How to find invisible stuff

In de serie ‘Students on Science’ presenteren we Engelstalige artikelen die zijn geschreven door studenten van het vak Wetenschapscommunicatie aan de UvA. Vandaag beschrijft Damian van Leeuwen donkere materie, en hoe we die raadselachtige materie met behulp van het XENONnT-experiment proberen op te sporen.

A Christmas tree as dark matter? One can compare regular, light-emitting matter to the lights in a Chrismas tree. The lights show us the shape of the tree, but there is a lot of matter is the branches that we don't observe.

How is it we can build skyscrapers, send people to the moon, or build neural networks that mimic the human brain, yet we cannot explain 95% of the matter content that surrounds us? Let me take you to the origin of this problem and describe how we aim to explain it.

Why do we need dark matter?

The XENONnT experiment, located at the Laboratori Nazionali del Gran Sasso (LNGS) in Italy, is one of the most sensitive dark matter detection experiments in the world. Over the past decades, physicists have been using experiments like XENONnT hoping to reveal the mysteries of dark matter. But what is dark matter? And why should we study it?

Let us go to where research of physics has taken us since the beginning of humanity. We have been exploring the world around us for as long as we can remember and it has taken us quite far. As an example, think of the technological development there has been since the first fire was made!

What is our current understanding of nature around us? At the one end, we have Einstein's theory of general relativity, which predicts the formation of large objects like planets or galaxies and their movement through spacetime. We can use it to explain gravity and study the structure of nature on a very large scale. On the other hand, we have structures on a very small scale, like atoms and molecules, which can be explained using the Standard Model.

The Standard Model is another theoretical framework that was formally developed throughout the past century. We can use it to explain matter on a small scale and its interactions and forces that make our world the way it is. Together, general relativity and the Standard Model form the most profound knowledge we have in physics. The two theories are widely used to investigate both the small and large scales of our world.

But here comes the problem: the two can't be used together. They don't operate in the same way, they don't speak the same language. Consequently, we run into a large misalignment when looking into the gravitational system of galaxies. Specifically, the gravitational forces we measure in galaxies are about 5 times stronger than the gravitational forces we predict as a consequence of the matter content we can account for in the Standard Model. This tells us that every particle as we know it is outweighed by 5 particles of dark matter, or else galaxies would not have enough gravitational pull to stay together in the way we observe. A clear picture of this misalignment can be found in Figure 1.

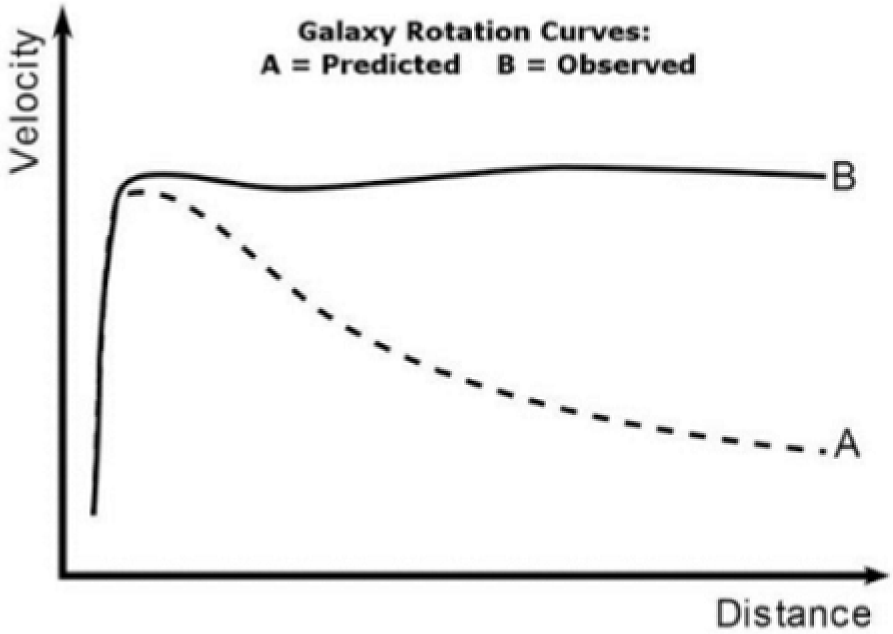

Figure 1. A disagreement. Here we see the disagreement between the Standard Model and general relativity and the evidence of an existing galaxy content we call dark matter. Stars in the outer regions of galaxies tend to move much faster in practice (B) than one would predict based on the amount of matter that is pulling on them (A). For A to become equal to B, we add dark matter to the matter content of the galaxy to increase the gravitational pull between large objects. This in turn increases the velocity of the large objects at large distances. Source: *Extended rotation curves of spiral galaxies – Dark haloes and modified dynamics*. Begemen, K Broeils AH, Sanders RH. 1991, Monthly Notices of the Royal Astronomical Society, vol. 249, April 1,p. 523-537

