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Q&A with Nobel laureate Barry Barish (https://www.symmetrymagazine.org/article/qa-with-nobel-laureate-barry-barish?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

2 days ago

Barish explains how LIGO became the high-achieving experiment it is today.

(https://www.symmetrymagazine.org/sites/default/files/images/standard/Inline_Barish_QA_0.png)

Illustration by Ana Kova

These days the LIGO experiment seems almost unstoppable. In September 2015, LIGO detected gravitational waves (https://www.symmetrymagazine.org/article/ligo-sees-gravitational-waves) directly for the first time in history. Afterward, they spotted them three times more, definitively blowing open the doors on the new field of gravitational-wave astronomy.

On October 3, the Nobel Committee awarded their 2017 prize in physics to some of the main engines behind the experiment (https://www.symmetrymagazine.org/article/nobel-recognizes-gravitational-wave-discovery). Just two weeks after that, LIGO scientists revealed that they'd seen, for the first time, gravitational waves from the collision of neutron stars (https://www.symmetrymagazine.org/article/scientists-observe-first-verified-neutron-star-collision), an event confirmed by optical telescopes—yet another first.

These recent achievements weren't inevitable. It took LIGO scientists decades to get to this point.

LIGO leader Barry Barish, one of the three recipients of the 2017 Nobel, recently sat down with *Symmetry* writer Leah Hesla to give a behind-the-scenes look at his 22 years on the experiment.

What has been your role at LIGO?

BB:
I started in 1994 and came on board at a time when we didn't have the money. I had to get the money and have a strategy that [the National Science Foundation] would buy into, and I had to have a plan that they would keep supporting for 22 years. My main mission was to build this instrument—which we didn't know how to make—well enough to do what it did.

So we had to build enough trust and success without discovering gravitational waves so that NSF would keep supporting us. And we had to have the flexibility to evolve LIGO's design, without costing an arm and a leg, to make the improvements that would eventually make it sensitive enough to succeed.

We started running in about 2000 and took data and improved the experiment over 10 years. But we just weren't sensitive enough. We managed to get a major improvement program to what's called Advanced LIGO from the National Science Foundation. After a year and a half or so of making it work, we turned on the device in September of 2015 and, within days, we'd made the detection.

What steps did LIGO take to be as sensitive as possible?

BB:
We were limited very much by the shaking of the Earth—at the low frequencies, the Earth just shakes too much. We also couldn't get rid of the background noise at high frequencies—we can't sample fast enough.

In the initial LIGO, we reduced the shaking by something like 100 million. We had the fanciest set of shock absorbers possible. The shock absorbers in your car take a bump that you go over, which is high-frequency, and transfer it softly to low-frequency. You get just a little up and down; you don't feel very much when you go over a bump. You can't get rid of the bump—that's energy—but you can transfer it out of the frequencies where it bothers you.

So we do the same thing. We have a set of springs that are fancier but are basically like shock absorbers in your car. That gave us a factor of 100 million reduction in the shaking of the Earth.

But that wasn't good enough [for initial LIGO].

What did you do to increase sensitivity for Advanced LIGO?

BB:
After 15 years of not being able to detect gravitational waves, we implemented what we call active seismic isolation, in addition to passive springs. It's very much equivalent to what happens when you get on an airplane and you put those [noise cancellation] earphones on. All of a sudden the airplane is less noisy. That works by detecting the ambient noise—not the noise by the attendant dropping a glass or something. That's a sharp noise, and you'd still hear that, or somebody talking to you, which is a loud independent noise. But the ambient noise of the motors and the shaking of the airplane itself are more or less the same now as they were a second ago, so if you measure the frequency of the ambient noise, you can cancel it.

In Advanced LIGO, we do the same thing. We measure the shaking of the Earth, and then we cancel it with active sensors. The only difference is that our problem is much harder. We have to do this directionally. The Earth shakes in a particular direction—it might be up and down, it might be sideways or at an angle. It took us years to develop this active seismic isolation.

The idea was there 15 years ago, but we had to do a lot of work to develop very, very sensitive active seismic isolation. The technology didn't exist—we developed all that technology. It reduced the shaking of the Earth by another factor of 100 [over LIGO's initial 100 million], so we reduced it by a factor of 10 billion.

