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ISS: THE AMS-02 EXPERIMENT AMONG THE GOALS OF THE MISSION BEYOND LED BY LUCA PARMITANO

Interview with Bruna Bertucci, INFN researcher and professor at the University of Perugia, deputy principal investigator of the AMS-02 international scientific collaboration

Since 15 November, in the context of the Beyond mission, Luca Parmitano, astronaut with the European Space Agency (ESA), has completed four ExtraVehicular Activities (EVAs), the last of which took place on 25 January. The aim of the EVAs was to replace the cooling system of the AMS-02 (Alpha Magnetic Spectrometer) tracker, that has been collecting data onboard the International Space Station (ISS) since 2011. The AMS-02 is an international experiment, in which Italy is participating with the Italian Space Agency (ASI) and INFN. Its scientific objective is to study cosmic rays in order to contribute, in particular, to the research into primordial antimatter and dark matter. We delved into the operations, which Parmitano has successfully coordinated and conducted so as to enable the experiment to continue its scientific activities, with Bruna Bertucci. Bertucci is a researcher with the INFN Division of Perugia and Professor at the University of Perugia. She is also Deputy Principal Investigator with the AMS-02 experiment international collaboration, which is led by Nobel prize winner Samuel C. C. Ting.

Why did the tracker cooling system need to be replaced?
To ensure the stability of the instrument's temperature conditions, and, therefore, to improve the quality of the data acquired. AMS-02 is directly exposed to space and, therefore, to extremely variable external temperatures. Because it is thermally isolated from the body of the Space Station, different thermo-regulation systems were planned during its design phase to maintain the temperature of its detectors and of the electronics for reading their signals in the optimal interval for their operation.
The tracker is AMS's most "internal" detector, and heat produced by its reading electronics needs to be transferred outside, where it can dissipate in space. For this purpose, the tracker uses a closed pipe filled with carbon dioxide (CO_2) as cooling liquid. In the section of circuit internal to the AMS, the heat produced by the electronics provokes the partial evaporation of the CO_2, keeping the temperature inside constant. In the outermost section, the circuit passes through a radiator panel exposed to the cold of space, which

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condenses the CO_2 again. The circulation of the fluid is guaranteed by a special mechanical pump, capable of operating in microgravity conditions. Despite having provided a system with high redundancy with two independent pipes, each capable of cooling the tracker, and with two pumps capable of operating for each circuit, in 2014 we started to see the first malfunctions in one of the four pumps and, therefore, “leaks” of CO_2, the level of which in the circuits began to decrease. Designing the UTTPS (Upgraded Tracker Thermal Pump System) therefore became necessary. The UTTPS, which interfaces with one of the original pipes, made re-filling with new CO_2 possible and introduced a new pump into the circuit. Now we have a reserve of 5 kg of CO_2 and four pumps, which will guarantee the AMS’s operativity for the entire duration of the ISS.

What operations engaged Luca Parmitano during his extravehicular activity?
Luca Parmitano and Andrew Morgan’s four EVAs were necessary to replace the active part (pump system, valves, gas cylinders) of the AMS-02 tracker cooling system.
Luca and Andrew first had to remove the protection covers and move tracker cables in order to access the tubes on which they were operating (EVA#1). They then performed a first cut, in order to disperse the gas present in the existing cooling system. The next step was to perform eight cuts to eight tubes to prepare to connect the new system (EVA#2). During the third EVA, they installed the UTTPS, the new system that is contained within a box that weights around 200 kg on Earth and has dimensions of 160x80x40 cm. They reconnected the eight tubes to this system, as well as the supply and communication cable (to send commands and to read the data on the state of the system itself, such as temperature, pressure, etc.). One of the most delicate elements of the whole operation was the connection of the eight tubes, which have a diameter of just 4 mm, and that, therefore, are easy to damage. The connectors that were used were specially developed for this operation. They needed to be handled by the astronauts with their heavy gloves, so as not to damage the existing tubes, and, once mounted, they needed to withstand pressure of 30 atmospheres.
The last EVA, EVA#4, was the crucial one: the astronauts checked the seal of the eight hydraulic connectors and had a bad surprise since the first one that was checked had a leak. The astronauts continued to follow the procedure and checked the other seven, without finding any flaws. Luca Parmitano, in contact with Houston, where the experts of both NASA and the AMS-02 Collaboration were present, then followed the procedure that had already been defined for this case and “tightened” the hydraulic connector. On checking it, one hour later, there was still evidence of a leak and, therefore, the connector was further tightened. Another hour of waiting, and, on the second check, the problem had been solved. The thermal covers for protecting the whole system were then mounted, and the control passed to the Payload Operation Control Center (POCC) of AMS-02 at CERN in Geneva.

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Why were four EVAs necessary to complete the replacement work?
The operation was, altogether, particularly complex because it was the first time that work had been done on a hydraulic system under high pressure during an EVA. Moreover, the whole AMS-02 experiment had not been planned for maintenance interventions in orbit and this required a great deal of preparation and all the skills of the astronauts to succeed in performing truly unique operations. In orbit, there is an infinite number of details that complicate life. Watching the videos, you immediately see that even just “grasping” a tool that fluctuates in the void can take several minutes. Each EVA cannot last more than around seven hours, and just reaching AMS-02, from the moment the astronauts exit the ISS, takes around 30 minutes. Thus, when the re-entry is taken into account, it means that each EVA allows a maximum of around six hours’ work.

