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THE BIGGEST DARK MATTER TRAP

Interview with Professor Elena Aprile, from Columbia University in New York, Spokesperson of the XENON1T experiment, inaugurated at the Gran Sasso National Laboratories (LNGS) of INFN

A new scientific endeavour, the XENON1T experiment, is starting at the Gran Sasso National Laboratories (LNGS) of INFN. The project is ambitious: understand what the universe still hides. About a quarter of what makes up the cosmos, in fact, is constituted by a type of matter, the nature of which is still unknown: dark matter. Physicists know that it exists, that it surrounds, for example, the Milky Way like a thick fog, but they do not know what it is made of. Like the explorers of the past, in search of an unknown continent, they are looking for it everywhere. First of all in space, with the Alpha Magnetic Spectrometer (AMS), the so-called Hubble of elementary particles, anchored to the International Space Station (ISS) like a lifeboat. But also at CERN in Geneva, with the Large Hadron Collider (LHC) super-accelerator. And in underground laboratories worldwide, starting with LNGS.
We asked Elena Aprile, from Columbia University in New York, the spokesperson of XENON1T, why the new experiment just inaugurated at LNGS has what it takes to succeed in this difficult task.

How did the idea of XENON1T come about and how does the experiment work?
The XENON project began in December 2002 and has evolved to a phase which will make it the most sensitive for the direct search of dark matter. XENON1T - hosted in the LNGS of INFN, under 1,400 metres of rock that shield the experiments from the incessant shower of cosmic rays - is the third in a series of detectors of the XENON project, after XENON10 and XENON100.
The detectors of the three XENON generations are dual-phase (liquid and gas) Xenon Time Projection Chambers (TPCs). When a particle releases energy in the liquid xenon, both excitation as well as ionization of the atoms is produced. The excitation generates a first luminous signal due to scintillation, while the ionization frees electrons that are brought by an appropriate electric field to the gaseous region, above the liquid, where they are accelerated to create a second luminous signal. Both signals are then detected by two groups of photomultipliers, 248 sensors in total, placed above and below the volume of xenon.

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Why use xenon? What makes this element suitable for searching for dark matter?
Xenon is a noble gas, and as such is easily separable from the contamination of other radioactive elements. Furthermore, in the liquid state it is three times denser than water, and this allows it to be effectively used as a shield against external radiation. Finally, it has excellent characteristics as a detector medium, because it has among the best scintillation - emission of light when excited by a release of energy - as well as ionisation properties among all noble gases.

Many people are searching for dark matter: in what way does XENON1T differ from other experiments, at CERN or on board the ISS?

It is certainly a very exciting time for the search for dark matter, in light of the various experiments dedicated to detecting it. It is important to search for dark matter in different ways which complement each other. With experiments such as XENON1T, in fact, we use the so-called direct method to observe the interaction of dark matter WIMPs (Weakly Interactive Massive Particles) - name by which physicists indicate one of the leading candidates for dark matter - with the nuclei of materials in terrestrial detectors. AMS, placed on the ISS, on the other hand, looks for signs of anti-particles generated in the annihilation of WIMPs in the galaxy. In particle accelerators, such as the LHC at CERN, the search is via the collision of very high energy protons in order to observe the production of new particles that meet the characteristics of dark matter.

What are, on the other hand, the differences with the predecessors XENON10 and XENON100?
The main difference concerns the size of the detector and, consequently, also the mass of xenon present inside it. This increase - by about a factor of 10 for each phase of the XENON project - allows the target mass for WIMP interaction to be increased, but also the background level must be decreased, since the most dangerous radiation comes from external materials. So with a larger detector, the external radiation is shielded by a thicker layer of xenon.

How do the LNGS physicists look for something that we still do not know what it looks like, such as dark matter? Isn't a bit like groping in the dark?
It's true that we do not know the details of the particles that constitute dark matter, but the various experimental indications that come from cosmology and astrophysics allow us to clearly outline the general characteristics of these particles: they must have mass and only interact weakly. In addition, also their abundance is well known. The experiments are, therefore, designed to detect particles with these characteristics. We know we are looking for a weak and rare signal, a veritable needle in a haystack, but we are also hoping to be able to overcome this challenge.

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What exactly do you expect to find with XENON1T? And what if the experiment doesn't see anything?
The most commonly searched for candidate is the WIMP, which produces an interaction with the nuclei of the detector. In XENON it is possible to distinguish between nuclear interactions, representing the signal, and electromagnetic interactions, which are instead a background. The interaction of a WIMP is, therefore, recognisable with a good probability. There are, however, some models suggesting that dark matter may also have interactions with xenon electrons. Also in this case, with XENON1T the search is possible, thanks to the very low background in the central part of the detector.
If we were to detect nothing, we will still have precisely defined which are the properties that dark matter does not possess, for example, placing an upper limit on their interaction cross section. The XENON1T experiment could provide a range of mass for WIMPs not yet accessible to accelerators. In this sense, even not observing anything would still be a result.

When will XENON1T data collection begin? What is the future of the experiment?
Assembly of the detector was recently completed. Now the commissioning phase begins, in which all the components, which have already been tested separately, will be tested in the final configuration. Within a few months, therefore, we will be ready for the actual scientific run. With a week of data we will be able to reach the sensitivity of current experiments, while we will need approximately two years of data to reach the design sensitivity of the experiment, which is two orders of magnitude better than that achieved with XENON100. We are, however, already prepared to further increase the size of the detector, using almost completely all the auxiliary structures developed for XENON1T, in order to expand it to almost twice the amount of xenon. The new detector will be called XENONnT. With the XENON project we would like to be the first to understand what the universe is hiding from us. ■