

SEARCH AND DISCOVERY

Explorers Focus More Sharply on Their Prey: Weakly Interacting Dark Matter

What you see is not what you get when it comes to mass in the universe. We've known for more than 50 years, for example, that spiral galaxies rotate much faster than one would expect based on the mass in their twinkling stars and the intervening gases. Furthermore, large-scale observations of the universe imply that the cosmic mass density is so large that radiant mass accounts for no more than a few percent of the total. So, what is the missing mass?

Italian and Chinese experimenters from the DAMA (for DArk MATter search) collaboration think the answer may be weakly interacting massive particles, known as WIMPs. At the Fourth International Symposium on Sources and Detection of Dark Matter in the Universe, held in early March in Marina del Rey, California, the DAMA team reported further results from its four-year quest, giving indications of a weakly interacting particle with about 50 times the mass of the proton.^{1,2} But at the same conference, DAMA's claim was countered by another collaboration, known as CDMS (for Cryogenic Dark Matter Search), whose search has so far turned up no sign of WIMPs.³

The DAMA collaboration includes researchers from the Universities of Rome 1 and Rome 2 and Italy's National Institute of Nuclear Physics (INFN), and from the Chinese Academy's Institute of High Energy Physics in Beijing. Rita Bernabei (Rome 2) is the spokesperson for DAMA. The CDMS collaboration has participants from ten institutions: Case Western Reserve University, Fermilab, Lawrence Berkeley National Laboratory, National Institute of Standards and Technology in Boulder, Princeton University, Santa Clara University, San Francisco State University, Stanford University, the Universities of California at Berkeley and at Santa Barbara, and the University of Colorado at Denver. It is led by Bernard Sadoulet (Berkeley), Blas Cabrera (Stanford), and David Caldwell (UCSB).

Both the DAMA and CDMS exper-

Results are starting to come in from detectors honed to hunt for the universe's missing mass. Although not conclusive, the reports are a harbinger of what's to come.

iments are works in progress, so it may be too early to worry about the conflicting results. More importantly, the two announcements signify that detectors for WIMPs are now reaching levels of sensitivity where they can confirm or deny the existence of these elusive particles, and provide checks on one another. The approaches of the DAMA and CDMS collaborations are different, and complementary: The DAMA group uses traditional sodium-iodide crystals buried deep underground, while the CDMS team has debuted germanium and silicon cryogenic detectors. As both collaborations continue to improve their setups, and as experiments now in the wings reach the same levels of sensitivity, we can expect many more reports of WIMP sightings (or not) in the near future.

WIMPs are just one of the candidates postulated to account for dark matter. WIMPs could possibly be neu-

tralinos, the lightest of a group of particles predicted by supersymmetric extensions to the Standard Model. Other candidates for weakly interacting dark matter are neutrinos and hitherto unknown axions, the latter having masses between 10^{-4} and 10^{-6} eV/ c^2 . Some portion of the unseen mass is probably baryonic matter (consisting of neutrons and protons) that for some reason does not radiate. But theorists tell us that less than 10% of the presumed dark matter can be baryonic.

Sodium-iodide detector

WIMPs have no charge and no strong interactions, but they do suffer occasional head-on elastic collisions with nuclei. The DAMA researchers look for such collisions within an array of sodium-iodide crystals whose total mass is 100 kg; the scintillations produced by nuclear recoils in the crystals are registered by the surrounding phototubes. The researchers record the number of events as a function of scintillation energy deposited in the crystals.

The infrequent nuclear recoils caused by WIMPs are seen against a larger background of electron recoils caused by gamma rays. Every attempt is made to minimize this unwanted background: The DAMA experiment runs in a tunnel at INFN's Gran Sasso National Laboratory in the Apennines (see the photo at left), where it is shielded from all but the most energetic cosmic rays, and the crystals are made as free as possible from contamination with radioactive isotopes. Nevertheless, there is inevitable background, from such sources as decays of radioactive nuclides, which cannot be totally eliminated

from the detectors and environment.

To discriminate the WIMP recoils from the much larger background, Bernabei and her collaborators looked for a seasonal modulation that should affect only the WIMP-induced portion of their spectrum. To understand this approach, imagine that our Milky Way galaxy is embedded in a spherical volume of dark matter, known as



THREE SODIUM-IODIDE CRYSTALS (brass-colored cylinders) set into the shielded copper box at the Gran Sasso Laboratory, where a member of the DAMA team works on the installation. With nine such crystals to record nuclear recoils, the DAMA team found evidence for weakly interacting massive particles (WIMPs). (Photo courtesy of the Italian National Institute of Nuclear Physics.)

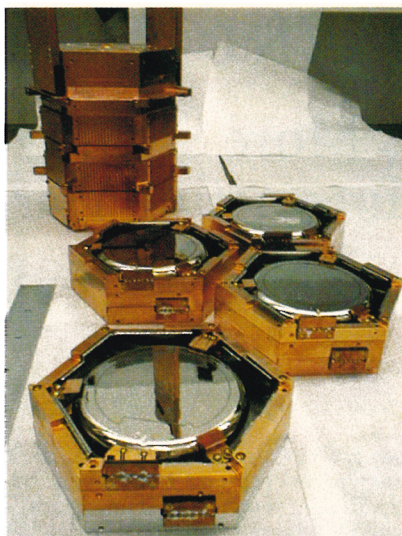
a “halo,” which does not participate in the galactic rotation. The Sun moves through this halo at a speed of 220 km/s, while the Earth orbits the Sun at a speed of about 30 km/s. Thus, the speed of the Earth relative to the halo of WIMPs varies seasonally: In early June, the Earth moves in the same direction as the Sun, and their velocities add; in early December, the motions are opposite and the speeds subtract.