So we could see a factor of 100 further out in the universe than we could have otherwise. And each factor of 10 gets cubed because we're looking at stars and galaxies [in three dimensions]. So when we improved [initial LIGO's sensitivity] by a factor of 100 beyond this already phenomenal number of 100 million, it improved our sensitivity immediately, and our rate of seeing these kinds of events, by a factor of a hundred cubed—by a million.

That's why, after a few days of running, we saw something. We couldn't have seen this in all the years that we ran at lower sensitivity.

What key steps did you take when you came on board in 1994?

BB:
First we had to build a kind of technical group that had the experience and abilities to take on a $100 million project. So I hired a lot of people. It was a good time to do that because it was soon after the closure of the Superconducting Super Collider in Texas. I knew some of the most talented people who were involved in that, so I brought them into LIGO, including the person who would be the project manager.

Second, I made sure the infrastructure was scaled to a stage where we were doing it not the cheapest we could, but rather the most flexible.

The third thing was to convince NSF that doing this construction project wasn't the end of what we had to do in terms of development. So we put together a vigorous R&D program, which NSF supported, to develop the technology that would follow similar ones that we used.

And then there were some technical changes—to become as forward-looking as possible in terms of what we might need later.

What were the technical changes?

BB:
The first was to change from what was the most popularly used laser in the 1990s, which was a gas laser, to a solid-state laser, which was new at that time. The solid-state laser had the difficulty that the light was no longer in the visible range. It was in the infrared, and people weren't used to interferometers like that. They like to have light bouncing around that they can see, but you can't see the solid-state laser light with your naked eye. That's like particle physics. You can't see the particles in the accelerator either. We use sensors to do that. So we made that kind of change, going from analog controls to digital controls, which are computer-based.

We also inherited the kind of control programs that had been developed for accelerators and used at the Superconducting Super Collider, and we brought the SSC controls people into LIGO. These changes didn't pay off immediately, but paved the road toward making a device that could be modern and not outdated as we moved through the 20 years. It wasn't so much fixing things as making LIGO much more forward-looking—to make it more and more sensitive, which is the key thing for us.

Did you draw on past experience?

BB:
I think my history in particle physics was crucial in many ways, for example, in technical ways—things like digital controls, how we monitored beam. We don't use the same technology, but the idea that you don't have to see it physically to monitor it—those kinds of things carried over.

The organization, how we have scientific collaborations, was again something that I created here at LIGO, which was modeled after high-energy physics collaborations. Some of it has to be modified for this different kind of project—this is not an accelerator—but it has a lot of similarities because of the way you approach a large scientific project.

Were you concerned the experiment wouldn't happen? If not, what did concern you?

BB:

As long as we kept making technical progress, I didn't have that concern. My only real concern was nature. Would we be fortunate enough to see gravitational waves at the sensitivities we could get to? It wasn't predicted totally. There were optimistic predictions—that we could have detected things earlier — but there are also predictions we haven't gotten to. So my main concern was nature.

When did you hear about the first detection of gravitational waves?

BB:
If you see gravitational waves from some spectacular thing, you'd also like to be able to see something in telescopes and electromagnetic astronomy that's correlated. So because of that, LIGO has an early alarm system that alerts you that there might be a gravitational wave event. We more or less have the ability to see spectacular things early. But if you want people to turn their telescopes or other devices to point at something in the sky, you have to tell them something in time scales of minutes or hours, not weeks or months.

The day we saw this, which we saw early in its running, it happened at 4:50 in the morning in Louisiana, 2:50 in the morning in California, so I found out about it at breakfast time for me, which was about four hours later. When we alert the astronomers, we alert key people from LIGO as well. We get things like that all the time, but this looked a little more serious than others. After a few more hours that day, it became clear that this was nothing like anything we'd seen before, and in fact looked a lot like what we were looking for, and so I would say some people became convinced within hours.

I wasn't, but that's my own conservatism: What's either fooling us or how are we fooling ourselves? There were two main issues. One is the possibility that maybe somebody was inserting a rogue event in our data, some malicious way to try to fool us. We had to make sure we could trace the history of the events from the apparatus itself and make sure there was no possibility that somebody could do this. That took about a month of work. The second was that LIGO was a brand new, upgraded version, so I wasn't sure that there weren't new ways to generate things that would fool us. Although we had a lot of experience over a lot of years, it wasn't really with this version of LIGO. This version was only a few days old. So it took us another month or so to convince us that it was real. It was obvious that there was going to be a classic discovery if it held up.

What does it feel like to win the Nobel Prize?

