Four readings on "Sightings of Dark Matter?"

1. "Four things you might not know about dark matter," Kathryn Jepsen, Symmetry Magazine (Dec 2013).

2. "Controversial dark matter claim faces ultimate test," Davide Castelvecchi, Nature (7 April 2016).

3. “A controversial sighting of dark matter is looking even shakier”, Emily Conover, Science Magazine, posted 5 Dec 2018, https://www.sciencenews.org/article/dark-matter-claim-dama-cosine

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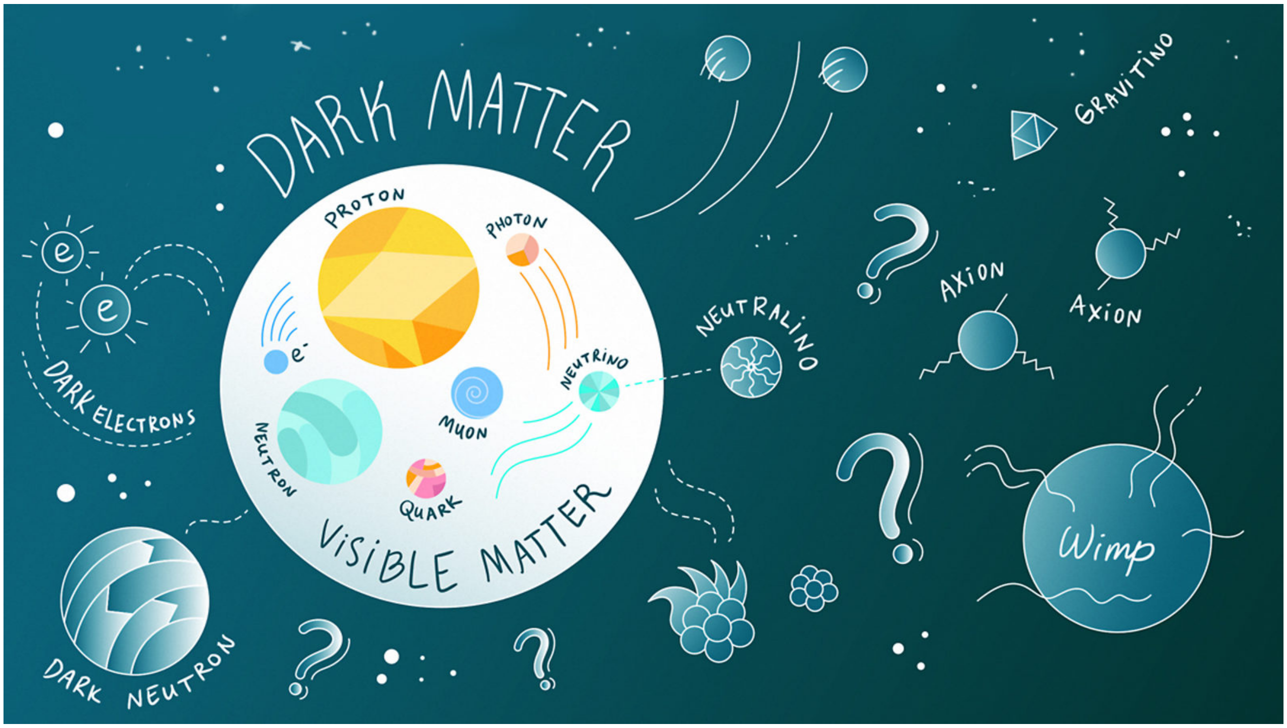


Illustration by Sandbox Studio, Chicago with Ana Kova

Four things you might not know about dark matter

12/17/13 | By Kathryn Jepsen

How much do you really know about dark matter? *Symmetry* looks at one of the biggest remaining mysteries in particle physics.

Not long after physicists on experiments at the Large Hadron Collider at CERN laboratory discovered the Higgs boson, CERN Director-General Rolf Heuer was asked, “What’s next?” One of the top priorities he named: figuring out dark matter.

Dark matter is five times more prevalent than ordinary matter. It seems to exist in clumps around the universe, forming a kind of scaffolding on which visible matter coalesces into galaxies. The nature of dark matter is unknown, but physicists have suggested that it, like visible matter, is made up of particles.

Dark matter shows up periodically in the media, often when an experiment has spotted a potential sign of it. But we are still waiting for that Nobel-Prize-triggering moment when scientists know they finally have it.

