SECRET IDENTITIES

According to current theory. 90% of the matter in the galaxy is invisible. How on Earth can we find it?

Astronomers observe matter in the universe by the electromagnetic radiation that it emits or obstructs, but there is much more out there than meets the eye. If the known mass accounts for only 10% of the total, what else is lurking out there? The search is one of the most challenging in modern physics, with instant fame up for grabs. The identity of the missing mass, or 'dark matter' as it is known, is crucial to understanding the arrangement the universe. One of the scientists who has taken up this challenge is Dr Yorck Ramachers, working at the Gran Sasso National Laboratory in Italy.

by Morag Hickman

Objects exert a gravitational pull on each other, according to their mass. If you know this force, you can calculate the mass using Newton's laws. For instance, from the Moon's speed and distance away from us, we can calculate the force attracting it to the Earth, and thus find our planet's mass. But can we use this technique weigh a whole galaxy?

The Milky Way as a whole rotates about its axis, with the outlying regions held from flying off into space by the gravitational tug of the rest. All would be well, were it not for the fact that something's missing. Observations of the motion of stars both within our own galaxy and further afield reveal a discrepancy [see figures 1 & 2]. The gravitational pull they feel is calculated as up to ten times what could possibly be exerted by observable matter. The galaxy must therefore be much more massive than the sum of its visible stars.

It has been proposed that this exposes a flaw in the theory of gravity - that its effect must thin more slowly with distance than predicted. This is not a welcome suggestion, as it would require a whole new theory of gravitation to be developed. The popular alternative is that the matter we can observe is only the tip of the iceberg. Theorists propose an invisible halo of ‘dark’ matter inhabiting the universe all around us, and Ramachers is one of those on the quest to determine its existence and identity.
There are two main camps: those of MACHOs (Massive Compact Halo Objects), and WIMPs (Weakly Interacting Massive Particles).

MACHOs would include such bodies as stars that are too small to ignite, stray planets known as 'Jupiters' and black holes left over from the Big Bang. Although not directly observable, these objects may be detected by the effect their mass has on the light from distant stars. A phenomenon known as 'gravitational lensing' [see figure 3] means that as the object passes in front of a distant star, its mass bends the light rays just as a glass lens will. The tell-tale distorted image of the faraway star can be detected with a telescope.

This gravitational lens technique for the observation of dark, massive halo objects has been proved to work, but Ramachers among others believes that these objects cannot tell the whole story. If all the dark matter in the universe were to be accounted for by massive lumps of normal matter, then their gravitational lensing fingerprints would be seen in far greater numbers across the night sky than is the case. As these are scarce, the search has turned to an explanation of a rather different scale.

DERVISH DANCE

A star in the outer reaches of a rotating galaxy such as our own will experience two components of gravitational pull - towards the centre of mass, and directly toward the disc or plane of the galaxy, which has a much greater concentration of matter than the extended halo which surrounds it. But from what we observe, the stars move too fast for the mass of the galaxy to hold them in check.

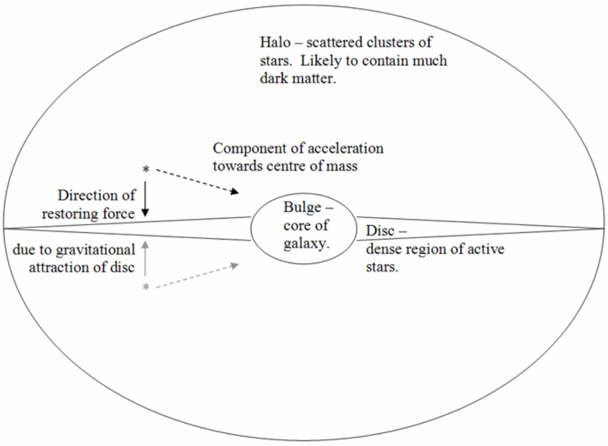

Figure 1 - Acceleration of star toward galactic disc

Locally, the gravitational pull of the matter within the galactic disc is greater than that of the centre of mass, and so a star will accelerate toward the plane of the galaxy. Once it passes through the disc, it will experience a restoring force, and thus oscillate back and forth.

The stars observed within our galaxy are moving much faster than expected, and it is calculated that the gravitational attraction of observable matter is not sufficient to hold the structure together. The kinetic energy of the stars is so great that if there were no additional gravity to maintain balance, the galaxy would fly apart.

This implies significant additional mass, that cannot be observed directly.

Dark matter was first postulated over 60 years ago, in an attempt to explain this phenomenon.

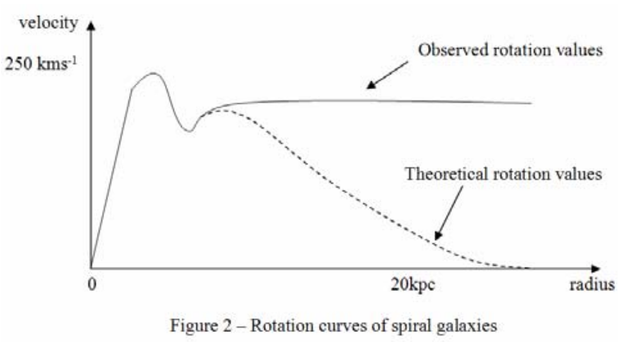

Figure 2 - Rotation curves of spiral galaxies

By measuring the difference in the Doppler shift of light across the diameter of a galaxy, the rotational velocity can be found in relation to distance from the centre of rotation.

When mass values obtained this way are compared to those calculated from the visible galaxy, there is a very large discrepancy. Rather than dropping with increasing distance from the centre as predicted, the speed of rotation remains high to very large distances from the canter of the galaxy.