An interesting analogy is that of a distant Christmas tree, decorated with lights, that is standing in complete darkness. From a distance, we can see the lights if we are lucky. If we use specialized equipment, we might even be able to see all the lights, but we will never be able to completely picture all of the particles that make up the tree and its lighting.

This is true for galaxies as well. We see a certain amount of matter which we can accurately picture using the Standard Model. This amount of matter predicts a gravitational force to make up for the movement of the large bodies in the galaxy. But since the 1970s, many physicists have measured the movement of these large bodies and found out this movement is consistently faster than the movement that is accounted for with Standard Model matter. This faster movement can be accounted for if we increase the content of the universe by 95%, with a high amount of matter (27%) and energy (68%) which we for now call dark matter and dark energy. And just to clarify, one of those lights in the distant Christmas tree represents our Sun, we just can't see the electrical wiring or the tree branches holding the bigger structure all together.

How XENONnT tries to find dark matter

Now that you know why dark matter is possibly all around us, how could we possibly find it? Many complicated theories are trying to predict its behaviour, using a vast amount of details and mathematics. I won't go into details in this article; a bit more can be read in this series. All you need to know for now is that one of the most prominent theories predicts dark matter to only very lightly interact with ordinary matter, excluding light (hence, the word 'dark' matter). This weak interaction is predicted as we only know dark matter has an influence on gravity, as explained by the measurements mentioned above.

In order for us to find such an interaction, we need to create an environment where very heavy and dense matter is present in a place where very little natural occurring radioactivity is present, as this radioactivity can create interactions very similar to those of the hypothetical dark matter. For this reason, physicists have created a large vessel of a very heavy and dense liquid, liquid xenon, buried deep into a mountain where radioactivity is minimized. Find a picture of XENONnT in Figure 2

As our planet is moving through our galaxy, the heavy liquid in the vessel will move through the dark matter halo present in it – that is, through the branches of the Christmas tree. When a dark matter particle enters the vessel, it deposits its energy when an interaction happens, much like bumping into people in a heavily crowded place. These energy deposits are what can be measured to successfully find evidence of an interaction with a dark matter particle.

Figure 2. XENONnT. The Time Projection Chamber (TPC) that holds 5.9 tonnes of ‘active’ xenon, waiting to bump into dark matter. Image: XENONnT collaboration.

The complications of data analysis

Now this doesn’t sound too difficult, does it? The fact is that we reduce radioactivity entering the vessel very much, but it still makes multiple particles enter the vessel every second, while dark matter is predicted to enter the vessel only a few times per year.

It’s the very complicated story of data analysis that deals with this problem; how to extract a single interesting event from a mountain of events? Since we only measure the energy that is deposited in the liquid, we cannot tell the two apart! This is where statistics comes in; we predict the amount of ordinary matter that enters the vessel during many years of non-stop data collecting and try to look for excesses in these signals. Efforts of analysing the vast amount of data is a challenge that equally takes a lot of time and resources, resulting in decades of research! Finally, if statistics tell us we have a 99.99994% certainty of a signal being due to dark matter, we consider it a new discovery and are one step closer to finding out more about dark matter!

Finding the invisible stuff

We went from the disagreement between our most profound knowledge in physics to the complication of researching the universe’s invisible contents. While the story of dark matter has only partly been written, and we are eagerly awaiting observational results, I hope you have found this brief summary of dark matter and XENONnT’s quest to find it as fascinating as I do. Let’s continue looking for possible solutions, and who knows, maybe we will find some of this mysterious dark matter along the way!

QU is sinds kort weer actief op Instagram! Volg ons voor nieuws en aankondigingen van nieuwe artikelen: https://www.instagram.com/quantumuniverse.nl/