The DAMA researchers did a statistical analysis of the measured energy spectrum, primarily at the lowest energies, where they expect to find the WIMPs. They used some tens of thousands of data points accumulated over four years. Riding above the background, they found a small ripple (a few percent of the total signal) that had the correct period and phase to be the seasonal variation caused by Earth's motion through the WIMP halo. As part of the statistical analysis, the DAMA researchers determined the most probable values of the WIMP mass and cross section. (This analysis included the upper limits on WIMP-induced nuclear recoils previously determined for the same setup by using pulse shapes to distinguish nuclear from electron recoils.) Under standard astrophysical assumptions, the group estimated the WIMP mass to be 44^{+12}_{-9} GeV/ c^2 , and the cross section for its interaction with a nucleon to be $5.4 \pm 1.0 \times 10^{-6}$ picobarn.

Of course, a seasonal effect can be induced by many factors, such as temperature or time-varying efficiencies. The DAMA researchers have ruled out as many such factors as they know about. Nevertheless, it's difficult to convince observers that all possible artifacts have been ruled out. DAMA plans to continue improving its experiment, most notably by increasing its total detector mass to 250 kg of sodium iodide.

Cryogenic detector

The CDMS experiment relies on newer technology—cryogenic solid-state detectors—developed over the past decade for this and other astrophysical applications (see the articles in *PHYSICS TODAY* by Leo Stodolsky, August 1991, page 24, and by Caroline Kilbourne Stahle, Dan McCammon, and Kent D. Irwin, August 1999, page 32). The CDMS collaboration uses two different cryogenic detectors—germanium detectors designed at Berkeley (see the photograph above) and silicon sensors developed at Stanford. By using thermistors or superconducting transition-edge ther-



GERMANIUM CRYOGENIC DETECTORS in copper mounts were used alongside similar silicon detectors to detect WIMP-induced recoils in the CDMS experiment. So far, none have been seen. In operation, these detectors (165 g each) are stacked face-to-face and suspended from the assembly shown in the background. (Photo courtesy of the CDMS collaboration.)

mometers, these detectors measure the heat deposited by the recoil of a single nucleus. To measure this tiny temperature rise, the detectors must be cooled below 50 mK. Both types also determine the ionization made by the recoil of electrons or nuclei.

The combination of the two measurements—heat and charge—gives a way to discriminate between electron recoils induced by unwanted gamma-ray background and the nuclear recoils caused by WIMPs. That's because the electron recoils generate about three times more ionization energy than nuclear recoils do.

Members of the CDMS team have worked hard to make their detectors sensitive to the expected interaction rate of WIMPs: less than one count per day per kg per keV. One problem that has plagued them is the events induced near the surface of the detectors by beta particles just outside the detector. They now have improved the electrode technology to minimize the problem, and they have added a fast-phonon sensor technology to reject such surface events based on phonon rise times.

Because the background is so low, the CDMS group, with only 0.5 kg of detector mass and 12 kg-days worth of data, has a sensitivity comparable to that of DAMA, with its 57 986 kg-days of data. Nevertheless, the CDMS

experiment is still limited by the background of recoils from cosmic-ray neutrons, whose scattering characteristics are virtually identical to those of WIMPs. For now, those neutrons are a problem because the CDMS team is running its experiment at a relatively shallow depth (only about 10 m deep at a site on the Stanford campus). Sometime next year, the experimenters will install many more of their detectors in the Soudan Mine in Minnesota, where the thick overburden will virtually eliminate the neutron flux.

For the data reported at Marina del Rey, the CDMS collaborators estimated that all of their events were consistent with a neutron background, within statistical errors. As part of their analysis, they studied how many particles went on to scatter a second time: Neutrons are far more likely than WIMPs to scatter twice. The number of particles with multiple scatters was consistent with the number one would expect if all the observed events were neutrons. Still, the CDMS result is based on fairly small statistics. The collaboration looks forward to getting much more data, with much less background, after the move to the Soudan Mine.

If, with more and better data, the results from DAMA, CDMS, and yet other groups still differ, there's a small out: The interaction rates of the WIMPs might be different in sodium targets from what they are in germanium or silicon detectors, as they might be if WIMP interactions are spin dependent.

For the future

Numerous other groups around the world are following a variety of approaches in hopes of finding WIMPs.⁴ They are striving to equal or exceed the levels of sensitivity reached by the DAMA and CDMS collaborations, some using similar technology, others exploring new ideas such as ways to sense the direction of the nuclear recoils.

BARBARA GOSS LEVI

References

1. R. Bernabei *et al.* (DAMA Collaboration), INFN/AE-00/01 (see <http://www.lngs.infn.it>).
2. R. Bernabei *et al.* (DAMA Collaboration), *Phys. Lett. B* **389**, 757 (1996); *Phys. Lett. B* **424**, 195 (1998); *Phys. Lett. B* **450**, 448 (1999); *Il Nuovo Cimento A* **112**, 545 (1999).
3. R. Abusaidi *et al.* (CDMS Collaboration), <http://xxx.lanl.gov/abs/astro-ph/0002471>.
4. See, for example, N. Smith, N. Spooner, *Physics World*, January 2000, 23 and A. Morales, <http://xxx.lanl.gov/abs/astro-ph/9912554>.