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INTERVISTA

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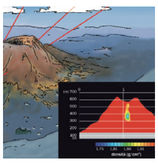

INFN - COMMUNICATIONS OFFICE

» INTERVIEW

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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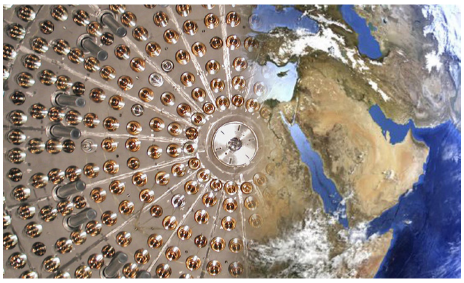
the isotopic abundance of lighter nuclei.

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! ■

RESEARCH POLICY

BAD HONNEF: THE 2020 EUROPEAN PARTICLE PHYSICS STRATEGY

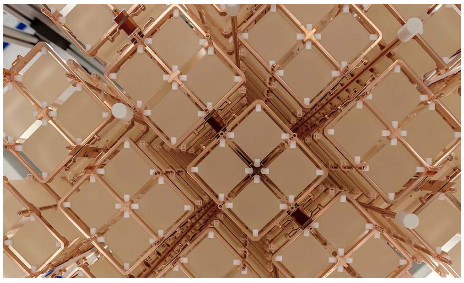
The working session on the 2020 European Strategy for Particle Physics, which took place in Bad Honnef, Germany, from 21 to 25 January, has concluded. It was a week of crucial discussion for the current process of defining the future of particle physics after the LHC. The meeting was convened by the European Strategy Group (ESG), which comprises a scientific delegate from each of the CERN member States and associated member States, directors and representatives of the main European laboratories and organisations involved in particle physics or related fields, and other international experts. At present, Europe, through CERN and the community engaged in this field, holds worldwide leadership, both in science and technology, which can be maintained by focusing on new ambitious projects. The process, which began in September 2017, will conclude in May of this year with a conference in Budapest, Hungary. During this conference, the priorities and recommendations, which will be identified and formalized in a document by the scientific community after having been discussed by the CERN Council, will be officially accepted. ■



RESEARCH

GEONEUTRINOS CONFIRM THAT WE ARE ON A MANTLE OF URANIUM AND THORIUM

Protected by the Gran Sasso massif from radiation coming from space, and thus immersed in what is called cosmic silence, Borexino is the purest experiment in the world for measuring neutrinos. Not only does the experiment measure neutrinos coming from the Sun, but also those coming from inside the Earth, so-called geoneutrinos. After more than ten years of acquiring data and performing a sophisticated analysis of these, the international collaboration that is conducting the experiment at the INFN Gran Sasso National Laboratories has published new results on geoneutrinos in the journal Physical Review D. The journal selected these results as an Editors' Suggestion, due to their value, including them among those articles considered to be of the greatest scientific significance and interest. For the first time, the signal of neutrinos produced by the radioactive decay of uranium and thorium distributed in the Earth's mantle was clearly observed. This means it is possible to exclude the hypothesis regarding the absence of radioactivity deep in the Earth by up to 99%. The published results demonstrate that a good part of the heat released from inside Earth originates from the radioactive decay of Uranium-238 and Thorium-232. These are both present in the Earth's mantle, which is almost 3,000 km thick, on which the thin crust that we tread on rests. In fact, the Borexino researchers have estimated, with a high probability (around 85%), that it is the radioactive decay in rocks that produces more than half of the Earth's heat, with the Earth's mantle playing a greater role than the crust. This evidence opens new avenues for a global, geochemical exploration of our planet. Having established a minimum value for the quantity of Uranium and Thorium in the Earth's mantle, it is possible to affirm that a non-negligible portion of the energy that supplies volcanoes, earthquakes, and the Earth's magnetic field is produced by terrestrial radiation. ■



RESEARCH

CUORE: A RECORD EXPERIMENT

The international scientific collaboration that conducts the CUORE experiment (Cryogenic Underground Observatory for Rare Events) at the INFN Gran Sasso National Laboratories has released its latest experimental results, which represent more than two years of data acquisition (from April 2017 to July 2019). This new study provides an even more cogent limit to the existence of a very rare process, neutrinoless double beta decay, which would prove that the neutrino is a Majorana particle. In other words, it would prove that the neutrino is its own antiparticle: a property with important implications in the process of forming matter in the first moments of the universe.

