FROM THE NOVEMBER 2011 ISSUE

How to See the Invisible: 3 Approaches to Finding Dark Matter

Physicists scour heaven, Earth, and everywhere in between for the mysterious particles that hold together galaxies and sculpt the universe.

By Lisa Randall | Wednesday, February 22, 2012

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Spiral galaxy M74 holds 100 billion stars. Oddly, stars at its outer edges rotate with the same velocity as those closer in, suggesting the influence of a substantial mass of unseen dark matter.

NASA

Although we live in a renaissance era of cosmology, in which theories and observations have advanced to the stage where ideas can be precisely tested, we also live in the dark ages. About 23 percent of the universe consists of dark matter, mysterious stuff that exerts gravitational forces but doesn't interact with light. Ordinary matter makes up just 4 percent. (Another 73 percent is dark energy, an even more mysterious component that permeates the universe.)

The last time something was called "dark" in physics was in the mid-1800s, when Urbain-Jean-Joseph Leverrier of France proposed an unseen dark planet, which he named Vulcan. Leverrier's goal was to explain the peculiar trajectory of the planet Mercury. Leverrier, along with John C. Adams of England, had previously deduced the existence of Neptune based on its effects on the planet Uranus. Yet he was wrong about Mercury. It turned out that the reason for Mercury's strange orbit was much more dramatic than the existence of another planet. The explanation could be found only with Einstein's theory of relativity. The first confirmation that the theory of general relativity was correct came when Einstein proved it could be used it to accurately predict Mercury's orbit.

It could turn out that dark matter presages a similar paradigm change. Even so, I'd say that it is very likely to have a more conventional explanation, consistent with the type of physical laws we now know. After all, even if novel matter acts in accordance with force laws similar to those we know, why should all matter behave exactly like familiar matter? To put it more succinctly, why should all matter interact with light? If the history of science has taught us anything, it should be the shortsightedness of believing that what we see is all there is.

Many people find dark matter's existence very strange and ask how it can possibly be that most matter—about six times the amount we see —is something we can't detect with conventional telescopes. In fact, we know something with dark matter's properties has to be there. We know it exists by the extensive observational evidence of its gravitational effects in the cosmos.

The first clue of dark matter's existence came from the speed with which stars rotated in galaxy clusters. Much more solid evidence for dark matter came from Vera Rubin, an observational astronomer, who in the late 1960s and early 1970s made detailed quantitative measurements of stars rotating in galaxies. The properties of a galaxy, such as the rate at which its stars orbit, depend on how much matter it contains. With only visible matter present, one would expect those stars well beyond the galaxy to be rather insensitive to its gravitational pull. Yet Rubin found that stars far from the luminous central matter rotated with the same velocity as stars one-tenth the distance from the galaxy's center. This implied that the mass density did not fall off with distance, at least to the distances Rubin observed. Astronomers concluded that galaxies consisted primarily of unseen dark matter. Supplementary evidence comes from studies of gravitational lensing.

We now know the density of dark matter, that it is "cold" (which is to say, it moves slowly relative to the speed of light), and that it interacts extremely weakly and certainly has no significant interaction with light. But that's about it. Dark matter could be small black holes or objects from other dimensions. Most likely, though, it is simply a new elementary particle that doesn't have the usual interactions associated with the standard model, the reigning physics theory that so far explains the known forces governing the fundamental particles of ordinary matter.

The Dark Matter Factory

Many connections exist between particle physics and cosmology, but one of the most intriguing is that dark matter might actually be produced at the energies explored by the world's most powerful particle accelerator, the Large Hadron Collider (LHC). The LHC contains an enormous, 16.5-mile-long circular tunnel that crosses the French-Swiss border deep underground. Electric fields inside this tunnel accelerate two beams—each consisting of billions of protons, which belong to a class of particles called hadrons, hence the collider's name—about 11,000 times a second as they circle the track.

When Lyn Evans, the LHC's chief engineer, spoke at the California LHC/Dark Matter conference in January 2010, he closed by teasing the audience. "You theorists have been thrashing around in the dark [sector]," he said. "Now I understand why I spent the last 15 years building the LHC." Evans's comments referred to the paucity of high-energy data over the previous couple decades. But they were also hints about the possibility that LHC discoveries might shed light on dark matter.

The intriguing possibility of producing dark matter is among the reasons cosmologists are curious about what the LHC might find. The LHC has just the right energy to search for a hypothetical dark particle called a WIMP, or weakly interacting massive particle. Even if that's the case, however, the dark matter particle won't necessarily be discovered there. After all, dark matter doesn't interact a lot, so dark matter particles certainly won't be produced directly in a detector, and even if produced indirectly, they will just fly through. Nonetheless, the LHC might produce other particles with stronger interactions that subsequently decay into dark matter, which could then carry away momentum and energy, providing proof that the dark particles were there.Finding evidence of the existence of dark matter would certainly be a major accomplishment. However, to establish that a particle indirectly detected at the LHC indeed constitutes dark matter would require further substantiation. That is what detectors on the ground and in space might provide.

1 of 3


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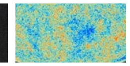
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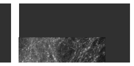
Dark matter, apparently, is midichlorians


It's full of stars!


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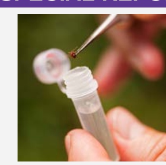

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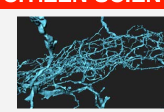

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