for space radiation biology, which enhances the management and comparison of experimental datasets. This effort aligns with the RBO ontology developed by a NASA Ames-led collaboration and aims to facilitate better data integration across studies.

Keywords: Human Space Exploration, Cosmic Ray, Space Radiobiology, Interdisciplinary Research

"Avanzando en la preparación para la exploración del espacio profundo": Estado y avances del Grupo del Espectrómetro Magnético Alfa

Resumen

El grupo AMS es pionero en el desarrollo de modelos dosis-efecto de la radiación ionizante (RI) de alta precisión para predecir con precisión los efectos biológicos de la RI en la salud humana durante las misiones espaciales. Estos modelos son esenciales para comprender los riesgos asociados a la exposición a la radiación y desarrollar medidas de protección para los astronautas. Además del modelado dosis-efecto, el grupo AMS evalúa activamente códigos existentes basados en Monte Carlo, como FLUKA y GEANT4. El objetivo es comparar el comportamiento de estos códigos al aplicarlos a simulaciones radiobiológicas típicas de la radiación espacial. Esta evaluación es crucial para identificar las fortalezas y limitaciones de estas herramientas y garantizar su precisión y fiabilidad en la predicción de los efectos de la radiación espacial en la salud humana. La investigación también aborda el impacto significativo de las erupciones solares y la radiación en la salud humana, lo que presenta desafíos clave para las misiones al espacio profundo. Comprender estos efectos es crucial para garantizar la seguridad de los astronautas y desarrollar estrategias de mitigación eficaces. Asimismo, la presentación abordará el desarrollo en curso de una ontología para la biología de la radiación espacial, que mejora la gestión y la comparación de conjuntos de datos experimentales. Este esfuerzo se alinea con la ontología RBO desarrollada por una

colaboración liderada por la NASA Ames y tiene como objetivo facilitar una mejor integración de datos en todos los estudios.

Palabras clave: Exploración espacial humana, rayos cósmicos, radiobiología espacial, investigación interdisciplinaria

“推进深空探索准备”：阿尔法磁谱仪小组的现状和发展

摘要

阿尔法磁谱仪(AMS)小组正带头开发高精度电离辐射(IR)剂量效应模型，以准确预测太空任务期间IR对人类健康的生物学影响。这些模型对于了解与辐射暴露相关的风险和制定宇航员保护措施而言至关重要。除了剂量效应建模外，AMS小组还在积极评价当前基于Monte Carlo的代码，如FLUKA和GEANT4。目的是比较这些代码在应用于典型的太空辐射放射生物学模拟时的行为。该评价对于确定这些工具的优势和局限性以及确保它们在预测太空辐射对人类健康影响方面的准确性和可靠性而言至关重要。本研究还探究了太阳耀斑和辐射对人类健康的重大影响，对深空任务提出了关键挑战。了解这些影响对于确保宇航员的安全和制定有效的缓解策略至关重要。此外，报告将讨论正在开发的空间辐射生物学本体论，这将增强实验数据集的管理和比较。此举与NASA Ames领导合作开发的RBO本体论相一致，并旨在促进不同研究间更好的数据整合。

关键词：载人太空探索，宇宙射线，空间放射生物学，跨学科研究

A collaboration between AMS Roma Sapienza and the Medical Physics Division of Sant'Orsola Hospital is pioneering research into the effects of space radiation on human health. Initiated in 2018, this collaboration capitalizes on the strengths of high-precision cosmic ray measurements, heliospheric propagation modelling, and specialized expertise in medical radiation applications. AMS Roma Sapienza, a renowned space science and technology institution, brings its expertise in particle detection and cosmic ray studies (Bartoloni et al., 2024). Collaborating with the Medical Physics Division of Sant'Orsola Hospital, specializing in radiation therapy and radiobiology, creates a multidisciplinary approach to investigate the intricate

interplay between space radiation and human physiology. The joint research currently encompasses, among the others, two research paths aimed to explore the reliability of existent Monte Carlo (MC)) method codes when applied to different space radiation research fields, such as space radiobiology and the existing and promising approaches to developing ontologies for radiobiology (Bartoloni et al., 2024). These two were the objects of a panel at the conferences.

Monte Carlo Method Codes for Space Radiation and Shielding Design

The Monte Carlo (MC) method is gaining prominence in space radiation research, particularly in areas previously underexplored. In that sense, Dr. Augusto Di Chicco delved into the MC method, emphasizing its critical role in designing effective radiation shielding for space missions. He presented a case study involving lunar regolith simulation, showcasing how MC methods can predict the effectiveness of using lunar soil as a natural barrier against cosmic radiation. The discussion also highlighted the potential for developing more accurate MC simulation codes to address the unique radiation environments of lunar and deep-space missions. By refining these codes, researchers can better optimize shielding materials and configurations, ultimately enhancing the safety and sustainability of future exploration efforts (Di Chicco et al., 2024; Di Chicco et. al., 2024).

Research Activities on Ontology Development at NASA Ames: The RBO Project

Assays play a crucial role in biomedical research by generating data that can be integrated, reused, and compared across studies. Collaborative efforts have led to developing structured approaches to represent assays, ensuring consistency and supporting diverse research needs. Over time, inconsistencies in design patterns emerged due to varied contributions, prompting a comprehensive review to align definitions, templates, and logic. This process improved usability and fostered better collaboration, serving as a model for standardization in other areas of biomedical research. Dr. Berrios outlined the RBO (Radiation Biology Ontology) Project at NASA Ames, emphasizing its role in structuring knowledge to support interdisciplinary research. He discussed the challenges of developing a comprehensive ontology for space radiobiology, including the complexity of integrating diverse datasets and terminologies (Wilson et al., 2023).

The SESA2024 Conference Panel discussion

We had the privilege of organizing a panel at the Space Education & Strategic Applications Conference (SESA 2024), hosted by the Policy Studies Organization. The roundtable discussion brought together all panelists to address key themes and explore opportunities for

advancing space radiobiology research:

1) **Enhancing Monte Carlo Simulations for space radiation**
   The panelists agreed that more accurate Monte Carlo simulation codes are essential for developing next-generation deep space missions. They emphasized the need to model the unique radiation profiles of deep-space environments more precisely and make an assessment of different existing libraries available (e.g., GEANT4, FLUKA, PHYTS). Furthermore, in this field, the radiobiological implications of deep space missions will generate synergies with the incoming application of IR in the medical field.

2) **Challenges and Benefits of Ontology Development**
   Developing a comprehensive ontology for space radiobiology presents significant challenges, including harmonizing diverse datasets and accommodating rapidly evolving research. However, the panelists highlighted its transformative potential in fostering interdisciplinary collaboration by enabling institutions and international research groups to work within a shared knowledge framework. The ontology could streamline joint projects and accelerate discoveries; this panel is an example.

3) **The Role of International Collaboration**
   The discussion underscored the importance of international partnerships in advancing space radiobiology. Panelists identified key areas where collaboration could yield significant benefits, including astronaut health monitoring, radiation countermeasure development, and habitat design for lunar and Mars missions. They emphasized the need for shared resources, such as global databases and co-funded research initiatives, to effectively tackle human space exploration's complex challenges.

Conclusions

The panel underscored the critical role of interdisciplinary approaches and international collaboration in advancing space radiobiology. By leveraging tools like Monte Carlo simulations and ontological frameworks, researchers can address current challenges and pave the way for safer and more sustainable space exploration.

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