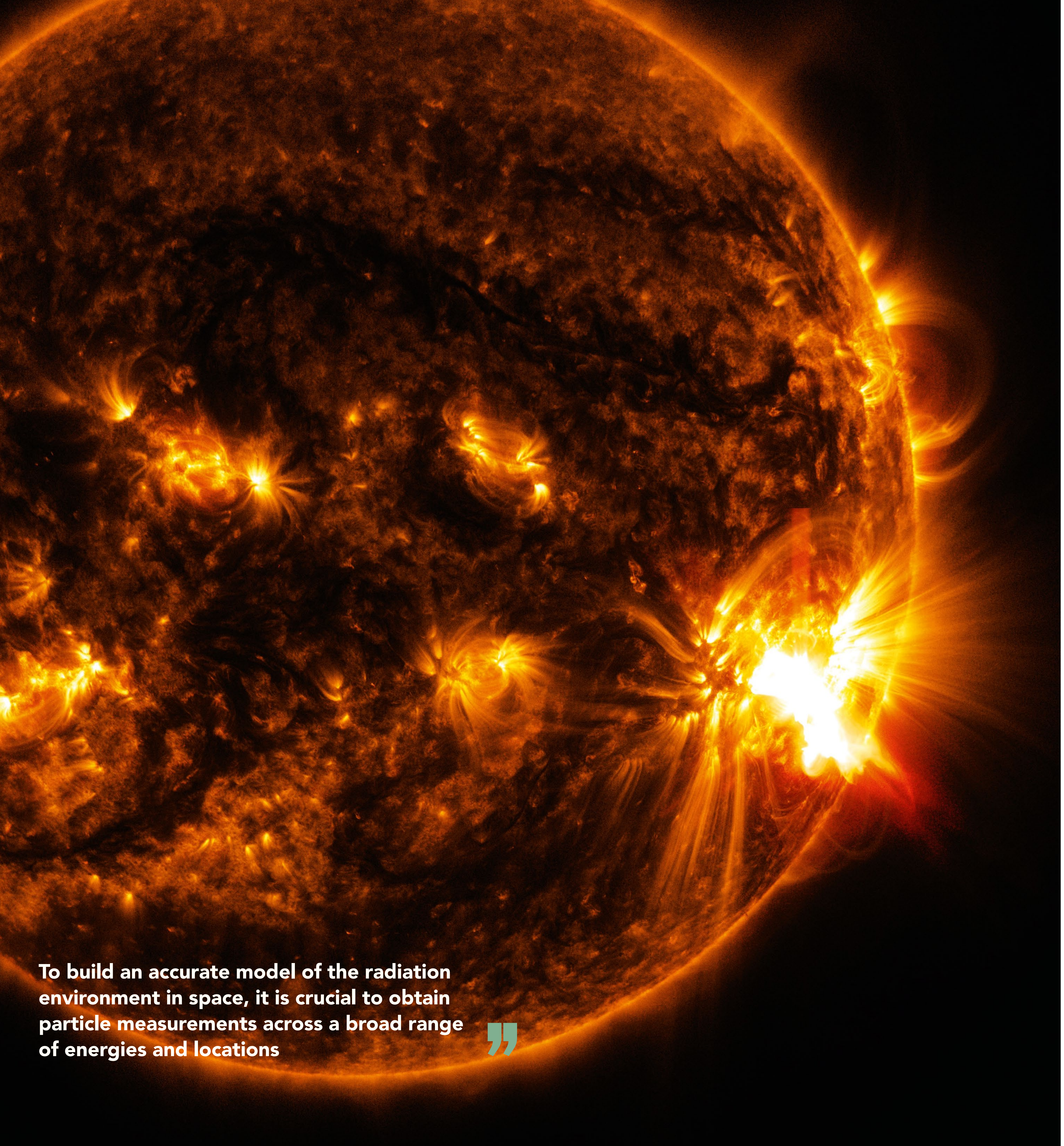

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Physics of the Sun and astronaut safety in the new era of space exploration

As Associate Professor at the University of Hawai'i, **Dr Veronica Bindi** and her team are analysing data from a unique instrument on the International Space Station to investigate high-energy particles originating from the galaxy and the Sun itself. A comprehensive understanding of these particles, their origin and transport processes will increase our understanding of the universe, solar physics and help to protect instruments and astronauts on future space missions.

Space exploration is currently entering a new and exciting era of discovery. With Voyager 1 making a historic journey beyond the heliosphere (the region of space influenced by the Sun), we are now, for the first time, able to explore interstellar space. At the same time, technological advancements are allowing instruments to measure particles from space at unprecedented precision. At the forefront of this research is Dr Veronica Bindi who, together with her team, is analysing new data to better understand our place in the universe and protect both technology and astronauts in space.