BB:
It happened at 3 in the morning here [in California]. [The night before], I had a nice dinner with my wife, and we went to bed early. I set the alarm for 2:40. They were supposed to announce the result at 2:45. I don't know why I set it for 2:40, but I did. I moved the house phone into our bedroom.

The alarm did go off at 2:40. There was no call, obviously—I hadn't been awakened, so I assumed, kind of in my groggy state, that we must have been passed over. I started going to my laptop to see who was going to get it. Then my cell phone started ringing. My wife heard it. My cell phone number is not given out, generally. There are tens of people who have it, but how [the Nobel Foundation] got it, I'm not sure. Some colleague, I suppose. It was a surprise to me that it came on the cell phone.

The president of the Nobel Foundation told me who he was, said he had good news and told me I won. And then we chatted for a few minutes, and he asked me how I felt. And I spontaneously said that I felt "thrilled and humbled at the same time." There's no word for that, exactly, but that mixture of feeling is what I had and still have.

Do you have advice for others organizing big science projects?

BB:
We have an opportunity. As I grew into this and as science grew big, we always had to push and push and push on technology, and we've certainly done that on LIGO. We do that in particle physics, we do that in accelerators.

I think the table has turned somewhat and that the technology has grown so fast in the recent decades that there's incredible opportunities to do new science. The development of new technologies gives us so much ability to ask difficult scientific questions. We're in an era that I think is going to propagate fantastically into the future.

Just in the new millennium, maybe the three most important discoveries in physics have all been done with, I would say, high-tech, modern, large-scale devices: the neutrino experiments at SNO and Kamiokande doing the neutrino oscillations, which won a Nobel Prize in 2013; the Higgs boson—no device is more complicated or bigger or more technically advanced than the CERN LHC experiments; and then ours, which is not quite the scale of the LHC, but it's the same scale as these experiments—the billion dollar scale—and it's very high-tech.

Einstein thought that gravitational waves could never be detected, but he didn't know about lasers, digital controls and active seismic isolation and all things that we developed, all the high-tech things that are coming from industry and our pushing them a little bit harder.

The fact is, technology is changing so fast. Most of us can't live without GPS, and 10 or 15 years ago, we didn't have GPS. GPS exists because of general relativity, which is what I do. The inner silicon microstrip detectors in the CERN experiment were developed originally for particle physics. They developed rapidly. But now, they're way behind what's being done in industry in the same area. Our challenge is to learn how to grab what is being developed, because technology is becoming great.

I think we need to become really aware and understand the developments of technology and how to apply those to the most basic physics questions that we have and do it in a forward-looking way.

What are your hopes for the future of LIGO?

BB:
It's fantastic. For LIGO itself, we're not limited by anything in nature. We're limited by ourselves in terms of improving it over the next 15 years, just like we improved in going from initial LIGO to Advanced LIGO. We're not at the limit.

So we can look forward to certainly a factor of 2 to 3 improvement, which we've already been funded for and are ready for, and that will happen over the next few years. And that factor of 2 or 3 gets cubed in our case.

This represents a completely new way to look at the universe. Everything we look at was with electromagnetic radiation, and a little bit with neutrinos, until we came along. We know that only a few percent of what's out there is luminous, and so we are opening a new age of astronomy, really. At the same time, we're able to test Einstein's theories of general relativity in its most important way, which is by looking where the fields are the strongest, around black holes.

That's the opportunity that exists over a long time scale with gravitational waves. The fact that they're a totally different way of looking at the sky means that in the long term it will develop into an important part of how we understand our universe and where we came from. Gravitational waves are the best way possible, in theory—we can't do it now—of going back to the very beginning, the Big Bang, because they weren't absorbed. What we know now comes from photons, but they can go back to only 300,000 years from the Big Bang because they're absorbed.

We can go back to the beginning. We don’t know how to do it yet, but that is the potential.