Although the distinctive signal of neutrinoless double beta decay still has not been detected, new CUORE data provide a limit that is two times better compared to that previously published on the frequency of this process in the tellurium-130 nuclei contained in the CUORE crystals. These results, in turn, can be interpreted as a narrower margin on the value of the mass of the Majorana neutrino, which would be lower than a tenth of an electronvolt, or around 5 million times lighter than that of an electron.

CUORE's latest results represent the biggest collection of data ever acquired from a particle physics experiment based on solid-state detectors, which use crystals instead of more common liquids for research into double beta decay. The results were obtained with the use of a new and sophisticated algorithm, which makes it possible to amplify the detectors' signals and, at the same time, to eliminate annoying background noise. In addition, the new algorithm makes it possible for CUORE, with its mass of almost one ton of detectors, to research dark matter particles never before observed, called WIMP, or Weakly Interacting Massive Particles, by exploiting the periodic nature of the expected signal. ■

RESEARCH

GRAVITATIONAL WAVES: A PROBABLE NEUTRON STAR COLLISION FROM LIGO-VIRGO

A gravitational wave signal coming from a point situated at a distance of 500 million light years from Earth has been observed by the LIGO and Virgo scientific collaborations. It was presented to the scientific community yesterday evening, which met at the Meeting of the American Astronomical Society underway in Hawaii. The signal, labelled GW190425, was observed at 8:18 a.m. (UTC) on 25 April 2019 and it is the first event captured and published during the third observing run that began last 1 April. The signal is compatible with the fusion of two neutron stars and is similar, therefore, to the event that was announced in October 2017, which led to the birth of multi-messenger astronomy. However, it exhibits some important peculiarities.
The total mass, around 3.4 times the mass of the Sun, is larger than that of any binary neutron star system known in our galaxy, and this has interesting astrophysical implications for the formation of these systems. In addition, no electromagnetic counterpart was observed by the telescopes that gathered the alert sent by the LIGO-Virgo collaboration, unlike what happened in 2017 (GW170817). The data have been analysed with precise analytic models that describe the gravitational wave signal emitted by two neutron stars according to Einstein's general theory of relativity, leading to a reasonable understanding of the event. Although the fusion of the two bodies was not observed, numerical simulations have confirmed that – assuming that the two objects were neutron stars – the probability that the object produced, in the end, was a black hole is equal to 96%.
In any case, the interpretation of the GW190425 signal is ambiguous precisely because of its weakness, and the possibility that one (or even both) of the objects were black holes cannot be entirely excluded. ■

TECHNOLOGY TRANSFER

THE RAPHAEL'S FORNARINA AS NEVER SEEN

From January 28 to 30, the Barberini Corsini National Galleries dedicated three whole days to investigations and studies on the Raphael's Fornarina. In that period visitors had the opportunity to watch the experts, including INFN researchers, at work on Raphael's masterpiece. In particular, the first day was spent in the Gigapixel+3D photogrammetric acquisition of the painting: a very high resolution shot, obtained by composing multiple detailed images of the same subject. Thanks to the new Ma-XRF multichannel scanner system developed by the INFN in its laboratories in Roma Tre (in collaboration with the department of science of the University of Roma Tre, Sapienza University of Rome and the CNR-ISMN), a chemical investigation campaign has been carried out during the other two days, which proved useful information to restorers and conservators for any work on the painting. The innovative aspect of the Ma-XRF analysis is the capacity to go beyond the analysis of a single point, thus providing real images of the distribution of the individual chemical elements revealed and offering wide and unprecedented possibilities of knowledge on the nature of the pigments, the pictorial techniques and the state of conservation of the works. Ma-XRF has been developed within MUSA (Multichannel Scanner for Artworks), a technology transfer project, realized thanks to the contribution of the Lazio Region and with the support of the INFN network for cultural heritage CHNet (Cultural Heritage Network), which aims at transferring the skills on electronics and detectors developed within the INFN to companies operating in the sector, for their technological enhancement. ■