Here are four facts to get you up to speed on one of the most exciting topics in particle physics:

1. We have already discovered dark matter

(https://www.symmetrymagazine.org/sites/default/files/images/standard/Feature_DarkMatter1.jpg)
Illustration by Sandbox Studio, Chicago

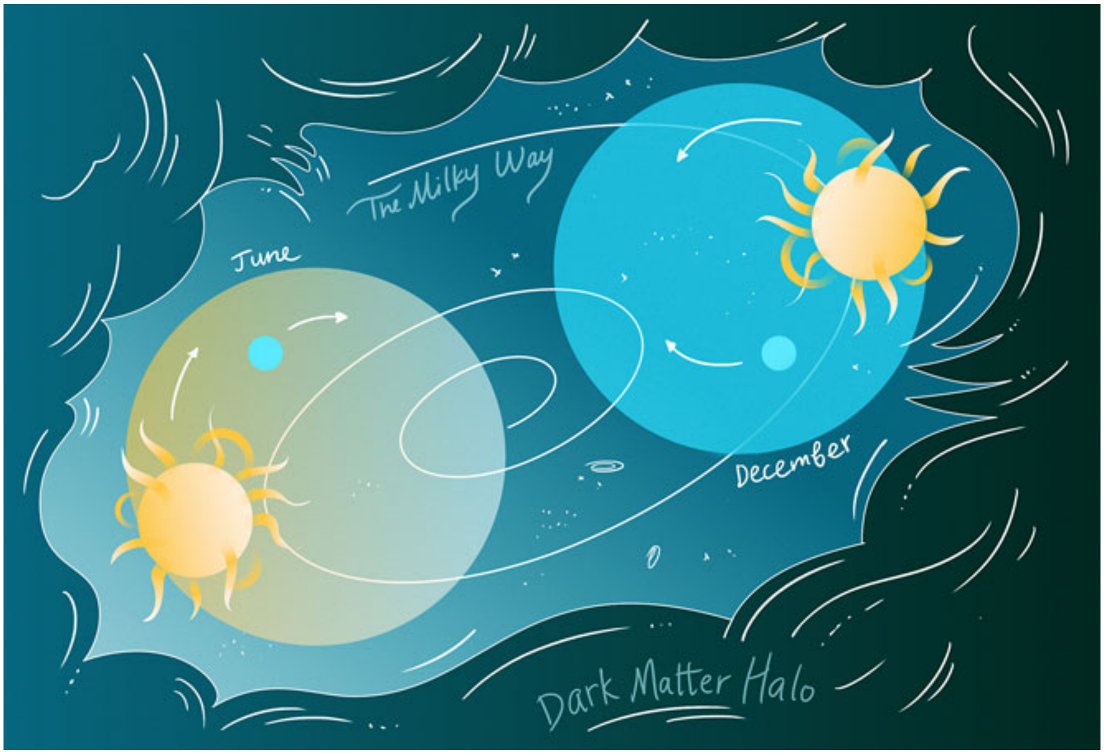
At this moment, several experiments are on the hunt for dark matter. But scientists actually discovered its existence decades ago.

In the 1930s, astrophysicist Fritz Zwicky was observing the rotations of the galaxies that form the Coma cluster, a group of more than 1000 galaxies located more than 300 million light years from Earth. He estimated the mass of these galaxies, based on the light they emitted. He was surprised to find that, if this estimate were correct, at the speed at which the galaxies were moving, they should have flown apart. In fact, the cluster needed at least 400 times the mass he had calculated to hold itself together. Something mysterious seemed to have its finger on the scale; an unseen “dark” matter seemed to be adding to the mass of the galaxies.

The idea of dark matter was largely ignored until the 1970s, when astronomer Vera Rubin saw something that gave her the same thought. She was studying the velocity of stars moving around the center of the neighboring Andromeda galaxy. She anticipated that the stars at the edge of the galaxy would move more slowly than those at its axis because the stars closest to the bright—and therefore massive—cluster of stars in the center would feel the most gravitational pull. However, she found that stars on the margins of the galaxy moved just as quickly as those in the middle. This would make sense, she thought, if the disc of visible stars were surrounded by an even larger halo made of something she couldn’t see: something like dark matter.

Other astronomical observations have since confirmed that something strange is going on with the way galaxies and light move through space. It’s possible that our confusion stems from a flaw in our understanding of gravity—Rubin herself said she favors this idea. However, if it’s true that dark matter exists, we’ve already seen its effects.

2. We have possibly already observed dark matter



(https://www.symmetrymagazine.org/sites/default/files/images/standard/Feature_DarkMatter2_0.jpg)
Illustration by Sandbox Studio, Chicago

Several experiments are searching for dark matter, and some of them may have even already found it. The problem is that no experiment has been able to make that claim with enough confidence to convince the wider scientific community—either due to statistics or an inability to rule out alternative possible explanations. And no two claims have lined up quite convincingly enough for scientists to declare any result confirmed.