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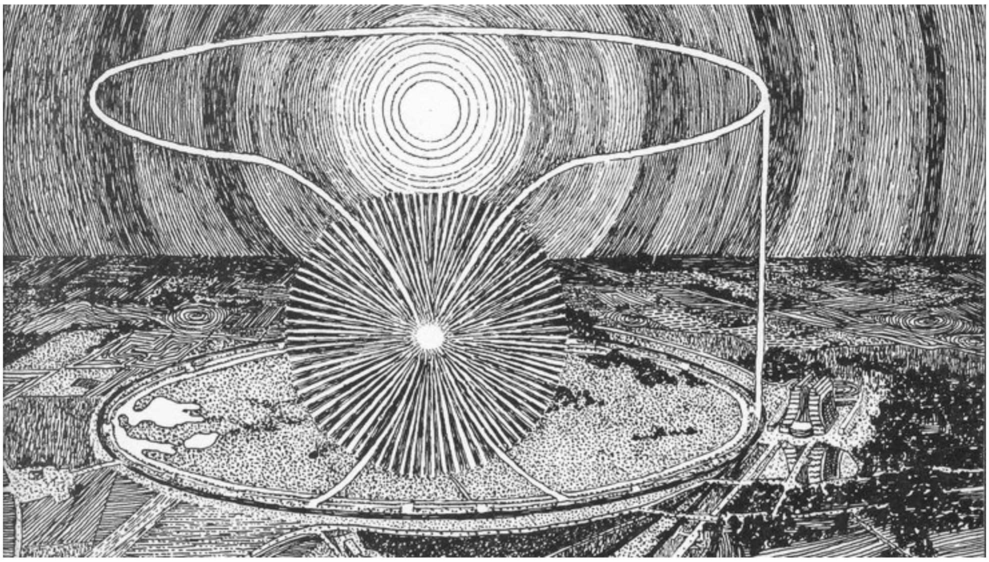
Fermilab’s 11th employee (https://www.symmetrymagazine.org/article/fermilabs-11th-employee?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

1 week ago

Fantastical designs elevate physics in works by Fermilab’s first artist.



Planning to start up a particle physics lab? Better hire an artist.

That was Robert R. Wilson’s thought in the 1960s, when he began forming what would become the Department of Energy’s Fermi National Accelerator Laboratory. He wanted a space to do physics that would inspire all who set foot on the lab. He knew, even then, the importance of mingling art and science. The 11th person hired was artist Angela Lahs Gonzales, and in her three decades at the lab, she influenced the character and aesthetic of nearly every part of the site.

Gonzales, the daughter of two artists who fled with her from Nazi Germany, had worked with Wilson previously at Cornell University. At Fermilab, she found herself responsible for a multitude of artistic choices. Working closely with Wilson, she created the lab’s logo, a union of dipole and quadrupole magnets used in accelerators to guide and focus the particle beam. She chose a bold color scheme, with vibrant blues, oranges and reds that would coat Fermilab buildings. She designed covers for scientific publications and posters for lab events and lectures.

“There was no project too small or large for Angela,” says Georgia Schwender, the curator of Fermilab’s art gallery. “She seemed to put just as much care and thought into sketches for the Annual Report as she did for a community Easter egg hunt. The whole lab was her canvas and her muse.”

A mix of themes and styles, from history to mythology and op-art to realism, are wrapped around images of accelerators, experiments and the Fermilab site. The images are often bizarre and fantastical, nearly always impressive. In one drawing, Fermilab’s bison dine at an elegant table; in another, winged creatures stare into a bubbling cauldron that contains the Fermilab accelerator complex and main building, Wilson Hall.

Gonzales typically worked in pen, sketching intricate details across paper, but she also branched out into different media, crafting jewelry, flags, vases, tables and even the elevator ceiling tiles. Her reach extended to typography, designs around doorways and drawings of things you might not expect: mundane things like emergency preparedness kits and literal nuts and bolts.

Her word on artistic choices was final. Employees were known to get a talking to if they painted something without consulting Angela. Some colors became tied to the science at hand. One time, an accelerator magnet was painted the wrong shade of blue (http://news.fnal.gov/2017/08/50th-memories-three-short-stories-fermilab-colors/) and thus installed incorrectly, causing some confusion in the control room.

“Gonzales was at the lab from 1967 to 1998, and in that time she was incredibly influential on the style of the lab,” says Valerie Higgins, Fermilab’s archivist. “But you can see how these tendrils of art spiral out to influence the science and the shape of the lab as well.”

More than 100 pieces by Gonzales were featured in a Fermilab art gallery exhibit earlier this year, as the lab celebrated its 50th anniversary. “A Lasting Mark” ran from June to September before briefly traveling and then being retired. An online catalog (http://history.fnal.gov/Gonzales_Exhibit/index.html) of the exhibit is available on the Fermilab site.

A whimsical rabbit urges families to attend the 1989 Easter egg hunt on the Fermilab site.

