Dark matter

Absence of evidence, or evidence of absence?

Physicists are learning more about what dark matter isn't. That will help them find out what it is

Print edition | Science and technology

Oct 30th 2013

COSMOLOGY and particle physics—or at least, the popular versions of them—tend to the grandiose. The Higgs boson, recently discovered at CERN, Europe's particle-physics laboratory, is not just any old particle. To the despair of many physicists, it has been dubbed the “God particle”. Books on cosmology promise to reveal the “fabric of the cosmos”, while their academic authors discuss different flavours of a “theory of everything”.

The reality, though, is more disappointing—or perhaps more exciting, depending on your point of view. Physicists have excellent, accurate theories to describe the behaviour of the matter that makes up atoms. But they also know that this matter constitutes less than 5% of the substance of creation. The remainder is split between “dark energy”, a notional force assigned responsibility for the accelerating expansion of the universe, and “dark matter”, ghostly stuff whose existence seems necessary to make sense of the arrangement of the heavens. Both are the subject of intense study, and both remain deeply mysterious.

On October 30th the team running the Large Underground Xenon (LUX) experiment, in a mine 1,500 metres below South Dakota, announced the results of their first three months spent hunting for dark matter: nothing. That is big news. It contradicts evidence from several other experiments, which offered hints that dark matter had been spotted. And LUX is the most sensitive dark-matter detector yet built.

The history of dark matter dates back to 1933, when Fritz Zwicky, a Swiss astrophysicist working at the California Institute of Technology, noticed something odd. The galaxies he was looking at seemed to be moving in ways inexplicable by the gravitational pull of their neighbours. This led him to argue that the universe is full of much more stuff than can be seen through optical telescopes.

Since then, further evidence has accumulated, from the ways in which galaxies spin, to measurements of the faint afterglow of the Big Bang, and the distorting effects that galaxy-sized concentrations of mass have on light travelling through space. None of these observations makes sense without assuming a large dollop of extra mass (more than five times the amount of atomic matter) alongside what astronomers can actually see. A small fraction of the absent mass might be mundane: sunless planets, wandering black holes, neutron stars and the like. But to be consistent with astronomical observations, most of it must be stranger stuff.

Absent friends

The leading candidate is the WIMP, or Weakly Interacting Massive Particle, which is physicist-speak for a big particle that responds to only two of the universe’s four fundamental forces. WIMPs feel the weak nuclear force (which governs radioactive decay, among other things) and gravity, but their ability to ignore both electromagnetism and the strong force that holds nuclei together makes them elusive objects that barely interact with atomic matter.

The LUX experiment consists of a cylinder filled with 368kg of liquid and gaseous xenon, which is in turn contained within a 270,000-litre tank of water. If WIMPS are real, then huge numbers of them should be streaming through the cylinder every second. Occasionally, a WIMP should bump straight into a proton or a neutron within the nucleus of a xenon atom, interact with it via the weak nuclear force, and thus cause the nucleus to recoil. The atom will then emit a scintilla of light, which will be picked up by the machine's ultra-sensitive detectors. The water shield, and the machine's location deep underground, are designed to protect it from cosmic rays, solar radiation and anything else that could cause false alarms.

That LUX has so far failed to find anything is important, because it runs against a promising line of evidence. Several other dark-matter detectors had seen signs, over the past few years, of the particles LUX is hunting for. Most recently, in April, the Cryogenic Dark Matter Search (CDMS), located in an iron mine in Minnesota, reported three potential WIMP detections, with a confidence level of 99.8%. (That may sound high, but in particle physics it is a result of only middling significance.) Daniel McKinsey, a physicist at Yale University who is a spokesman for LUX, says that if the CDMS results were accurate, then LUX ought to have seen around 1,500 WIMPs during its first three months of operation.

Although a definite detection of dark matter would have generated more headlines (and probably, also, a Nobel prize), coming up empty-handed is a vital part of science. The WIMPs dreamed up by theorists are almost endless in their variety, says Katherine Mack, a cosmologist at the University of Melbourne, with wildly differing masses and levels of shyness about interacting with the rest of the cosmos. Rick Gaitskell, LUX's chief scientist, reckons two decades of dark-matter hunting have covered about half the possibilities.

A process of elimination

While astrophysicists attack the problem by looking outward, their particle-physicist brethren are looking inward. The masters of the Large Hadron Collider at CERN, fresh from running the Higgs boson to ground, are trying to spot the signature of dark matter by looking for missing chunks of energy in the debris produced by the machine's high-speed particle collisions.

Other teams are putting their detectors in space, instead of underground. The Alpha Magnetic Spectrometer (AMS), bolted to the side of the International Space Station, is designed to search for dark matter by detecting the particles, called positrons, produced when WIMPS in the Milky Way collide and annihilate each other. In April those running the AMS announced results consistent with the idea that such annihilations are happening, although Dr Mack points out that these results are tentative, and the positrons could also have come from other things, such as pulsars.

So far, then, the great search has found nothing. But each negative result rules out certain theories and strengthens others, shrinking the conceptual space in which dark matter can be hiding. Most physicists expect a robust detection sooner or later. But if every search actually were to come up empty-handed, then that would be the most exciting negative result of all—for it would imply that whatever is responsible for the movements of the galaxies is even stranger than people think.

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