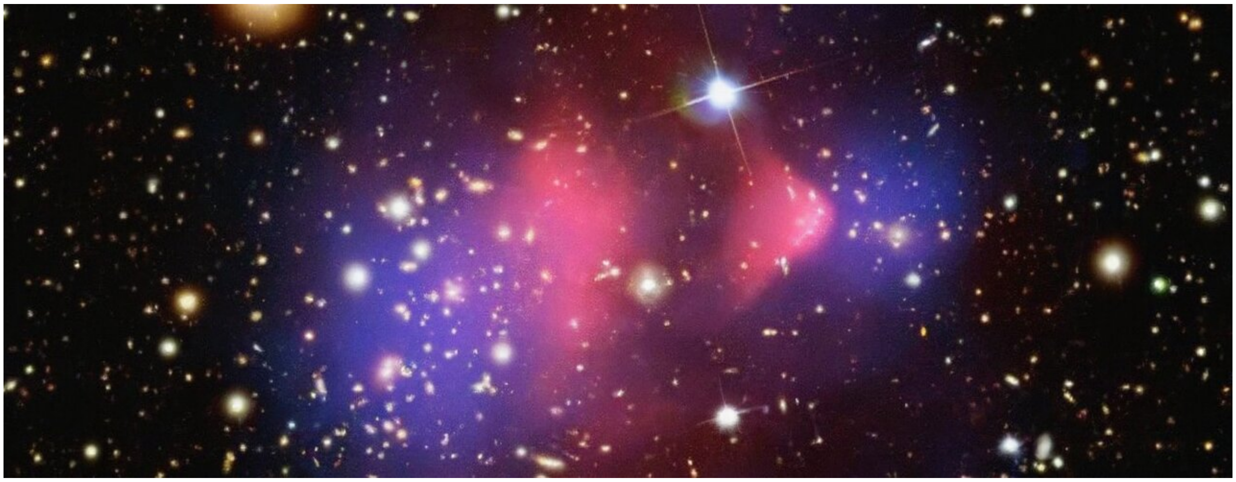
New analysis of SuperCDMS data sets tighter detection limits for dark matter

July 28 2023, by Kimberly Hickok



A collision of clusters of galaxies, showing separation of dark matter (shaded blue) from normal matter (shaded pink). Credit: NASA

For nearly a century, dark matter has continued to evade direct detection, pushing scientists to come up with even more creative methods of searching. Increasingly sensitive detection experiments are a major undertaking, however, which means scientists want to be sure they analyze data from these experiments in the most thorough and robust way possible.

With that in mind, the Super Cryogenic Dark Matter Search (SuperCDMS) collaboration has published a reanalysis of previously published experimental data. Their study, published recently in *Physical Review D*, describes the team's search for dark matter via two processes called Bremsstrahlung radiation and the Migdal effect.

In a first-of-its-kind analysis, the team also worked with geologists to consider how the Earth's atmosphere and inner composition interact with dark matter particles to cause their energy to dissipate. The analysis represents one of the tightest limits on dark matter detection yet and sets the stage for future dark matter searches.

