Newsletter Interview

HUNTING COSMIC RAYS IN THE ARGENTINIAN PAMPAS WITH THE PIERRE AUGER OBSERVATORY

Interview with Antonella Castellina, researcher at INAF associated to the Turin INFN Division, spokesperson of the Pierre Auger Observatory.

Antonella Castellina was recently elected spokesperson of the Pierre Auger Observatory, which is managed by an international collaboration of more than 400 scientists from 17 countries in which INFN participates. The Observatory is dedicated to studying the origin of ultra-high energy astroparticles thanks to a large detector spread out across Argentina's Pampas near the city of Malargüe, in Mendoza Province. On the occasion of her recent appointment, we asked Castellina to tell us about the observatory's activities, which she coordinates, and its future goals.

Can you introduce us to the Pierre Auger Observatory? What are its goals?

The Pierre Auger Observatory is dedicated to studying extreme energy astroparticles, the ultra-high energy cosmic rays (UHECR), with an energy greater than one trillion (10^{18}) electronvolts. Very few particles with these energies reach the Earth. For this reason, they cannot be directly observed, but we try to observe the secondary products of the interaction of these particles with the Earth's atmosphere, the "extensive air showers". To observe these showers, very large observatories, which take up a very large area, are required. The Pierre Auger Observatory, for example, extends across a total area of 3,000 square kilometres. In addition, to obtain the greatest possible amount of information, a hybrid detector system is used in the Observatory. 1660 Cherenkov stations record the particles of the showers that reach Earth and constitute the surface detector; four sites placed around this area, each with six fluorescence telescopes, measure the light emitted by the showers crossing the atmosphere; and other three telescopes at a higher elevation (able to observe the light emitted by showers between 30 and 58 degrees above the horizontal plane) make it possible to further extend the range of measurable energies. The main goal of the Observatory is to determine the sources, which are still unknown, of UHECR, measuring their composition in mass, energy, and directions of arrival. Using the various data measured, we can study the features of the possible sources and their acceleration mechanisms. Auger is also the only existing observatory that can be sensitive to ultra-high energy neutrino and photon fluxes of cosmological origin, contributing to the measurements of multi-messenger astronomy. Beyond astrophysical studies, the data collected can help us explore features of hadron interactions at energies accelerators cannot reach and assess the existence of physics beyond the Standard Model, the theory that describes elementary particles.

The observatory now has more than twenty years of history, what are the main scientific results that you obtained so far?

The scientific results obtained by the Pierre Auger Collaboration cover various, complementary fields of research, from astrophysics to particle physics, up to atmospheric physics. We succeeded in achieving the first experimental observation of the extragalactic origin of cosmic radiation at energies greater than 8 x 10^{18} eV, with high statistical significance, greater than 7σ. Moreover, at energies above 3 x 10^{19} eV, we've studied the possible correlation between the arrival directions of the UHECR with the position of possible sources, using the galaxy catalogues obtained from experiments like Fermi-LAT and 2MRS (2MASS Redshift Survey). Today, the best correlations that we have obtained concern the UHECR that come from starburst galaxies, in which the star formation process is extremely violent. We then established that the nuclear composition of UHECR is not constant, but evolves towards heavier masses as energy increases, revolutionising past models. Auger also has a central role in multi-messenger astronomy, thanks to its capacity to distinguish showers generated by photons and neutrinos from those of hadron origin. Research into diffuse fluxes or point sources of neutrinos and photons makes it possible to study the features of possible sources and to establish limits in the emission of photons and neutrinos during the fusion processes that produce gravitational waves. Since the universe is an extraordinarily powerful particle accelerator, with Auger we can study the production of particles in energy ranges that the experiments of the Large Hadron Collider of CERN cannot reach (LHC reaches energies in proton interactions up to approximately 14 TeV, compared with the 450 TeV and beyond that we measure at Auger). Thus, we can verify the validity of the extrapolations of the Standard Model, based on LHC data, at extreme energies. The results of Auger on neutrino and photon fluxes also make it possible to verify the existence of possible effects not predicted by the Standard Model. We have established limits to the possible violation of the so-called “Lorentz invariance” and the features of superheavy dark matter.

The Observatory has just completed the AugerPrime upgrade programme. What did this consist of?