In 1998 scientists on the DAMA experiment, a dark matter detector buried in Italy’s Gran Sasso mountain, saw a promising pattern in their data. The rate at which the experiment detected hits from possible dark matter particles changed over the course of the year—climbing to its peak in June and dipping to its nadir in December.

This was exactly what DAMA scientists were looking for. If our galaxy is surrounded by a dark matter halo, the Earth is constantly moving through that halo as it orbits the sun—and the sun is constantly moving through the dark matter as it orbits the center of the Milky Way. During half of the year, the Earth is moving in the same direction as the sun. During the other half, it is moving in the opposite direction. When the Earth and the sun are moving in tandem, their combined velocity through the dark matter halo is faster than the Earth's velocity when it and the sun are at odds. DAMA's results seemed to reveal that the Earth really was moving through a dark matter halo.

However, some loopholes exist; the particles the DAMA detector has been seeing could be something other than dark matter, something else the Earth and sun are constantly moving through. Or something else could be changing in the nearby environment. The DAMA experiment, now called DAMA/LIBRA, has continued to see this annual modulation, but the results are not conclusive enough for most scientists to consider it a dark-matter discovery.

It's going to be difficult for any one experiment to convince scientists that they've found dark matter. It might be that people will come around only when several experiments start to see the same thing. But that will depend on what they find, says theorist Neal Weiner, director of the Center for Cosmology and Particle Physics at New York University. Dark matter could turn out to be something stranger or more complicated than we expect.

"If dark matter turns out to be something totally garden-variety, then maybe it will only take one experiment for people to be excited about it—and two for people to be borderline convinced," he says. "But if something unexpected shows up, it might take more than that to persuade people."

In 2008 the space-based PAMELA experiment detected an excess of positrons—a possible result of dark matter particles colliding and annihilating one another. In 2013 the AMS-02 experiment, attached to the International Space Station, found the same result with even more certainty. But scientists remain unconvinced, arguing that the positrons could also come from pulsars.

Underground experiments—including CoGeNT, XENON, CRESST, CDMS and LUX—have gone back and forth supporting and disclaiming possible dark matter sightings. It seems we will need to wait until the upcoming generation of dark matter experiments is complete to get a clearer picture.

3. We don't know what dark matter is like; there could be several kinds making up a whole "dark sector"

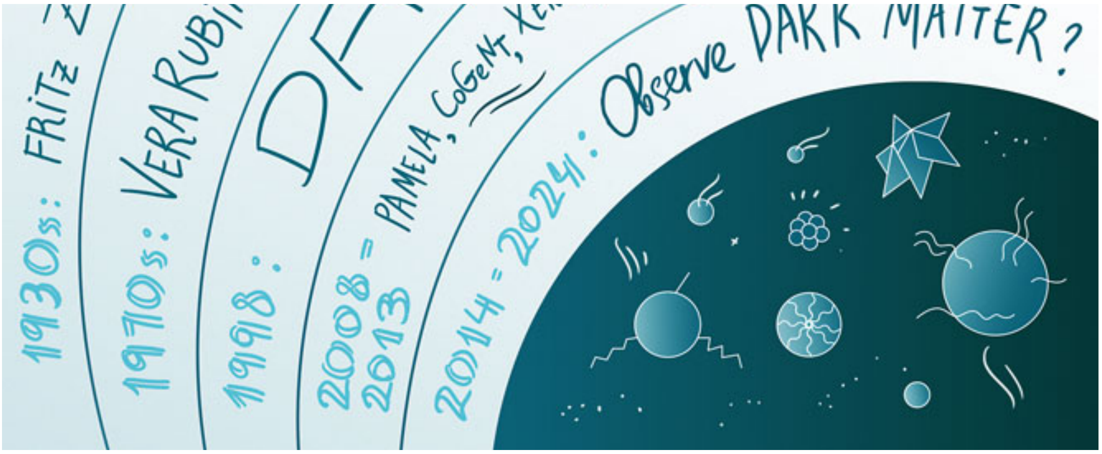
(https://www.symmetrymagazine.org/sites/default/files/images/standard/Feature_DarkMatter3.jpg)
Illustration by Sandbox Studio, Chicago

Scientists have come up with several models for what dark matter might be like. The current leading candidate is called a WIMP, a Weakly Interacting Massive Particle. Other possibilities include particles conveniently already predicted in models of supersymmetry, a theory that adds a new fundamental particle to correspond with each one we already know. Groups of scientists are also searching for dark-matter particles called axions.