Fermilab

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Something borrowed (https://www.symmetrymagazine.org/article/something-borrowed?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Nov 7, 2017

SLAC engineer Knut Skarpaas designs some of physics' most challenging machines, finding inspiration in unexpected places.

At a recent meeting of the Mountain View Handweavers club, five women chatted in their rocking chairs with an unusual newcomer: Engineer Knut Skarpaas of SLAC National Accelerator Laboratory. He was an affable, inquisitive man about the age of their sons and grandsons.

He explained he was looking for advice on how to build a loom to help particle physicists catch dark matter.

This wasn't the first time Skarpaas had consulted with experts well outside high-energy physics for a project. Not by a long shot. He has found inspiration for machine designs and fabrication methods in ancient Egyptian jewelry, silversmithing, origami, spider webs and honeycombs. He is currently seeking permission to build a machine primarily from sapphire.

"The mechanical world is his playground," says colleague Michelle Dolinski of Drexel University.

An insatiable curiosity

Back at his office, Skarpaas's desk drawers rattle with the gears and tools he played with as a kid when his father, also a SLAC engineer, worked at the same desk.

"He has many of his father's gifts, but they are not identical," says Gordon Bowden, a fellow engineer at SLAC who has worked with father and son. "Curiosity has driven Knut to accumulate much diverse, direct, hands-on experience—a trait becoming more and more rare in engineering."

In his briefcase, Knut carries a magnifying glass and a miniature microscope to examine objects he finds. He has picked apart and reassembled thousands of machines since childhood, from his father's watch to sunken cameras salvaged on scuba expeditions and his grandmother's Opel Kadett automobile.

(https://www.symmetrymagazine.org/sites/default/files/images/standard/Inline_Something_borrowed_hires.jpg)
Artwork by Corinne Mucha

The details, he says, make the difference between something that works and something that doesn't. But studying things that don't work can be half the fun. "If the things are actually going to get thrown away anyway, you can take them apart more violently because you're not going to put them back together," Skarpaas says.

That might mean hitting them with a sledgehammer, or taking them back to his shop at home where he keeps his 20-ton press. "I can destroy pretty much—well, a lot of things will yield with 20 tons on them," he says.

Skarpaas says taking things apart and looking at how they break—looking at failures—is important. It shows him the weak points, and then he can make sure those weak points don't exist in his designs.

An especially interesting mechanism might earn a place in his filing cabinets among a collection of other components that prove useful when he discusses design problems with his colleagues.

"I'll just pull one out and say, 'You mean like this?' And frequently one of those things can end up being a solution," Skarpaas says.

Working within extreme constraints

"Knut can see solutions that no one else would see," says Dolinski.

She worked with Skarpaas on the construction of a neutrino experiment, the Enriched Xenon Observatory. EXO-200, a 200-kilogram container of liquid xenon, looks for an elusive type of radioactive decay that could help physicists discover fundamental truths about the neutrino, including the nature and origin of its mass.

Engineering for high-energy physics requires a healthy dose of imagination because it often requires working within extreme constraints, Dolinski says. The EXO-200 team, for instance, could not use anything that could be contaminated even slightly with radioactive material, such as most normal materials like steel and ceramics. When measuring to parts-per-quadrillion, almost all things are radioimpure.

So the team made the difficult choice to construct 1000 electrical connections with no solder, no gold plating and no wire bonds. In fact, no wire. Nothing could be bought from a commercial catalog. Every screw, connection, spring and contact was made in-house from a block of raw material. And the connections couldn't fail. Ever. "Because once you seal this thing up, it's inaccessible for, you know, a decade," Skarpaas says.

Skarpaas recalls a refrain he used to hear from his department head: "Presume you have to make this out of gossamer."

"And he means, basically, make this out of nothing," Skarpaas says. Use the fewest materials and the lightest structure—effectively weightless—to have a minimum effect on the physics.

Year after year, Dolinski says, Skarpaas has always found elegant ways to do this. For the LZ dark matter detector, that means using four 1.47-meter-diameter high-voltage grids of hair-thin wires—carefully woven on a Skarpaas-designed loom, informed by the women of the Handweavers' club.

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An international celebration of dark matter (https://www.symmetrymagazine.org/article/dark-matter-day-recap?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Nov 6, 2017

Around the world, scientists and non-scientists alike celebrated the first international Dark Matter Day.

