A new unknown universe:

A southern hemisphere perspective on dark matter

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> Astronomers in the first half of the 19th century found something unusual when they studied galaxies: the Universe contained more matter, or 'stuff', than was visible with any kind of astronomical instrument that observes light.

We now know that only 20% of the matter in the Universe is made of ordinary atomic matter (the 'stuff' that makes up all objects on Earth). The remainder is made up of dark matter. Definitive evidence of dark matter has come from many sources. But what this substance, that holds galaxies together and keeps the Universe from flying apart, is currently a mystery.

Particle and nuclear physicists have discovered the fundamental building blocks of atoms and refined the human concept of the physical world, connecting the smallest building blocks of matter to the cosmic web of galaxies and to the birth of the Universe (the Big Bang). But now, evidence for dark matter demands a revolutionary new vision of this new 'dark' universe.

Understanding this unknown 'new' universe means we need to discover the physics that underpins its fundamental nature. There are many theories suggesting what dark matter could be made of. One even suggests the existence of a 'hidden valley' - a parallel world made of dark matter having very little in common with matter we know. One very popular hypothesis suggests that dark matter is made of 'weakly interacting massive particles' (WIMPs). These are leftover materials from the Big Bang, passing through normal matter and leaving almost no trace. The astrophysical observations tell us about the macroscopic properties of dark matter (how it works across the Universe), terrestrial astroparticle physics experiments will tell us its quantum properties and which kind of particle, or particles, dark matter is made of.

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Light on dark matter

We are moving through a sea of dark matter as the galaxy rotates, as the solar system moves through the galaxy, and as the Earth rotates around the Sun. Sometimes, very rarely indeed, a dark matter particle will collide with the nucleus of an atom, and this can be detected in a carefully designed experiment.

Our lack of knowledge about the particle nature of dark matter makes for a challenging search. In the last decade, there has been impressive experimental progress to detect dark matter interactions with normal matter, with the development of new direct detection experiments. Most direct dark matter experiments attempt to reduce background 'noise' from other particles like cosmic rays to an absolute minimum and interpret any excess counts as a signal of dark matter. So far none of these experiments have had a positive result.

Looking at the sky from deep under the ground

Experiments aimed at detecting dark matter have to be designed carefully. Dark matter can sometimes be difficult to distinguish from environmental and cosmic background radiation. The only way to reduce these effects is to build the experiment in a deep underground site.

In order undertake the first direct-detection dark matter experiment in Australia we built the first-ever integrated underground laboratory in the Southern Hemisphere the Stawell Underground Physics Laboratory (SUPL).

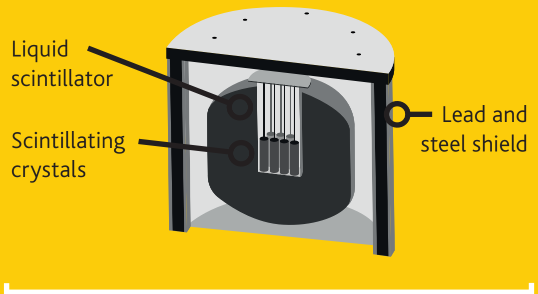
We are going to conduct a pair of linked experiments in the Northern and Southern Hemispheres, to search for the dark matter annual modulation signal, and at the same time rule out any seasonal environmental variation that might mimic the signal. This experiment, SABRE, is the first dual-sited direct-detection experiment. The Southern Hemisphere experiment will be located at SUPL in Australia, and the Northern Hemisphere experiment will be hosted at Laboratori Nazionali del Gran Sasso, Italy.

The Stawell Gold Mine is a dry, basalt rock mine, and reaches a depth of 1.6 km. The location and the nature of the mines make it ideal for a dark matter experiment. We have identified a cavern at 1025 metres underground, which could host a dark matter experiment and an integrated underground laboratory facility, and is at a similar to the average depth of the Gran Sasso National Laboratory in Italy.

The SABRE experiment

The essence of the SABRE experiment is that dark matter must interact very weakly with ordinary matter. Dark matter can collide with atoms, and if the target nucleus is in an atom of a scintillating crystal, such as sodium iodide doped with thallium - otherwise known as NaI (Tl) - then the recoiling nucleus can cause the atom to ionise. This releases electrons, and causes photons to be emitted when the electrons are reabsorbed. If we have photomultiplier tubes around the scintillating crystal then the photons will be absorbed, and an electronic pulse will be generated signalling the dark matter or nucleus collision. However, almost any other particle or photon colliding with the scintillating crystal will also cause an electronic pulse.

Dark Matter Detector



The most important thing about experiments like this is to carefully get rid of unwanted signals. Going deep underground reduces the flux of cosmic rays. Having a passive external shield of lead and steel helps, but is not enough. We also need an active background rejection and so we place the scintillator inside another scintillator to detect more strongly interacting particles coming from outside that would cause a signal in both of them.

This technique is called an 'active background detection' or an 'active veto'. Dark matter particles would only interact with one, since they interact so weakly. We also have to protect against radiation coming from inside the detector itself which can cause a signal, hence the need for ultrapure materials such as the ultrapure NaI scintillating crystal. Moreover, appropriate passive and active veto shielding (from muons, neutrons and gamma-rays) will also surround the experimental setup.

What next?

The SABRE experiment will either confirm that dark matter particles have been directly detected, or conclusively eliminate previous readings of dark matter. If we are able to confirm the discovery of dark mater, we will open a door on the new mysterious universe we cannot see.