But there's no reason there should be only one type of dark matter particle. Visible matter, the quarks and gluons and electrons that make up all of us and everything we can see, along with an entire zoo of fundamental particles and forces including photons, neutrinos and Higgs bosons, makes up just 5 percent of the universe. The rest is dark matter—which makes up about 23 percent—and dark energy, a whole other story—which claims the remaining 72 percent.

As Weiner puts it: Imagine a scientist in the dark-matter world trying to understand visible matter. Visible matter composes such a tiny fraction of what's out there; what dark-matter scientist would guess at its variety? The world we know is so diverse; why would dark matter be so simple? Scientists have wondered whether dark particles could combine into dark atoms that would interact through dark electromagnetism. Could dark chemistry be next? Scientists have begun to look for light dark-matter particles predicted in models of the "dark sector."

4. Chances are good that we'll observe dark matter in the next 5 to 10 years—but we may never see it at all



(https://www.symmetrymagazine.org/sites/default/files/images/standard/Feature_DarkMatter4.jpg)
Illustration by Sandbox Studio, Chicago

These are heady times for a scientist searching for dark matter. With a number of different experimental ideas scheduled to come to fruition in the coming years, many predict that dark matter will be in our grasp within a decade.

“Really one of the exciting things is all of these techniques are coming to maturity at the same time,” says theorist Tim Tait of the University of California, Irvine. “It’s a great opportunity to play them against each other and see what’s going on.”

Scientists could find dark matter in a few different ways.

First, they could detect it directly. Direct detection involves waiting patiently with a big, sensitive experiment in a quiet, underground laboratory, as free as possible from potential interference from other particles. In the next few years, scientists will narrow down their current list of detector technologies to focus their resources on building the biggest, most sensitive generation of experiments yet.

The second way to find dark matter is to observe it indirectly—by seeking out the effects of dark matter with space-based experiments. Updates from current experiments on satellites and the

International Space Station will give scientists more data to help them determine the meaning of the possible dark-matter effects they have been seeing.

The third way to find dark matter is to produce it in an accelerator such as the Large Hadron Collider. It is possible that, when two particle beams collide in the LHC, their energy will convert into mass in the form of dark matter. The LHC is currently shut down for maintenance and upgrades, but when it restarts in 2015, it will reach almost double its previous energy, opening the door for it to make particles it has never made before.

Once scientists find dark matter using one method, they'll be able to focus their efforts, Tait says. Once we know more about its properties, "that'll really energize all of this activity," he says. "Right now we're in a dark room, fumbling around. Once you know where the thing you're looking for is, you can study it a lot more carefully."

But it is also possible that dark matter is out of our reach, simply too elusive to detect or produce. If scientists don't see dark matter in the next 10 years, they might need to find a new way to look for it. Or they might need to reconsider what they know about gravity.

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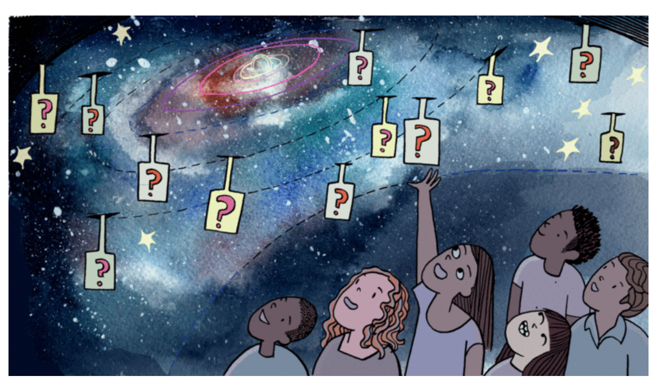

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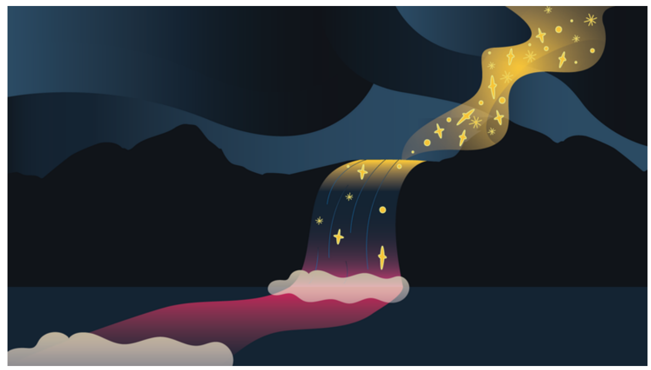

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Rivers in the sky (/article/rivers-in-the-sky)
Local communities named newly discovered stellar streams for bodies of water close to home.

science-advocacy group in Alexandria, Virginia. "We don't want that to turn around now."