To achieve future scientific goals and respond to questions raised by the results obtained up to today, it is essential to acquire additional measurements of the composition of cosmic rays in a large statistical sample of ultra-high energy events, fully exploiting the surface detectors. For this purpose, we upgraded the Observatory, by installing a scintillation detector with optical-fibre readout, and a radio antenna at every Cherenkov station to measure the signals produced by the showers at frequencies ranging between 30 and 80 MHz. In addition, the Auger electronics were totally renewed and optimised and scintillation detectors were installed at approximately 2.5 metres underground for directly measuring the muon component of the showers.

What is the scientific programme that the Auger Collaboration is pursuing now, after the upgrade?

Our goal is to measure the composition in mass of the UHECR up to energies above 10^{20} eV and to respond to various questions opened up by the current Auger results. First of all, we’ll be able to establish the origin of the strong decrease observed in the flux of UHECR above ~5x10^{19} eV, establishing whether it is due to the effects of the UHECR or to the reach of a maximum value of energy available to the sources. In addition, by measuring the fraction of protons at maximum energies, we’ll be able to lay the foundations for future experiments and assess the feasibility of the astronomy of charged particles. With the upgrade of the electronics and the presence of radio antennae, we’re also able to increase our efficiency in recording neutrinos and photons: the identification of even just one of these would have huge consequences in terms of astrophysics. Finally, we want to add additional information on hadron interactions at ultra-high energies, where the measurements of the large particle colliders cannot reach, and explore phenomena beyond the Standard Model, predicted, for example, by the theory of quantum gravity or in string theory.

Italy, and in particular INFN, is strongly involved in the observatory's work. What are the main Italian contributions to the project?

INFN takes part in Auger with the Catania, Lecce, Milan, Rome Tor Vergata, Naples, and Turin Divisions and the associated group in L'Aquila; its researchers are approximately 10% of the total of the collaboration. The design, testing, and production of the electronics and filters for the fluorescence detectors, the design of the bases for the phototubes of the surface detector are examples of INFN's contribution, like the contribution to building fluorescence telescopes and managing the photomultipliers and electronics of the surface detectors. For the Observatory's upgrade, in Italy, we produced the new electronics and the system for extending the dynamic range for measuring signals, managed the construction and testing of part of the scintillators, developed the infrastructure for testing the phototubes and for high voltages. In addition, INFN researchers have important roles in the collaboration, both in management and as heads of various analysis groups. Currently, two of the Observatory scientific coordinators are Italian.

The Auger collaboration is strongly committed to adopting a policy of open access to data. Why do you believe it's important that an increasingly broad and diversified community of users has access to these data?

The Auger data are the result of a vast, long-term moral, human, and financial investment by the international community. The re-use of these data, at various levels and at different times, offers a unique scientific opportunity. We believe that open access to data and software will enable, in the long term, the full realisation of their scientific potential. Making the data public, at various levels of complexity, can be useful for education initiatives, for example in "Masterclasses" dedicated to high school students, and for generally raising the awareness of citizens regarding scientific research.

You are asked to lead a collaboration of hundreds of people coming from all over the world. What will be your responsibilities and the main challenges that you believe need dealing with?

As spokesperson, I represent the Collaboration on scientific, technical, and management matters. My first responsibility is to choose, together with the co-spokesperson, the science and detector performance coordinators who have responsibility for establishing Auger's scientific goals, alongside myself, and to propose the leaders of various research groups into which the Collaboration is organised. In addition, I am in charge of defining the resources needed for the project and of seeking to obtain the commitment of these resources for the construction and operation of the Observatory. The Collaboration has a long history behind it. Thus, a renewal effort is needed, involving new young staff to work on the upgrade and concluding the testing for implementing the data acquisition of the new phase. It is a very tough challenge, but the re-starting of the observatory after the upgrade will be an incredible boost for all of us.

What do you predict and hope for the future of the Auger Observatory?

In 2026, the second phase of the Observatory will start, with the conclusion of the new detectors' testing phase. We will have another ten years' data acquisition, which will definitely be very interesting and challenging. We will need to work on strengthening the international dimension of Auger, involving new groups.

I expect to obtain significant results for the research of the sources of these ultra-high energy particles, and, above all, to be able to announce the detection of ultra-high energy neutrinos and photons, an exceptional discovery for all multi-messenger physics.