The dark side

Hunting the dark matter

by Mauro Raggi

Although Modern Physics – specifically the theory describing its behavior at the microscopic level (the Standard Model of interactions) – managed to explain with astonishing accuracy all the experimental results/evidences obtained in laboratory so far, our understanding of the universe surrounding us is actually extremely limited.
The first astronomer to realize that was the astronomer F. Zwicky who, in 1933, while observing the Coma of Berenices cluster, noticed that its internal motion velocities were not consistent with the visible mass of the cluster. He concluded that an enormous amount of mass, which could not be seen by his telescope (because it did not emit any radiation), but that held the cluster together should exist. He called it "dark matter". Since then, we have been collecting plenty of observations and evidences supporting the existence of dark matter and we are now convinced it constitutes up the 27% of the universe content. It sounds like a little quantity, doesn't it? The problem is that the matter forming all the galaxies and stars we see is just the 5% of the universe. What about all the rest? A huge amount of energy, the "dark energy" - about which we know even less – which "is necessary" to the theories explaining the universe evolution, though. However, not all cosmologists agree on this point and there are many who do not believe that dark matter exists at all. In the 80's the physicist M. Milgrom suggested the effect observed by Zwicky was solely due to the fact that the Newton-Einstein gravitational

theory had to be “corrected”. The so-called “Mond theories” (Modified Newtonian Dynamics), capable of explaining galaxy rotation, were born.
However just this year, an observation undermined the Mond basis. A team of astrophysicists of the Yale University has observed a galaxy (the NGC 1052-DF2) which would seem to be made up purely of ordinary matter. Interestingly, the observation of a possible absence of dark matter within this galaxy could become the most important evidence of its existence. In fact, if the “dark matter effect” was due to an inaccuracy of the gravitational theory, it would not be possible to observe galaxies with a purely Newtonian dynamics, as the NGC 1052-DF2 seems to be.
Now that we are convinced about its existence: what is dark matter made of? How does it interact? And how can we find it?
Physicists have been trying to answer all these questions for decades. They immediately realized it could not have an electromagnetic interaction. It would have been visible when interacting with photons, otherwise. The strong interaction was too “strong” and dark matter particles would have been easily observed by their impacts against ordinary matter. Of course, neutrinos! No, way too light. However, heavy particles with a very weak interaction could really solve the problem without upsetting our understanding of the microscopic world.
If our galaxy is so full of dark matter, these particles must also reach the Earth, then we can try to detect them. Over the last 30 years, the hunting of the so-called Wimps (*weakly interacting massive particles*) has been involving several laboratories all over the world, among which the INFN Gran Sasso National Laboratories played a leading role.

Several generations of experiments have been going after this elusive dark matter candidate, getting bigger in terms of

dimension and sensitivity, so far without producing any hard evidence of its existence, confining the Wimps towards smaller and smaller couplings with ordinary matter. Wimps are also the natural products of one of the most successful extensions of the Standard Model, known as the Supersymmetry theory.
This theory predicts it is possible to produce them using accelerators, but their high mass forces us to build ultra-high energy ones. One of the main missions of the LHC accelerator and of its four experiments is precisely to try to produce Wimps from the ultra-high energy collisions of its protons. Unfortunately, in the first phase of its data taking, LHC did not observe any Wimp, but there are still great expectations from the study of the data that will be collected over the next years.
The temporary failure of those attempts guided researchers towards new hypothesis that go beyond the Wimp paradigm. In the last few years, a growing interest focused around the so-called "dark or secluded sectors" theories. In this category of models it is assumed that the dark matter is completely decoupled from the Standard Model and it is confined in a hidden sector, whose complexity is unknown and subject of speculations.
The dark sector could have one or more new forces and one or many new particles, but none of those could be able to interact with the ordinary matter.
According to the simplest version of these models, only one particle would exist, named "mediator", capable of interacting both with dark sector particles and with the ordinary matter ones, through an interaction called "portal".
Portal interactions can take several forms: "vector", "scalar", "pseudoscalar", and they are associated to different mediators, the "dark photon", the "dark Higgs", the axion.
The dark photon has become particularly fascinating because of its special affinity with ordinary matter. The new interaction

mediated by it (the fifth force" or "dark force") would then be identical to the electromagnetic interaction, just weak enough to hide it from our eyes, in other words to make it obscure. Unlike the ordinary photon, the dark photon would have a little mass. The dark photon may then be already hiding among ordinary photons (a phenomenon that physicists called "kinetic mixing"). Only a careful observer could glimpse its existence, which would explain why we missed it until now.
How would this "dark messenger" look like, though? We don't know it for sure, it depends on what the dark sector contains. As physicists inspired by the Wimp model think, if it was the lightest particle among the ones of the dark sector, then we would see it appearing through its decays into ordinary matter particles, for example electron-positron couples, the so-called "visible decays". The hypothesis that the dark sector contains several new particles, of which at least one lighter than the dark photon, is even more intriguing. In such a scenario, the dark photon would decay into dark matter, remaining invisible: it would be a real challenge then to find it!
To stay on the safe side, physicists advanced in both directions, preparing experiments that aim at driving it out wherever it hides. The U.S. are in the front line in this research, but Italy plays a major role too, participating in the experiments at the Jefferson Laboratory (at Hps and Bdx) and with the commitment of the Frascati National Laboratories, with Kloe first, which concluded its data taking at the end of April, and now with Padme, a new experiment for invisible decays search.
But we might already be too late!
In a little Hungarian nuclear physics laboratory, in fact, it may have been observed a first "dark flicker". The physicists from Debrecen observed an abnormal abundance of electron-positron decays in the nuclei of Beryllium-8 which have precisely the characteristics

required to derive from a light dark photon.
Padme and the other experiments are already catching up.

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