Scientific issues have scarcely been mentioned on the campaign trail so far. Hillary Clinton, the Democratic front runner, has pledged to boost support for research into Alzheimer's disease, and has pushed back against Trump's anti-immigration and anti-Muslim stance. When she was a senator, Clinton backed health and research-related bills, and as first lady to former president Bill Clinton, she advocated for research on women's health.

Trump is a wealthy real-estate mogul with no political legacy to mine for clues as to his scientific opinions. In the course of the campaign, he has linked autism to childhood vaccines, and dismissed climate change. ("It's called weather," he said.) In October, conservative radio host Michael Savage suggested on air that if elected, Trump should appoint him as head of the US National Institutes of Health (NIH). "Well, you know you'd get common sense if that were the case, that I can tell you," Trump replied, during the light-hearted conversation. "Because I hear so much about the NIH, and it's terrible."

With little more than this to go on, advocates of science funding are worried. "It feels like there's a lot of cynicism toward science and scientists, and that's concerning," says Benjamin Corb, public-affairs director at the American Society for Biochemistry and Molecular Biology in Rockville, Maryland.

Trump's position on immigration is clearer. He frequently boasts that if elected, he would build a wall along the border with Mexico — and force Mexico to pay for it — which has earned him both supporters and derision. A President Trump could bode ill for long-running efforts to boost the number of foreign professionals working in the United States on visas for highly skilled workers, known as H-1Bs. But Trump's statements regarding H-1B visas have been difficult to parse. At times, he has advocated bringing skilled workers into the country; at others, he has said that the H-1B programme is too often abused and should be restricted.

"There's a lot of cynicism toward science and scientists."

Such statements worry Brad Hayes, a computer scientist at the Massachusetts Institute of Technology in Cambridge. Hayes is an US citizen, but says that some of his most outstanding colleagues are not. "A lot of them want to end up here after they get their PhDs, but now that's in doubt," he says. "We absolutely want these people to stay. If they get lumped in with this 'close our borders, keep everybody out', we're doing ourselves a disservice."

Hayes inadvertently cast a spotlight on the simplicity of Trump's rhetoric when he decided to use a neural network to model Trump's noticeably repetitive and simplistic speech patterns. He has been posting the results — computer-generated parody quotes based on Trump's campaign speeches — on Twitter using the handle @DeepDrumpf. (Trump's ancestral name, Drumpf, was changed by the family several generations ago.)

"We're going to build the wall," says one tweet, in reference to Trump's Mexico plan. Hayes says that the project was only meant to be fun, but it ended up making a point. "A lot of the rhetoric that's being used is fairly content-light."

But that rhetoric is having an effect, says Ehab Abouheif, a developmental biologist at McGill University in Montreal, Canada, who is Muslim. On a recent trip to be interviewed for a position in the United States, recruiters' "constant question was, 'Are you really sure you would want to come?'" he says. "My scientist colleagues are really scared."

To Abouheif, who fondly remembers completing his PhD and his postdoc in the United States, the current climate is surreal. "If you are trying to stop Muslims from coming in, it means that the ones who are there already are not going to feel comfortable either," he says. "It would be a shame to alienate this big swathe of society." ■

COSMOLOGY

Controversial dark-matter claim faces ultimate test

Multiple teams finally have the material they need to repeat enigmatic experiment.

BY DAVIDE CASTELVECCHI

It is the elephant in the room for dark-matter research: a claimed detection that is hard to believe, impossible to confirm and surprisingly difficult to explain away. Now, four instruments that will use the same type of detector as the collaboration behind the claim are in the works or poised to go online. Within three years, the experiments will be able to either confirm the existence of dark matter — or rule the claim out once and for all, say the physicists who work on them.

"This will get resolved," says Frank Calaprice of Princeton University in New Jersey, who leads one of the efforts.

The original claim comes from the DAMA collaboration, whose detector sits in a laboratory deep under the Gran Sasso Massif, east of Rome. For more than a decade, it has reported overwhelming evidence[1] for dark matter, an invisible substance thought to bind galaxies together through its gravitational attraction. The first of the new detectors to go online, in South Korea, is due to start taking data in a few weeks. The others will follow over the next few years in Spain, Australia and, again, Gran Sasso. All will use sodium iodide crystals to detect dark matter, which no full-scale experiment apart from DAMA's has done previously.

Scientists have substantial evidence that dark matter exists and is at least five times as abundant as ordinary matter. But its nature remains a mystery. The leading hypothesis is that at least some of its mass is composed of weakly interacting massive particles (WIMPs), which on Earth should occasionally bump into an atomic nucleus.