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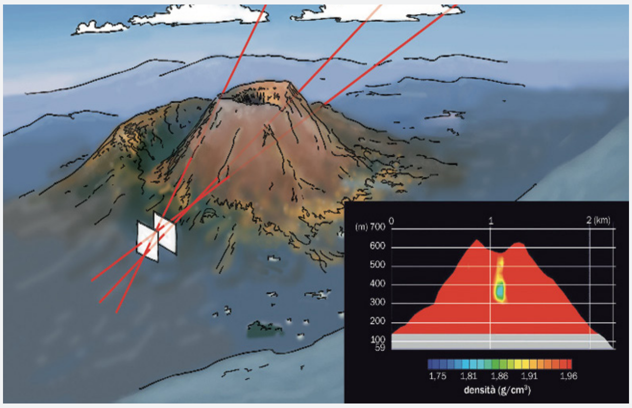

COSMIC PARTICLES FOR STUDYING VULCANOES

The Earth's surface is constantly being reached by muons, produced by the interactions of cosmic rays coming from space with atoms in Earth’s atmosphere. They are very energetic particles that are identical to electrons but with a mass 200 times higher, and it is precisely this characteristic of theirs that makes them so penetrating – capable, that is, of passing through matter while losing very little of their energy. After neutrinos, they are the most penetrating particles and, in any case, unlike neutrinos, they are not a source of astronomic information as they are only produced in the Earth’s atmosphere. They do constitute, however, a very powerful tool for investigating structures and objects on Earth. The ability to pass through very thick matter, including several kilometres of rock, makes it possible, in fact, to use muons to perform “muographies” of structures with large dimensions. These are very similar to radiographies, but have the advantage, compared to X-rays, of performing deeper probes.

The technique called muography was first used in the late 1960s by the Nobel prize for physics Luis Alvarez to search for hypothetical secret chambers inside the pyramid of Chefren. The study of pyramids with this technique has brought recently, in 2017, to the discovery of a secret chamber inside the Great Pyramid of Giza by a team of researchers on the international ScanPyramids project.

Starting in the 90s, this technique began to be applied for the study of volcanoes, initially in Japan and later in Italy, two countries that have similar geological phenomena: a high frequency of earthquakes and volcanic eruptions, and they are at the forefront of theoretical and experimental studies in these disciplines. In particular, the use of muons enables researchers to visualise magma conduits, or other internal structures, in the emerging part of volcanoes. Visualizations of this type are important diagnostic tools for understanding magma dynamics. One application of this technique was implemented at the beginning of 2015 by the MIUR MURAVES (MUon RAdiography of VESuvius) research group, a collaboration

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between INFN, INGV (National Institute for Geophysics and Volcanology), and the universities of Naples and Florence. It has enabled the installation of detectors for measurements on Stromboli and Mount Vesuvius. MURAVES is the evolution of the Mu-Ray prototype that was developed by INFN, and with which, in April 2013, a demonstration data acquisition was conducted on Mount Vesuvius. Placing the detector even deeper, the technique also enables the study of subterranean structures. The Neapolitan subsoil, where numerous cavities have been excavated in the tuffaceous rock since antiquity, provides an ideal situation for such study. The MURAVES project researchers have applied the same technique used on Mount Vesuvius to explore cavities surrounding the Bourbon tunnel, in the historic centre of Naples.
With the cosmic muons it is also possible to analyse smaller structures, making it possible to identify very dense objects, such as radioactive materials illegally transported in a container. Passing through the material, the muons lose energy but are also deflected by an angle that tends to be bigger, the greater the density of the material it has passed through. It is possible, therefore, to measure the deflection of the muon using two detectors that are placed, one above and one below the object to be studied, and measuring its direction before and after it has passed through the material. From the measurements recorded, thanks to a significant number of muons, it is possible to produce a three-dimensional tomography to reveal the denser objects inside the container. A prototype of this equipment was produced at the INFN Legnaro National Laboratories with very promising results.
The MURAVES project, already in data acquisition, will be fully underway in the spring of 2020, with the completion of four planned detectors, installed on Mount Vesuvius. ■

Italian National Institute for Nuclear Physics

COVER
Details of Raphael's painting La Fornarina under analysis through the new Ma-XRF system developed by the INFN. © Gallerie Nazionali Corsini Barberini

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