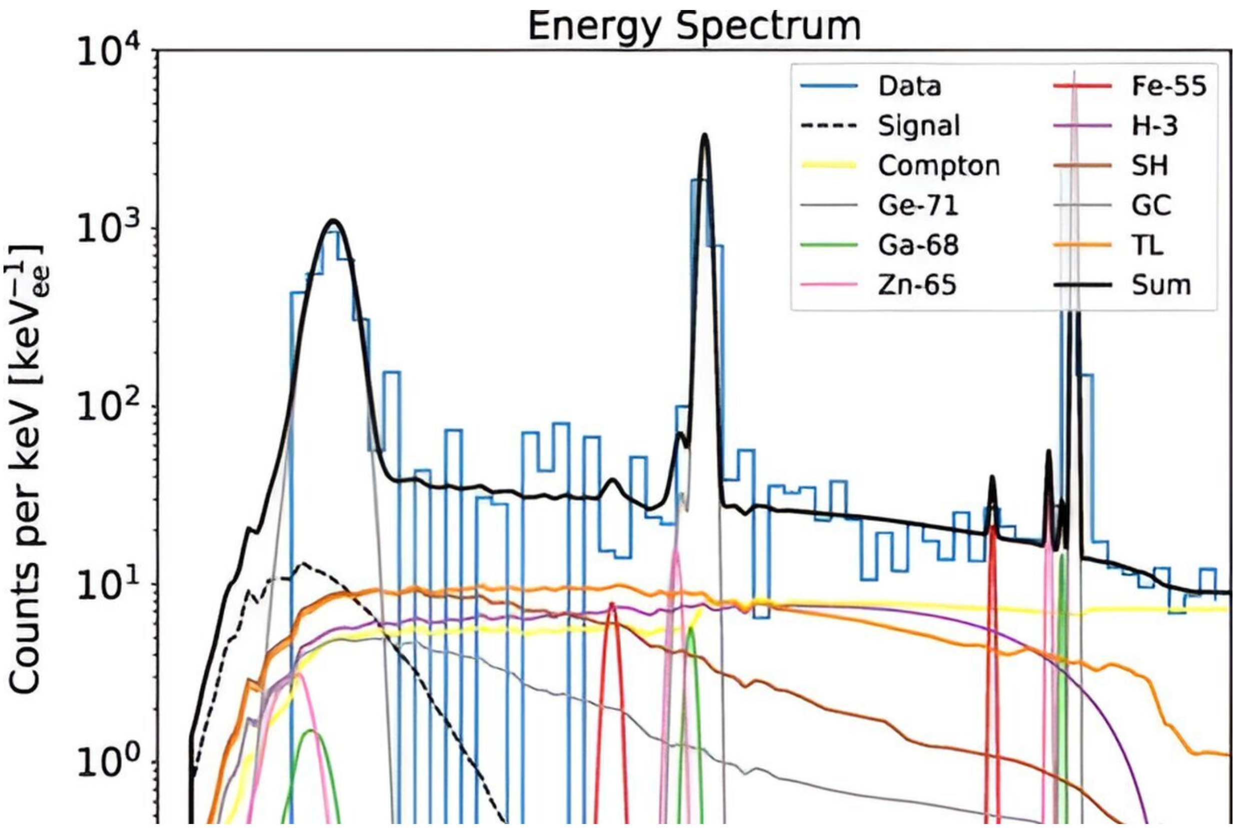
"As we search for dark matter, we need to extend detection sensitivities," said Noah Kurinksy, a staff scientist at SLAC and corresponding author on the study. "Having better ways to model these processes and understand these sorts of measurements is very important for the dark matter community."

Invisible scattering

In an experiment like SuperCDMS, physicists look for signs that dark matter has collided with the atomic nuclei—the protons and neutrons—inside a material such as silicon and germanium.

Usually, the assumption is that when a dark matter particle whacks into a nucleus, the collision is elastic: Any energy the dark matter particle loses is transferred into the motion of the nucleus, so that both particles recoil. "Your typical billiard balls scattering example," Kurinsky explained.

In recent years, however, researchers have proposed that dark matter may be detected through inelastic collisions, in which the energy from the collision is transferred to something else that's possibly easier to detect, such as photons or electrons. This could lead to more sensitive detection capabilities for dark matter detection experiments.



Example of an energy spectrum from the maximum likelihood fit for a Migdal signal model for a WIMP with a mass of 0.5 GeV/c^2 and a cross section of 3×10^{-37} cm^2 (black dashed curve). The data (blue histogram) have been logarithmically binned and overlaid with the background models (colored solid curves). The thick black line is the sum of all the models, signal and background. Normalization of the surface background model components (TL, SG and GC) are described in Sec. 5b. The plot on the bottom shows the residual between data and the model with the 1σ statistical uncertainty indicated by the shaded region. Credit: *Physical Review D* (2023). DOI: 10.1103/PhysRevD.107.112013

Considering that the SuperCDMS experiment is already one of the most sensitive dark matter detectors of its kind, "we wanted to know what the probability was that we see this particular type of signal in SuperCDMS data," said Daniel Jardin, a co-author of the new study and a postdoctoral scholar at Northwestern University who helped lead the analysis.