DAMA's sodium iodide crystals should produce a flash of light if this happens in the detector. And although natural radioactivity also produces such flashes, DAMA's claim to have detected WIMPs, first made in 1998, rests on the fact that the number of flashes produced per day has varied with the seasons.

This, they say, is exactly what is expected if the signal is produced by WIMPs that rain down on Earth as the Solar System moves through the Milky Way's dark-matter halo[2]. In this scenario, the number of particles crossing Earth should peak when the planet's orbital motion lines up with that of the Sun, in early June, and should hit a low when its motion works against the Sun's, in early December.

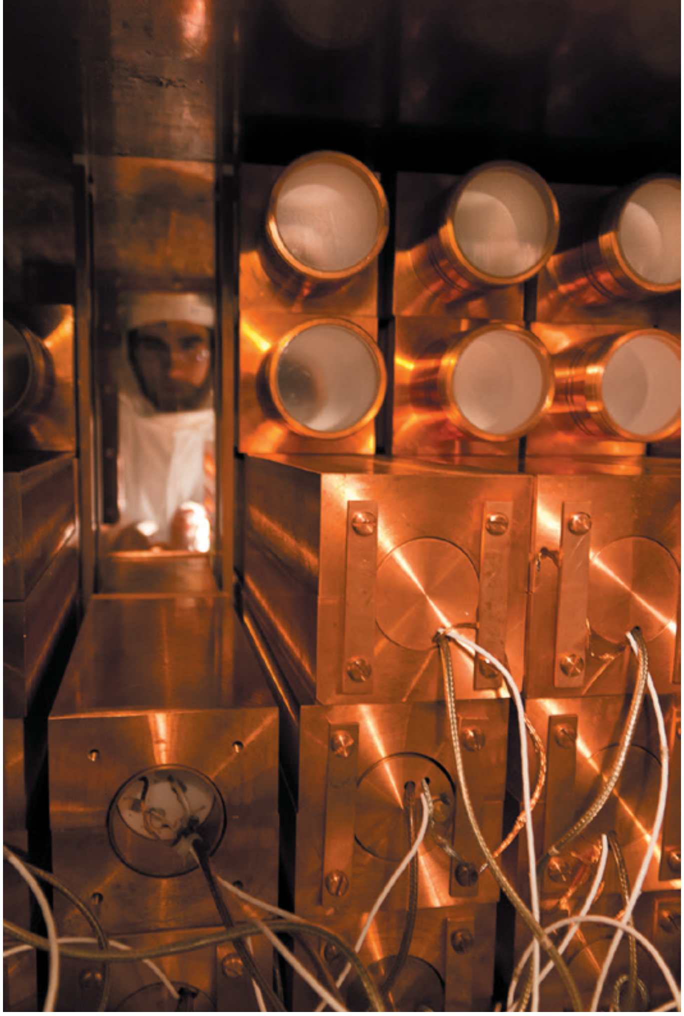
There is one big problem. "If it's really dark matter, many other experiments should have seen it already," says Thomas Schwetz-Mangold, a theoretical physicist at the Karlsruhe Institute of Technology in Germany — and none has. But at the same time, all attempts to

LNGS-INFN

find weaknesses in the DAMA experiment, such as environmental effects that the researchers had not taken into account, have failed. "The modulation signal is there," says Kaixuan Ni at the University of California, San Diego, who works on a dark-matter experiment called XENON1T. "But how to interpret that signal — whether it's from dark matter or something else — is not clear."

No other full-scale experiment has used sodium iodide in its detector, although the Korea Invisible Mass Search (KIMS), in South Korea, used caesium iodide. So the possibility remains that dark matter interacts with sodium in a different way to other elements. "Not until someone has turned on a detector made of the same material will you grow convinced that nothing is there," says Juan Collar at the University of Chicago, Illinois, who has worked on several dark-matter experiments.

Many have found it challenging to grow sodium iodide crystals with the required purity. Contamination by potassium, which has a naturally occurring radioactive isotope, is a particular problem.



The DAMA team uses sodium iodide housed in copper to hunt for dark matter.

But now three dark-matter-hunting teams — KIMS; DM-Ice, run from Yale University in New Haven, Connecticut; and ANAIS, at the University of Zaragoza, Spain — have each obtained crystals with about twice the level of background radioactivity of DAMA's. That is pure enough to test its results, they say.

The KIMS and DM-Ice teams have built a sodium iodide detector together at Yangyang Underground Laboratory, 160 kilometres east of Seoul. This instrument uses an 'active veto' sensor that will enable it to separate the dark-matter signal from the noise better than DAMA does, says Yeongduk Kim, the director of South Korea's Center for Underground Physics in Daejeon, which manages KIMS.