This year, October 31 was more than just Halloween. It was also the first global celebration of Dark Matter Day. In 25 countries, 11 US states and online, people interacted with scientists, watched demonstrations, viewed films, took in art exhibits and toured laboratories to learn about the ongoing search for dark matter.

Symmetry has collected a series of photos from participants around the world. Check out how people celebrated Dark Matter Day and download a commemorative dark matter poster (/sites/default/files/images/hi-res/Dark_Matter_Day_Poster.pdf) (to be printed using visible matter).

More than 270 attendees onsite as well as on the live webcast learned from CERN experts about the experiments and theories that seek to provide us with a deeper understanding of this strange and unknown matter.

CERN

Download the poster (/sites/default/files/images/hi-res/Dark_Matter_Day_Poster.pdf)

(https://www.symmetrymagazine.org/sites/default/files/images/standard/Dark_Matter_Day_Poster.png)
Artwork by Ana Kova

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How is the Force like dark matter? (https://www.symmetrymagazine.org/article/how-is-the-force-like-dark-matter?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Oct 31, 2017

For Dark Matter Day, scientist and *Star Wars* fan Dan McKinsey talks dark matter and the Force.

Scientist Dan McKinsey of Berkeley Lab and UC Berkeley shares some thoughts on dark matter.

Ask Symmetry – How is the Force like dark matter? (/file/ask-symmetry-%E2%80%93-how-is-the-force-like-dark-matter)

McKinsey recently answered questions about dark matter on Reddit Science (https://www.reddit.com/r/science/comments/79n3hp/i_am_dan_mckinsey_and_i_am_a_dark_matter_hunter/).

Read More... (https://www.symmetrymagazine.org/article/how-is-the-force-like-dark-matter?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

CERN alumna turned deep-sea explorer (https://www.symmetrymagazine.org/article/cern-alumna-turned-deep-sea-explorer?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Oct 26, 2017

Grace C. Young is fascinated by fundamental questions about realms both quantum and undersea.

Each summer, the international research laboratory CERN, home to the Large Hadron Collider, welcomes dozens of students to work alongside seasoned scientists on cutting-edge particle physics research. Many of these students will pursue physics research in graduate school, but some find themselves applying the lessons they learned at CERN to new domains.

In 2011, MIT undergraduate Grace Young was one of these CERN summer students.

Like many young adults, Young didn't know what career path she wanted to pursue. "I tried all the majors," Young says. "Physics, engineering, architecture, math, computer science. Separately, I always loved both the ocean and building things; it wasn't until I learned about ocean engineering that I knew I had found my calling."

Today, Young is completing her PhD in ocean engineering at the University of Oxford and is chief scientist for the deep-sea submarine Pisces VI. She develops technology for ocean research and in 2014 lived underwater for 15 days. During a recent visit to CERN, Young spoke with *Symmetry* writer Sarah Charley about the journey that led her from fundamental physics back to her first love, the ocean.

As a junior in high school you competed in Intel's International Science Fair and won a trip to CERN. What was your project?

GY:
A classmate and I worked in a quantum physics lab at University of Maryland. We designed and built several devices, called particle traps, that had potential applications for quantum computing. We soldered wires onto the mirror inside a flashlight to create a bowl-shaped electric field and then applied alternating current to repeatedly flip the field, which made tiny charged particles hover in mid-air.

We were really jumping into the deep end on quantum physics; it was kind of amazing that it worked! Winning a trip to CERN was a dream come true. It was a transformative experience that had a huge impact on my career path.

You then came back to CERN as a freshman at MIT. What is it about CERN and particle physics that made you want to return?

GY:
My peek inside CERN the previous year sparked an interest that drove me to apply for the Openlab internship [a technology development collaboration between CERN scientists and members of companies or research institutes].

Although I learned a lot from my assignment, my interest and affinity for CERN derives from the community of researchers from diverse backgrounds and disciplines from all over the world. It was CERN's high-powered global community of scientists congregated in one beautiful place to solve big problems that was a magnet for me.

You say you’ve always loved the ocean. What is it about the ocean that inspires you?

GY:
I’ve loved being by the water since I was born. I find it very humbling, standing on the shore and having the waves breaking at my feet.

This huge body of water differentiates our planet from other rocks in space, yet so little is known about it. The more time I spent on or in the water, either sailing or diving, the more I began taking a deeper interest in marine life and the essential role the ocean plays in sustaining life as we know it on Earth.

What does an ocean engineer actually do?