A QUEST FOR ANSWERS

Looking up at the night sky, few among us won't have been struck by questions of overwhelming proportions. What is space made of? How old is the universe? To answer these questions, Dr Bindi's research focuses on Galactic Cosmic Rays (GCRs), accelerated particles that originate from outside the solar system, and Solar Energetic Particles (SEPs), high-energy particles originating from the Sun. By collecting precise measurements of these particles, Dr Bindi hopes to better understand their origin and behaviour and shed light on the nature of matter in space.

NEW DATA: FILLING THE VOID

Associated with solar flares and coronal mass ejection, SEPs are a key focus of heliophysics (the study of the Sun and its effects on space) research. SEPs are a type of Cosmic Ray that are accelerated by the Sun and its activity. The study of their composition and charge can allow us to better understand the mechanisms involved in producing solar flares and coronal mass ejection. The energy range of SEPs can vary over five orders of magnitude. Whilst low-energy (up to a few hundred MeV/nucleon) SEPs have been well observed, there is a lack of high-energy (near 1 GeV) measurements, and thus SEP characteristics at high energies are poorly understood. As a result, SEP models are currently unconstrained at higher energies. The dearth of high-energy measurements has also fuelled controversy within the heliophysics community regarding the source regions and processes responsible for accelerating particles up to high (GeV/nucleon) energies.

In addition, both SEPs and GCRs pose significant radiation risks for technology and people in space. To build an accurate model of the radiation environment in space, it is crucial to obtain particle measurements across a broad range of energies and locations. With the current push for long-duration manned space missions, accurate modelling of the radiation environment in space is increasingly important to ensure the safety of astronauts.

Working for ten years at CERN, Dr Bindi was involved in the construction, characterisation and optimisation of the Alpha Magnetic Spectrometer (AMS), a state-of-the-art

AMS, the largest magnetic spectrometer in space, is capable of measuring particles with unprecedented precision

magnetic spectrometer installed on the International Space Station (ISS). Now Associate Professor in the Department of Physics and Astronomy at the University of Hawai'i, and the Principle Investigator of a long-term NASA grant and an NSF Career award, Dr Bindi and her team are analysing data collected by AMS.

AMS: A UNIQUE TOOL

AMS, the largest magnetic spectrometer ever built for space application, is capable of measuring particles with energies ranging between 400MeV/nucleon to a few TeV/nucleon and provides measurements with unprecedented precision. With five different detectors, the charge, energy, trajectory and velocity of particles can be measured accurately and continuously. Installed on the ISS in May 2011, it will collect data for the duration of the station (currently extended to 2024), allowing for the observation of particle behaviour across multiple solar cycles. These characteristics make AMS a unique and powerful instrument for heliophysics research.

NEW INSIGHTS

By analysing the data already collected by AMS, Dr Bindi and her team have proved that it is possible to measure high-energy solar particles with a precision instrument, with 27 high-energy SEP events observed by AMS to date. Of these 27 events, only one of them has been measured by the ground instruments that are normally used to detect these type of high energy SEP events. This demonstrates unprecedented high sensitivity of this instrument. Data from AMS is also challenging previous theories relating to particle acceleration. Where previous observations have only recorded particles being accelerated for short time periods, AMS has detected particles up to 1GeV/nucleon persisting for hours and even days. The team are also analysing SEP measurements to get a better understanding of the mechanisms producing SEP events, with the aim of generating a baseline for SEP event modelling. In addition, new AMS data at high particle energies has identified several new behaviours and is challenging current thinking on dark matter and GCR propagation.

Furthermore, AMS is providing measurements of how GCR flux is changing over an entire solar cycle. This data will provide important insight into long-term solar modulation: how GCRs vary in intensity and energy when they encounter the heliospheric magnetic field. Two papers about the time variation of proton and helium and electrons and positrons in GCRs will be published before the end of the year in *Physical Review Letters*.

RESEARCH AND BEYOND

In addition to her main research work, Dr Bindi also dedicates significant time to outreach and education. Working with schools in Hawai'i, Dr Bindi and her team are developing high- and middle school curricula and providing opportunities for students to engage with science through real-world applications. Current projects include incorporating physics, engineering, mathematics, astronomy, biology and arts to plan a mission to send astronauts to Mars, and a practical project constructing a particle detector from everyday objects such as webcams.

INTO THE UNKNOWN

Dr Bindi's work with AMS occupies an exciting position at the frontier of heliophysics research. The unique capability of AMS and its location above the atmosphere is providing new, detailed information to the research community. The data collected throughout the lifetime of AMS will greatly increase our understanding of SEPs and GCRs and will contribute significantly to heliophysics research, greatly increasing the safety of astronauts on future manned space missions. Dr Bindi's work has the potential to not only contribute to scientific advancements by achieving their current objectives but also to contribute to science in unanticipated ways, as is often the case with new discoveries.

Contrary to the popular saying – for Dr Bindi and her team, the sky, and indeed the atmosphere, is definitely not the limit.

Q&A

What features of the AMS allow it to collect unique data?

