Measuring dark matter: The ultimate signal-to-noise problem

Ransom Stephens - June 08, 2015

In my last article, I tried to convince you that particle physicists are on the verge of discovering dark matter. We also sorted out why they believe dark matter is made out of WIMPs (weakly interacting massive particles) and what makes WIMPs wimpy.

You may have seen hype from CERN saying that the LHC (Large Hadron Collider) experiments are on the lookout for dark matter, but those reports may have left out a crucial caveat: the LHC experiments are not capable of identifying dark matter. That is, they might see something new, and that new stuff might turn out to be dark matter, but they won't be able to connect the dots.

Dark matter saturates your home, your office, your lab, your town, your underground lair, even your body. Experimental constraints that incorporate what we know about normal matter and the four forces suggest that, out here where earth loiters around the sun, 50,000 dark matter WIMPs pass through every square centimeter each second. They travel at a speed around 0.1% of the speed of light, which isn't very energetic, and they probably weigh anywhere from the mass of a proton to a few hundred times that. By particle physics standards, they're a little hefty but not remarkable—except that they make up 80+% of the matter in the universe and we don't know what they are.

At those weights and speeds, WIMPs might not pack enough punch to break into nuclei and send charged particles or light rays zipping through the detector. Since neutrinos are the only particles we have experience with that interact purely through the weak and gravitational forces, dark matter experiments have a lot in common with neutrino experiments. We went through the difficulties of detecting neutrinos in “Measure of neutrinos,” but today we're going after the ultimate signal-t-noise problem:

How do you detect particles whose only fingerprint is a rare, faint vibration?

WIMPs colliding with atoms might bring to mind a simple picture of collisions, stuff hitting stuff and bouncing around like balls on a pool table, but the WIMP factor makes them more complicated. Billiard ball collisions are interactions of the electromagnetic force—electron clouds on one ball bouncing off the electron clouds of the other ball. For a WIMP to tap something, the tap, the touch, the force exchanged must come from either a gravitational interaction or a weak interaction. Those are the only two forces in play for WIMPs—they're invisible to electromagnetism, perfectly transparent. Since the gravitational force between objects with the weight of an atom can't possibly be detected, if we're ever to discover WIMPs then it must be through an interaction of the weak nuclear force.

When dark matter collides with normal matter, the particles involved still obey the conservation of momentum you learned in high school physics, but unlike collisions mediated by electromagnetic
forces—the kind you're used to experiencing—the weak force has a very short range, about an "attometer," a thousandth of the radius of a proton or a millionth of the size of an atom. So we have a very weak force that only interacts when infinitely small particles manage to get really, really close to each other and then, when they do interact, they don't break something into pieces that we can detect, no, they just leave little vibrations behind. Think of tapping an iron mountain with a feather and then listening for the faint "ping."

The problem for the experimentalist is difficult but straightforward: detect extraordinarily rare and faint vibrations and be able to distinguish those vibrations from all the others.

Located deep below the surface of earth, safe from the cacophony of life and insulated to a large extent from cosmic rays, the major background noise for dark matter experiments consists of the natural background radioactivity of both the surrounding environment and the medium of the detector itself (and any stray vibrations from geologic shifts or grad students listening to death metal on their MP3 players).

The SuperCDMS experiment will be the third generation of the cryogenic dark matter search, from which SuperCDMS gets its acronym. The new experiment will be located at SNOLAB (the Sudbury Neutrino Observatory at Vale Inco Mine, Sudbury, Canada) which is 2 km underground. By dark matter experiment standards, it's not very big, a total of about 900 lb of instrumented cylindrical germanium crystals. Each crystal has a 3 inch diameter, is about one inch thick, and weighs a little more than a pound.

![Figure 1: One of SuperCDMS's germanium crystals (photo source](http://cdms.berkeley.edu/gallery.html)](http://cdms.berkeley.edu/gallery.html)

The detector is housed in a cryostat and kept really cold, a few degrees above absolute zero, (about -270 C or -453 F) which serves several purposes. Recall from high school science that when you measure temperature, you're really measuring how fast molecules are moving. To detect tiny WIMP vibrations, a cold detector is a quiet, sensitive detector. We'll see in a minute that there's another reason to keep it so cold.

Also, recall that vibrations are waves of molecular motion. Think of a guitar string or a drumhead. The vibrating string or drum-skin hits the air and sends a pressure wave through the air that ultimately vibrates your ear drum.
Picture a WIMP tapping a germanium nucleus. The vibration propagates through the germanium crystal lattice. Like ripples on a pond, the vibrations grow weaker the farther they get from the tap. Vibrations that make it to the surface of the germanium are absorbed by aluminum fins connected to tungsten strips. At these temperatures, aluminum and tungsten are both superconductors.

Superconductors have zero electric resistance; which means that current propagates through them with no resistance. Hence the name, superconductors function with total disregard for Ohm's law.

When the ripple makes it to a tungsten strip, the vibration increases the speed of the tungsten molecules. A faster moving molecule has a higher temperature. For the instant that the tungsten vibrates, its temperature rises and it ceases to be a superconductor. During that instant, the tungsten becomes resistive and that change in resistance, from nothing to something, reduces the current flowing through the strips.

The change in current is amplified into an observable pulse that can be digitized and written to disk. Voila!

One last thing, notice how the weak interaction between the dark matter WIMP and an atomic nucleus first produced a mechanical vibration and then produced a change in current; it went from a weak force to a mechanical force that's rooted in the electromagnetic force and then to a straight-up, bread-and-butter-to-engineers-and-physicists electrical pulse.

You could say that this chain of events, converting a force, a vibration, a sensation--even an experience--into electrical pulses is how humans roll. We're really good at converting phenomena of all types into current and voltage.
Also See:

- *Is dark matter about to be discovered?*
- *Quantum refrigerator cools to extreme temps*
- *What the Large Hadron Collider scientists teach us about avoiding collisions*