What followed the conclusion of the replacement operations?
Immediately after the fourth EVA, after checking the perfect seal of the eight hydraulic connectors, the UTTPS system experts worked on “filling”, or loading, the correct amount of gas into the pipes, in order to ensure the system’s optimal performance. At the conclusion of this step, after around 48 hours, we could start the pump to circulate the gas and, therefore, the nominal cooling operations of the tracker. After some hours of checking the system, the AMS-02 tracker was finally completely switched on and the data acquisition activities resumed their nominal configuration, or with the whole system active and according to project performance specifications.

What are the scientific objectives of AMS-02?
AMS-02 was planned for taking accurate measurements of cosmic rays in order to research weak signals of primordial antimatter or deriving from the annihilation of dark matter. Small amounts of antiparticles may be created as cosmic ray particles collide with interstellar dust, but it is possible that the excess of antiparticles observed, compared to that expected from a “standard” production, might be linked to the presence of new exotic sources, such as the annihilation of dark matter particles or new astrophysical sources.
Another mystery surrounding antimatter being investigated by AMS concerns the origins of the universe: according to the Big Bang theory, matter and antimatter should have been created in equal amounts, but the universe as we know it is made of matter. To date, we don’t know why, nor do we know what the mechanisms are that might have led to the annihilation of all the antimatter in the first moments of life in the universe. We dont't even know if there are any residues of antimatter of primordial origin. The positive identification of even a single antinucleus in cosmic radiation, for example antihelium or

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anticarbon, would, therefore, be extremely important. This is because the antinucleus would, potentially, be due to new physics, whether it had been produced in the primordial universe or in subsequent phases of the universe's evolution, for example through the annihilation of dark matter or through processes that haven't yet been studied in the interstellar medium.

What are the main results that have been obtained so far thanks to the detector?
To date, AMS-02 has gathered the most complete sample of cosmic rays ever recorded, with around 150 billion particles detected from its first activations in 2011 until today. On the basis of this enormous pile of data, it has been able to measure, with extraordinary accuracy, the flow of different components of matter (atomic nuclei and electrons) and of antimatter, providing the richest sample of antiprotons and positrons (antielectrons) including at energies that were previously unexplored. An excess of positrons in "excess", compared to standard production, has clearly emerged from our data, and, for the first time, its features have been measured, such as the energy in which the excess is at its greatest and how it tends to disappear around the TeV. The origin of this signal is still being debated: does it come from new astrophysical sources or from the annihilation of dark matter? The accuracy of the measurement is currently limited by the statistic sample that has been collected, and only the acquisition of new data and a better understanding of the mechanisms that lie behind the origin, acceleration, and propagation of cosmic rays will help us to resolve this enigma.
And it is precisely the systematic study of all these kinds of cosmic rays, electrons, and nuclei, launched over the last few years with AMS-02, that can help us to understand the whole picture. The large amount of statistical data collected and the precision of AMS detectors have already made it possible to highlight unexpected features in the forms of the spectra of all the elements from protons (nuclei of hydrogen) to oxygen, also distinguishing the different behaviour of "primary" species, produced by sources (for example protons, helium, oxygen), and "secondary" ones (such as lithium, beryllium, and boron), which are mainly produced in collisions with the interstellar medium.

What is planned for AMS-02 now?
After these last few months, which were focussed on the installation of the UTTPS and the preparation of procedures for its use, the scientific collaboration can finally return to "standard" operations of data acquisition and data analysis. AMS-02 is the only experiment in space that is capable of measuring antiparticles, and this will be the case for at least the next decade. The years to come will, therefore, be crucial for continuing the hunt for signs of new physics in these channels, expanding, at the same time, the study of nuclides to also include rarer components, including iron, and continuing measurements on

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the isotopic abundance of lighter nuclei.

The extension of its operating life, will, finally, allow AMS-02 to provide important contributions to the study of the solar influence on the radiation environment around Earth throughout an entire solar cycle, and beyond. Our star, in fact, is characterised by a variable energetic emission that is distinguished by an 11-year cyclicity that deforms the characteristics of the low energy cosmic ray spectrum. When solar activity is at its maximum, the number of cosmic rays that reach us from the galaxy is at its minimum and viceversa. Despite there being many systems on Earth that are capable of giving information on the whole behaviour of cosmic rays in different solar cycles, or satellites in orbit that are capable of recording low energy protons, electrons, and nuclei flows, AMS-02 can provide, for the first time, distinct information for the different components of the radiation throughout an entire solar cycle and at energies never before continuously monitored over time. The knowledge thus acquired will not only be fundamental for reconstructing the features of the cosmic ray spectrum in the galaxy, but it could have important consequences for the understanding and prediction of radiation levels to which astronauts may be exposed in different phases of the solar cycle. It could be our way of thanking Luca Parmitano and his astronaut colleagues for their excellent work! ■