ANAIS is building a similar detector in the Canfranc Underground Laboratory in the Spanish Pyrenees. Together, KIMS/DM-Ice and ANAIS will have about 200 kilograms of sodium iodide, and they will pool their data. That is comparable to DAMA's 250 kilograms, enabling them to catch a similar number of WIMPs, they say. Even though the newer detectors will have higher levels of background noise, it should still be possible to either falsify or reproduce the very large DAMA signal, says Reina Maruyama of Yale, who leads DM-Ice.

But Calaprice argues that high purity is more important than mass. He and his collaborators have developed a technique to lower contamination, and in January announced that they were the first to obtain crystals purer than DAMA's. He expects to reduce the background levels further, to one-tenth of DAMA's.

The project, SABRE (Sodium-iodide with Active Background Rejection), will put one detector at Gran Sasso and the other at the Stawell Underground Physics Laboratory, which is being built in a gold mine in Victoria, Australia. SABRE will also use a sensor to pull out the dark-matter signal from noise, and will have a total mass of 50 kilograms.

SABRE should complete its research and development stage in about a year, and will build its detectors soon after that, says Calaprice. It will then make its technology available to other labs — something that DAMA did not do. And having twin detectors in both the Northern and Southern hemispheres could clarify whether environmental effects could have mimicked dark matter's seasonality in DAMA's results — if the signal is from WIMPs, then both detectors should see peaks at the same time.

DAMA will wait at least until 2017 to release its latest results, says spokesperson Rita Bernabei of the University of Rome Tor Vergata. She is not holding her breath about the upcoming sodium iodide detectors. "Our results have already been verified in countless cross-checks in 14 annual cycles, so we have no reason to get excited about what others may do," she says. If other experiments do not see the annual modulation, she adds, her collaboration will conclude that they do not yet have sufficient sensitivity.

Could the teams prove DAMA right? "I was unwilling to believe the DAMA results or even take them seriously at first," says Katherine Freese, a theoretical astroparticle physicist at the University of Michigan in Ann Arbor, who with her collaborators first proposed the seasonal modulation technique used by DAMA[2]. But, as DAMA's data have accumulated, and no other explanation for their signal has arisen, Freese is now excited by the possibility that dark matter may have been discovered after all. The fact that many have tried and failed to repeat DAMA's experiment shows that it is not easy, says Elisabetta Barberio at the University of Melbourne, who leads the Australian arm of SABRE. "The more one looks into their experiment, the more one realizes that it is very well done." ■

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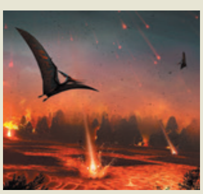

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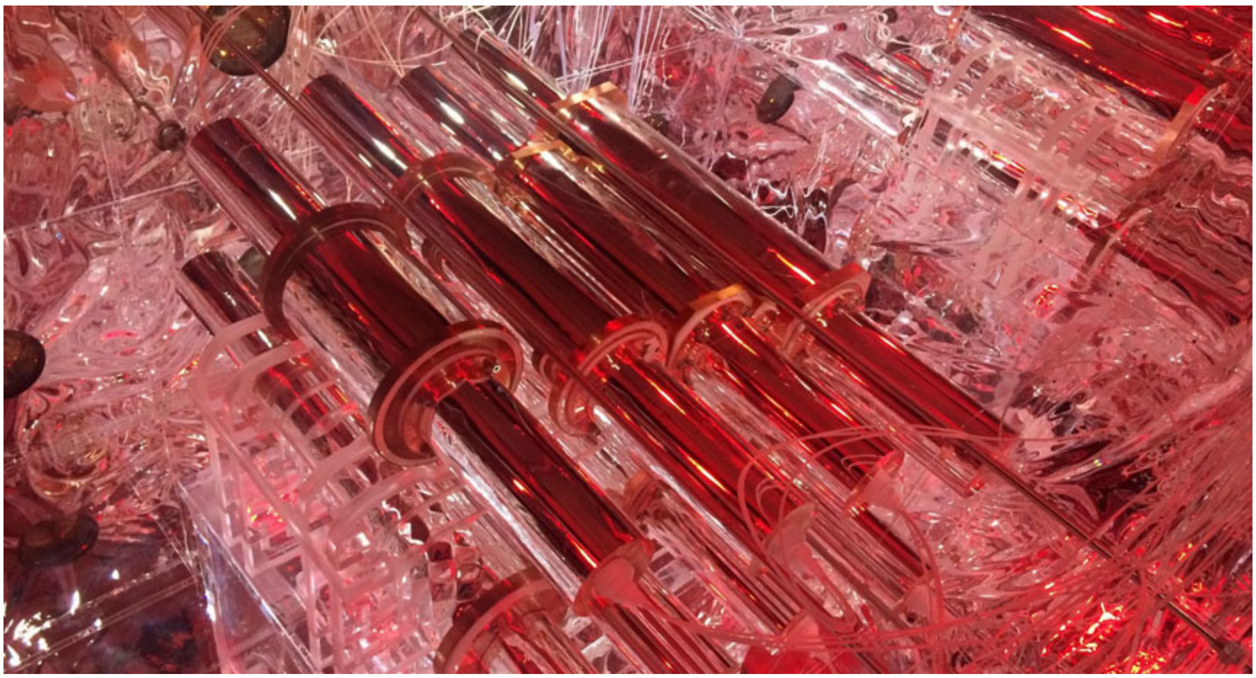
CORRECTION
In the article ‘Controversial dark-matter claim faces ultimate test’ (*Nature* **532,** 14–15; 2016), the last paragraph was amended to better reflect Katherine Freese’s views on the DAMA collaboration’s results.