For this to be the case, the halo must make a significant contribution to the mass of the galaxy.

A very large database of galactic rotation graphs has been built up since the 1970s, which verifies that this is not an isolated phenomenon.

Astroparticle physicists propose WIMPS as their candidate for dark matter: massive, exotic subatomic particles. Despite having a mass similar to a iron nucleus, they interact so seldom that it could be possible for them to travel straight through the Earth or even our galaxy without a single interaction with normal matter. Millions may be streaming through our bodies every day. The hunt such particles will be challenging and difficult.

The presence of WIMPs is predicted by conditions thought to prevail in the early universe. As these conditions place limits on the amount of normal matter in the universe, the discrepancy - the missing mass - could be
accounted for by hitherto undetected elementary particles. If detected, these could completely alter the standard model of particle physics.

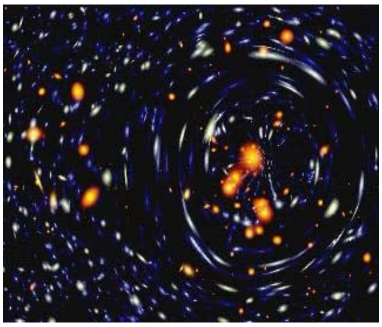

Figure 3 - Gravitational lensing simulation

The mass of large compact objects - whether they be clusters of galaxies or dark, unlit stars of only a few solar masses - can distort the path of light from distant objects. As the light path is bent towards the object, the observer will see a distorted ring or multiple images of the distant object. This not only allows astronomers to see further into the galaxy than they would otherwise be able, but also allows the indirect detection of MACHOs. Although they are dark and cannot be seen directly, a distorted image will reveal their presence.

The search

For such a fundamental piece in the jigsaw of our understanding of the universe, surprisingly little investment is needed in the search for dark matter. Most modern particle physics experiments involve accelerators, for which gargantuan international collaborations are needed. These may involve hundreds of physicists, multi-million pound budgets, and take many years to complete. The search for particles of dark matter however, can be carried out by a small team in a laboratory, becoming operational in only few years, on a much more modest budget.

Ramachers is part of the team involved in dark matter research at the Gran Sasso National Laboratory in Italy. CRESST [Cryogenic Rare Event Search using Superconducting Thermometers] is an experiment run deep underground, and is currently the most advanced of its type in the world. The team is searching for the telltale footprints left by the elusive exotic particles of dark matter.

Nothing is firmly known about WIMPs, but there are a few predictions to work with. The hunt for them hinges on the assumption that they will interact with normal matter - though very rarely, and weakly - via collisions. Elastic scattering will transfer some momentum from the exotic particle to the nucleus or electrons of the material it interacts with. The best way of spotting them is to patiently wait for an atomic nucleus to undergo unexpected recoil. The problem with this method is the rate of collisions. Each gram of detector material will on average interact with just one WIMP particle per day, and this is in danger of being drowned out by noise.

False signals at rates of millions per day can come from the collision of space-borne particles of normal matter, or from radioactive decay of impurities or contaminants. These may be present both in the detector and its surroundings. Extremely careful preparations are needed to make the experiment work.
By situating it in a chamber deep underground, the experiment is shielded from cosmic rays and the high background radiation levels on the surface.

Detection methods

There is more than one approach to detecting the interaction of a WIMP. The energy transferred by the collision with an atomic nucleus may be dispersed and can be distinguished in three different ways.

It can cause a miniscule temperature rise, which can be detected in materials only slightly above absolute zero. Cryogenic detectors use this technique.

Collisions can also cause the excitation of electrons. When the electrons subsequently release this energy it is in the form of photons of a particular wavelength. This process is known as scintillation. By using transparent liquids or crystals as detector materials, light can be collected and multiplied into a measurable signal.

Excitation can also free electrons completely within the material, which can then be detected directly. With the right choice of materials, more than one of these signals can be monitored in combined detectors.

The CRESST experiment

The CRESST experiment uses one such combined detector, with sensitivity to both scintillations and temperature changes. The entire apparatus is enclosed in a cold box, chilling it to a mere 12mK above absolute zero. At this low temperature, the noise is reduced to a level that gives sensitivities only otherwise achievable with far larger detectors. The detector comprises a total 10kg of ultra-pure sapphire, in the form of 300g crystals.

The ratio of scintillation to temperature signals can be used to distinguish between real signals and noise due to radioactive decays and stray photons. The experiment is able to reject 99.7% of all false signals from photons and electrons.

Along with being buried deep and ultra-clean, the equipment is shielded from electromagnetic radiation by a faraday cage, and supported on vibration dampeners.
The experiment is so sensitive that even radioactive lead deposited by the decay of radon gas in the air can pose a serious problem. Air must be stored for several weeks until the levels of radon left are low enough to keep equipment uncontaminated through the final stages of preparation.

The CRESST experiment fulfils all the necessary criteria of low noise and long-term functionality needed in the search for dark matter for such a long-term experiment, it has yet to directly produce evidence of WIMPs. It has however succeeded in narrowing the range of possible mass and energy values of WIMPs.
The experimental setup at Gran Sasso is currently being upgraded, with a complete revamp of its electronics and the addition of a neutron shield. Work is expected to be complete early in 2005.

As the most advanced and sophisticated detector around today, Ramachers believes that CRESST provides the best chance of detecting particulate dark matter, though there are no signs as yet.

If the team succeeds in finding the secret identity of the universe's missing mass, their names will go down in history, and they will shake both physics and cosmology to the very core.