GY:
One big reason that we’ve only explored 5 percent of the ocean is because the deep sea is so forbidding for humans. We simply don't have the biology to see or communicate underwater, much less exist for more than a few minutes just below surface.

But all this is changing with better underwater imaging, sensors and robotic technologies. As an ocean engineer, I design and build things such as robotic submersibles, which can monitor the health of fisheries in marine sanctuaries, track endangered species and create 3-D maps of underwater ice shelves. These tools, combined with data collected during field research, enable me and my colleagues to explore the ocean and monitor the human impact on its fragile ecosystems.

I also design new eco-seawalls and artificial coral reefs to protect coastlines from rising sea levels and storm surges while reviving essential marine ecosystems.

What questions are you hoping to answer during your career as an ocean engineer and researcher?

GY:
How does the ocean support so much biodiversity? More than 70 percent of our planet is covered by water, producing more than half the oxygen we breathe, storing more carbon dioxide than all terrestrial plant life and feeding billions of humans. And yet 95 percent of our ocean remains unexplored and essentially unknown.

The problem we are facing today is that we are destroying so many of the ocean’s ecosystems before we even know they exist. We can learn a lot about how to stay alive and thrive by studying the oceanic habitats, leading to unforeseeable discoveries and scientific advancements.

What are some of your big goals with this work?

GY:
We face big existential ocean-related problems, and I'd like to help develop solutions for them. Overfishing, acidification, pollution and warming temperatures are destroying the ocean’s ecosystems and affecting humans by diminishing a vital food supply, shifting weather patterns and accelerating sea-level rise. Quite simply, if we don't know or understand the problems, we can't fix them.

Have you found any unexpected overlaps between the research at CERN and the research on a submarine?

GY:
Vision isn’t a good way to see the underwater world. The ocean is pitch black in most of its volume, and the creatures don’t rely on vision. They feel currents with their skin, use sound and can read the chemicals in the water to smell food. It would make sense for humans to use sensors that do that same thing.

Physicists faced this same challenge and found other ways to characterize subatomic particles and the celestial bodies without relying on vision. Ocean sciences are moving in this same direction.

What do you think ocean researchers and particle physicists can learn from each other?

GY:
I think we already know it: That is, we can only solve big problems by working together. I'm convinced that only by working together across disciplines, ethnicities and nationalities can we survive as a species.

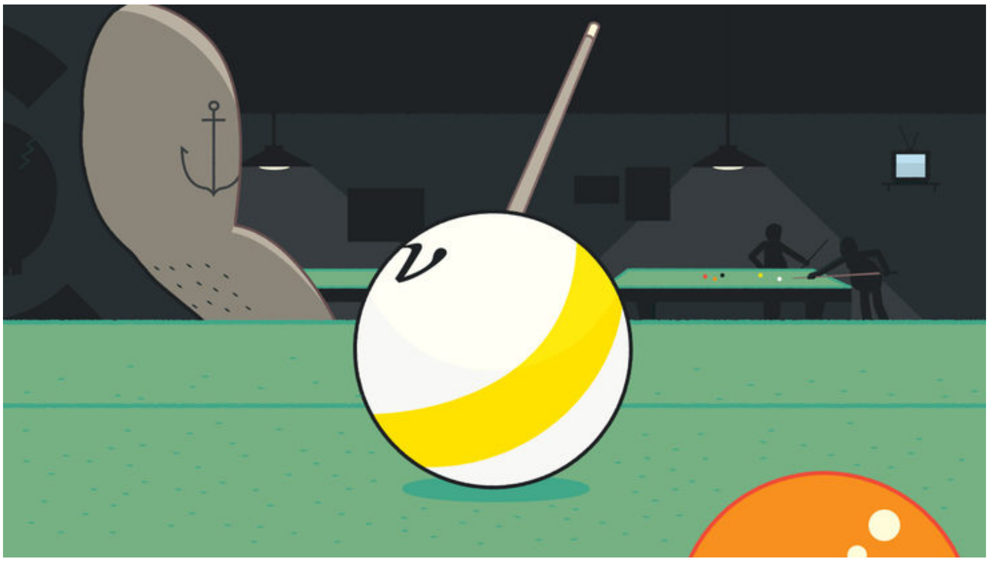
Of course, the physical sciences are integral to everything related to ocean engineering, but it's really CERN's problem-solving methodology that's most inspiring and applicable. CERN was created to solve big problems by combining the best of human learning irrespective of nationality, ethnicity or discipline. Our Pisces VI deep sea submarine team is multidisciplinary, multinational and—just like CERN—it's focused on exploring the unknown that's essential to life as we know it.