The team focused on two potential avenues for inelastic collisions to occur: Bremsstrahlung radiation and the Migdal effect.

Bremsstrahlung is a well-known and previously observed phenomenon caused by the deceleration of a charged particle—the word is German for "braking radiation." In a dark matter detector, this could happen when a dark matter particle collides with a nucleus, which then transfers some of its energy to a photon instead of just recoiling. If detected, that photon would suggest some mysterious, fast-moving particle—perhaps dark matter—slammed into the nucleus and sent the photon flying.

Another possible mode for inelastic collisions is through the Migdal effect. Although it has yet to be experimentally demonstrated, the idea is that when a dark matter particle strikes a nucleus, that nucleus gets knocked out of the center of its electron cloud. After some very short amount of time, the electron cloud readjusts around the nucleus, ejecting electrons that researchers could detect. In recent years, scientists have calculated what such a signal would look like should it happen within dark matter detectors.

Reanalyzing the data taking inelastic processes into account didn't reveal evidence of dark matter, Jardin said, but "each of these analyses extended the experiment's existing limits to lower masses." A previous SuperCDMS data analysis ruled out dark matter particles with masses as low as that of the proton. Taking Bremsstrahlung into account, the experiment can now rule out dark matter particle masses down to about a fifth of the proton mass—and even lower masses when the hypothetical Migdal effect is considered.

When Earth gets in the way

But the researchers didn't stop there. "We wanted to innovate beyond taking these ideas and applying it to our data," said Jardin. "So, we added other things that no one else has been doing."

Jardin and his colleagues not only extended the lowest limits of detection for dark matter interactions, but also considered the upper limit. "Researchers in the field are now realizing that if dark matter interacts strongly enough, it could interact with the atmosphere and the Earth on its way to the detector, which is deep underground. In that interaction there's actually an upper limit where you'd be blocked by the Earth itself," Jardin said.

In particular, the more strongly dark matter interacts with other types of matter on its way to the detector, the more energy it loses. At some point, a dark matter particle could lose so much energy that by the time it reaches the detector it can no longer create a detectable signal.

To calculate the energy limit for dark matter particles reaching the SuperCDMS experiment, the researchers modeled how the densities of Earth's atmosphere and inner layers might affect a dark matter particle pummeling through our planet to the detector. The team worked with geologists who determined the exact composition of the soil and rock surrounding the detector in the Soudan Mine in Minnesota.

With this information, the team could set upper limits for dark matter interaction strength depending on where the particle would be coming from, whether that's directly above the detector or the other side of the Earth.

After analyzing the SuperCDMS data with the new models established by the Bremsstrahlung and Migdal effects and the new upper limits, the team was able to expand the range of particle masses the experiment was sensitive to but found no evidence of dark matter interactions.

Nonetheless, the analysis represents one of the most sensitive search for ultralight dark matter and helped researchers gain more information from existing data.

"We put a lot into this experiment, so we want to get the most out of it that we can," Jardin said. "We really don't know the mass of dark matter, and we don't know how it interacts with matter. We're just reaching out into the darkness, as best we can."

More information: M. F. Albakry et al, Search for low-mass dark matter via bremsstrahlung radiation and the Migdal effect in SuperCDMS, *Physical Review D* (2023). DOI: 10.1103/PhysRevD.107.112013

Provided by SLAC National Accelerator Laboratory

Citation: New analysis of SuperCDMS data sets tighter detection limits for dark matter (2023, July 28) retrieved 2 May 2024 from
https://phys.org/news/2023-07-analysis-supercdms-tighter-limits-dark.html