New detector fails to confirm would-be evidence of dark matter

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Brazilian researchers are participating in the COSINE-100 experiment, installed 700 meters underground in South Korea. An article on the first run of data has just been published in *Nature* . Credit: thallium-doped sodium iodide crystals in dark matter detector / COSINE-100

Almost 20 years ago, the DAMA/LIBRA experiment at Italy's Gran Sasso National Laboratory—LNGS began publishing data showing that it had detected a signal modulation produced by an interaction with the Milky Way's dark matter halo.

Dark matter is believed to constitute approximately 27 percent of the known universe, with ordinary matter accounting for only 4 percent. The remaining 69 percent is thought to be made up of dark energy. Because dark matter interacts weakly with normal matter, its presence has thus far been inferred only from gravitational effects on visible bodies such as stars, galaxies and galaxy clusters.

According to the most widely accepted model, the combined motion of the Earth, the sun and the galaxy itself result in a dark matter wind for an observer on the Earth—more specifically, a wind of weakly interacting massive particles or WIMPs, hypothetical particles that are thought to constitute dark matter.

During the Earth's annual orbit around the sun, signals from the detector's interaction with WIMPs increase when the planet moves in the opposite direction to the wind and decrease when they are both moving in the same direction. The fluctuation has a cosine shape.

DAMA/LIBRA personnel state that it has detected signals at rates that vary according to a cosine wave during the year and that they correspond to a dark matter signature. The problem is that no such signature has been confirmed by any other experiments since this was first announced. It should be stressed that other experiments use different materials and analytical techniques.

To check the discrepancy between DAMA/LIBRA's data and the data from other experiments and to look for robust evidence of dark matter, COSINE-100 was built 700 meters underground at the Yangyang

Underground Laboratory—Y2L in South Korea.

An article presenting the results of the first 59.5 days of data from COSINE-100 was published in December 2018 in the journal *Nature*.

Nelson Carlin Filho, Professor at the University of São Paulo's Physics Institute (IF-USP) and two supervisees constitute the Brazilian participation in the COSINE-100 international collaboration. "The results of the first 59.5 days of COSINE-100 failed to confirm the data from DAMA/LIBRA. The results obtained don't correspond to a signature of WIMPs," he said. Carlin stressed that this negative finding is particularly important because both DAMA/LIBRA and COSINE-100 use detectors made of sodium iodide (NaI) crystals. "It's the first published finding for a detector comprising this material with sufficient size and sensitivity to investigate the DAMA/LIBRA signal region," he said.

"We're not saying the researchers at DAMA/LIBRA were wrong. They may have captured a periodic modulation in actual signals. However, unless the dark matter model is significantly modified, the signals are highly unlikely to be attributed to interactions with WIMPs. In any event, our work is only just beginning. Several years of data will be needed before the annual modulation claimed by DAMA/LIBRA can be totally confirmed or refuted."

The COSINE-100 detector is made up of eight thallium-doped sodium iodide crystals with a total mass of 106 kg. Each crystal is coupled to two photomultiplier tubes to measure the amount of energy deposited in the crystal. The entire array is immersed in 2,200 liters of liquid scintillator and surrounded by copper, lead and plastic scintillator panels.

The point of all this shielding—as well as the decision to install the detector 700 meters underground—is to reduce disturbances caused by cosmic rays (muons), cosmic background radiation (photons remaining from the primordial universe, detected in the microwave band), and particles emitted by the materials of which the detector is made.

"The probability of observing interactions between dark matter particles and the detector material is tiny. Apart from shielding, it's important to analyze the shape of the signals in order to rule out background contributions," Carlin said.

Based on a highly sophisticated statistical treatment using the standard model for the dark matter halo, with Monte Carlo simulations and other resources, COSINE-100 defined a curve considered the "exclusion limit" for interactions between WIMPs and the nuclei in the detector material.

This limit corroborated and fine-tuned the limits established by previous experiments. The curve was plotted using a two-dimensional Cartesian coordinate system. The WIMP-nucleon scattering cross-sections are shown on the Y-axis, simplistically representing the probability of interactions, while the WIMP mass is shown on the X-axis.

Any event whose coordinates can be plotted below the exclusion limit is a candidate WIMP-nucleon interaction. Any event situated above it fails to meet the necessary conditions for an interaction in accordance with the model.

"The DAMA/LIBRA signals are above the exclusion limit. Note that in addition to using detectors made of the same material as DAMA/LIBRA [sodium iodide crystals], COSINE-100 also used similar event selection techniques. This minimized discrepancies in results due to differences in the experiments. We didn't find dark matter and we discovered that the DAMA/LIBRA measurements aren't consistent with the standard model for the dark matter halo," Carlin said.

Theories about dark matter

There is now a broad consensus in the scientific community that dark matter exists. The first evidence was found in 1933 in studies of galactic rotation speeds by Swiss astronomer Fritz Zwicky (1898-1974).

Zwicky realized that galactic rotation speeds were faster than they should have been according to the observed luminous mass and proposed that the gravitational contribution of another kind of matter, which he called "dunkle materie" ("dark matter" in German), must be affecting these speeds.

In the 1970s, American astronomer Vera Rubin (1928-2016) confirmed Zwicky's hypothesis in a systematic study of galactic rotation speeds. Rubin's rigorous calculations, confirmed by subsequent research, showed that the galaxies concerned must contain at least five to 10 times more dark matter than normal matter.

Today, based on galactic rotation speeds and other evidence such as gravitational lensing, first proposed by Einstein, and the background microwave radiation, the accepted proportions for the composition of the universe are approximately 4 percent normal matter, 27 percent dark matter and 69 percent dark energy.

If the existence of dark matter is widely accepted; the point now is to determine what it is made of. The WIMP-based model is still the most widely accepted model. Such particles are believed to interact with normal matter only through gravity and the weak nuclear force. This is presumably why they have not been consistently detected. The failure to detect WIMPs has led scientists to propose alternatives such as axions and dark photons.

"There's nothing to prevent dark matter from being made up of several different elements," Carlin said. "A great deal of work remains to be done. In our case, COSINE-100 is still taking its first steps. The next step, which is very important, is to try to reproduce the annual modulation or prove it can't be reproduced. This is actually in progress right now. We're also preparing phase two of the experiment, COSINE-200, with 200 kg of crystals, to be installed at a different site in South Korea."

More information: An experiment to search for dark-matter interactions using sodium iodide detectors, *Nature* (2018). DOI: 10.1038/s41586-018-0739-1

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