A controversial sighting of dark matter is looking even shakier

The COSINE-100 experiment finds no evidence of the evasive subatomic particles

By
Emily Conover
1:00pm, December 5, 2018 SCIENCE NEWS



DAMA DRAMA The COSINE-100 dark matter detector (pictured) found no signs of the mysterious subatomic particles interacting in sodium iodide crystals, casting doubt on the earlier DAMA experiment.

For years, some physicists have rowed against the tide, controversially claiming that they've found the universe's elusive dark matter, despite mounting evidence to the contrary. A new experiment makes that upstream paddling even more of a challenge.

Observations of the cosmos indicate that an invisible, unknown type of subatomic particle must pervade the universe. The extra mass this dark matter provides is necessary to explain the motions of stars within galaxies and how matter clumps together in the universe. Despite a slew of experiments, no one has ever conclusively spotted the particles (*SN: 11/12/16, p. 14*).

The DAMA/LIBRA experiment, at Italy's Gran Sasso National Laboratory near L'Aquila, is the one outlier; researchers there say that they have strong evidence that dark matter is interacting in their detector. Now an experiment called COSINE-100 has searched for the particles using the same type of detector as DAMA, and found no signs of dark matter, scientists report online December 5 in *Nature*.

"I think this is one more nail in the coffin," says astrophysicist Dan Hooper of Fermilab in Batavia, Ill., who was not involved with the research. Earlier experiments using different types of detectors have likewise tried and failed to reproduce DAMA's results.

Both DAMA and COSINE search for dark matter particles slamming into atomic nuclei in crystals of sodium iodide. If a collision occurs, it should produce a tiny flash of light in the crystal. But mundane interactions can produce similar flashes, like those caused by minute amounts of radioactive elements.

So the DAMA team monitored their crystals for years to tease out the purported dark matter signature. The researchers reported that the rate of collisions in the DAMA detector rises and falls with a specific annual pattern. That pattern, the argument goes, is the result of Earth's motion through a stream of dark matter as the planet orbits the sun.

Some previous experiments have tested for the same type of yearly variation DAMA reports and found nothing (*SN: 2/4/17, p. 15*). The sticking point, however, was that those experiments were using a different detector material, rather than sodium iodide crystals. Now, by using the same detector material, "we're going to take out any possible loophole as to why DAMA sees something," says Yale University physicist Reina Maruyama, co-spokesperson of the COSINE-100 collaboration.

Instead of looking for annual variation, COSINE-100 researchers compared the rate of hits in their detector, located in the Yangyang Underground Laboratory in South Korea, with the number expected from known sources, such as radioactivity. The team found no sign of extra blips that could be from dark matter.

Still, DAMA researchers are sticking to their claims. Physicist Rita Bernabei of the University of Rome Tor Vergata wrote in an e-mail, "COSINE-100 has no impact on the long-standing results obtained with the DAMA setups."

Performing an experiment made with the same material as DAMA is important, says Katherine Freese of the University of Michigan in Ann Arbor. "The fact that they've got a working sodium iodide detector is huge." But, Freese says, what's really needed to check DAMA's claims is for COSINE to search for an annual change.

Maruyama agrees that COSINE's job is not finished. The annual variation search is in the works, she says.

Citations

The COSINE-100 Collaboration. An experiment to search for dark-matter interactions using sodium iodide detectors. *Nature*. Published online December 5, 2018. doi:10.1038/s41586-018-0739-1.

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