The AMS is a state-of-the-art magnetic spectrometer installed on the International Space Station in 2011. It performs extremely precise measurements and is composed of five detectors and a magnet. These measure similar quantities using different techniques, to univocally identify the crossing particle. The detector has been calibrated on the ground using beams of known particles and energies.

AMS is the largest spectrometer (3m x 4m x 5m in dimension and weighing 7 tons) in space and is the only detector in space capable of measuring all the chemical species of cosmic rays up to iron in the GeV to TeV energy range. In only six years, it has collected an impressive 100 billion particles.

Your research focuses in part on the detection and analysis of Solar Energetic Particles (SEPs). How do these particles originate and what can they tell us?

The satellites in the Heliophysics System Observatory detect solar particles in the eV up to hundreds of MeV – an energy range that covers the majority of SEPs. There is, however, very little data available above 500 MeV. Experiments on the ground detect these highly energetic particles during ground level events (GLE), but, there are many high energy solar events that do not result in GLEs because of the absorption in the atmosphere. SEPs provide critical insight into the physics and environment of their acceleration regions. Models predict a variety of ways for SEP to be accelerated which can be constrained using precision data from AMS. Measuring SEPs and how they evolve during the event offers an opportunity to improve the understanding of particle acceleration and propagation in the solar system and in the galaxy. This is a necessary step to not only forecast space radiation, the current biggest challenge for manned missions into the solar system, but also to build radiation shields for spacecrafts and space habitats.

What radiation risks are astronauts exposed to on long-duration manned space missions?

GCRs exposure is one of the main health risks for long duration exploration. GCRs tear through DNA molecules, splitting them or damaging cellular reproduction. Radiation can also damage the central nervous system and lead to cancers, as well as develop degenerative tissue disease such as cataracts.

Space radiation is the biggest challenge for space manned missions, and therefore, accurate GCR and SEP models are required to assess crew exposure during long missions. This will help to build effective protective shielding. A manned mission to Mars should occur during periods when the flux of GCRs is significantly low, around the maximum of the solar activity. In this case, we need to alert astronauts of SEP events and protect them in special shielded locations while they occur.

Alongside your research you are also involved in outreach, education, and promoting diversity in STEM fields. Why do you think this is particularly important?

Physics is a competitive and a male dominated environment – I did not fit in with the "physicist" stereotype. I have often felt that I was not good enough to be working in this field and it took me several years to become confident in myself. But I never gave up, I stayed focused on what was important and what I liked most and now, I am a Physics Professor. In all disciplines, it is important to have passion and commitment, to work hard and stay focused. A lot of role models inspired me and are still inspiring me right now. To grow as a human being, it is necessary to leave your comfort zone and go for something you love. For this reason, I think it is important that I share my enthusiasm and passion, as well as my challenges and difficulties, to inspire younger generations to go for their dreams as I did for mine. Your journey will be worthwhile!

What can data collected by AMS tell us about dark matter (DM) in space?

Multiple evidence of the existence of DM in space has been measured. There are three different ways to show evidence of DM: (1) in the collision of ordinary matter in particle accelerators; (2) in the interaction of DM with ordinary matter or, (3) as in AMS, in the flux of rare cosmic ray particles where we look for an unexpected excess produced by DM particles annihilation. An excess above the expected background of GCRs in rare particles, such as positrons, antiprotons or antideuterons would provide a major indication of the DM mass and nature. AMS measured an excess in positrons but its nature in still unknown, since it could be mimicked by astrophysical sources. An antiprotons excess is under debate while antideuteron analysis is ongoing. Recent unexpected results from AMS have led to a new physical description of GCRs, making any conclusions about the excesses premature. With new theories emerging that comprehensively describe all AMS data, the search for DM will continuously become more definitive.

Detail

RESEARCH OBJECTIVES

Dr Bindi and her team are conducting research of dark matter, Galactic Cosmic Rays (GCRs), solar modulation, Solar Energetic Particles (SEPs), Forbush decreases, and space radiation for a greater understanding of the universe and solar physics, and to also help protect instruments and astronauts on future space missions.

FUNDING

- National Science Foundation (NSF)
- The National Aeronautics and Space Administration (NASA)

COLLABORATORS

- Partners in Veronica's team at the University of Hawai'i: Cristina Consolandi, Claudio Corti, Chris Light, Xi Luo, Matteo Palermo, Alexis Popkow, and Katie Whitman.
- Outreach partners: Mary Ann Kadooka, Silvia Rocchi, Davin Sasaki, Cheryl Ishii, and Clyde Kobashigawa.
- Collaborators: AMS collaboration, Eddie Semones, Marius Potgieter, Ilia Usoskin, Allan Tylka, Martin Lee, AES NASA, AGS NSF.

BIO

Dr Bindi received her PhD at the University of Bologna in 2006. Since 2002, she has been part of the team at CERN that led to the construction, integration and testing of the Alpha Magnetic Spectrometer (AMS) detector installed on the International Space Station. She is the TOF and trigger expert for the AMS experiment and she is dedicated to the AMS data analysis.

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