Read More... (https://www.symmetrymagazine.org/article/cern-alumna-turned-deep-sea-explorer?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Speak physics: What is a cross section? (https://www.symmetrymagazine.org/article/speak-physics-what-is-a-cross-section?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Oct 24, 2017

Cross sections tell physicists how likely particles are to interact in a given way.



Imagine two billiard balls rolling toward one another. The likelihood of a collision depends on easy-to-grasp concepts: How big are they? How precisely are they aimed?

When you start talking about the likelihood of particles colliding, things get trickier. That's why physicists use the term "cross section."

Unlike solid objects, elementary particles themselves behave as tiny waves of probability.

And their interactions are not limited to a physical bump. Particles can interact at a distance, for example, through the electromagnetic force or gravity. Some particles, such as neutrinos, interact only rarely through the weak force. You might imagine them as holograms of billiard balls that occasionally flit into a solid state.

Inline 1_ Speak physics What is a cross section_2
Elastic reaction

In physics, a cross section describes the likelihood of two particles interacting under certain conditions. Those conditions include, for example, the number of particles in the beam, the angle at which they hit the target, and what the target is made of.

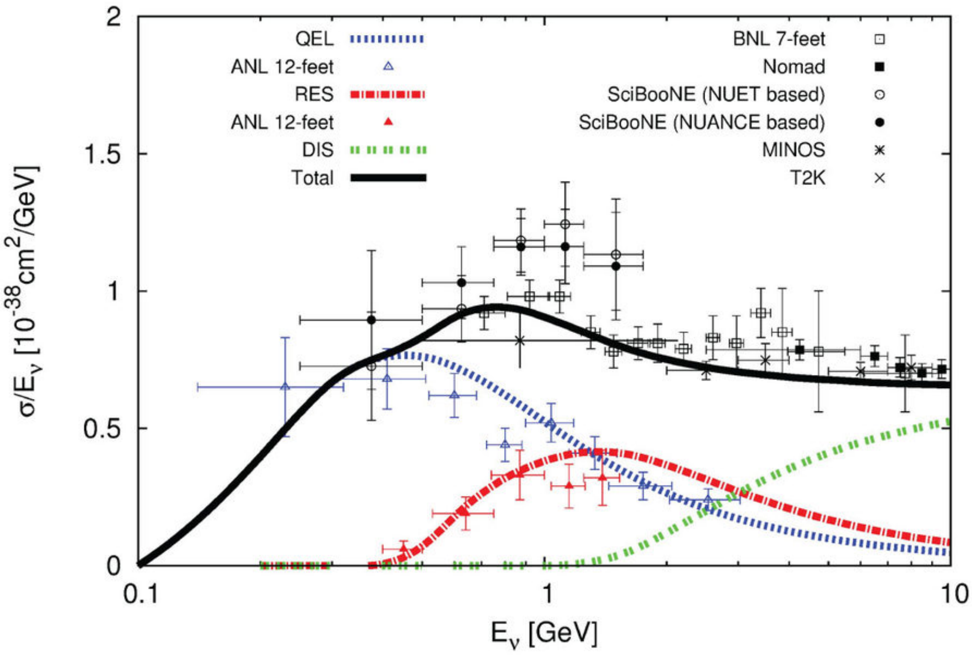
"Cross sections link theory with reality," says Gerardo Herrera, a researcher at the Center for Research and Advanced Studies of the National Polytechnic Institute in Mexico City and a collaborator on the ALICE experiment at the Large Hadron Collider. "They provide a picture of the fundamental properties of particles. That's their greatest utility."

Cross sections come in many varieties. They can help describe what happens when a particle hits a nucleus. In elastic reactions, particles bounce off one another but maintain their identities, like two ricocheting billiard balls. In inelastic reactions, one or more particle shatters apart, like a billiard ball struck by a bullet. In a resonance state, short-lived virtual particles appear.

Inline 2_ Speak physics What is a cross section_2
Inelastic reaction

These measurements of one or more aspects of the interaction are called differential cross sections, while summaries of all of these reactions put together are called total cross sections.

Physicists represent cross sections in equations with the Greek letter sigma (?). But once they have been measured in actual collisions, their data can be visualized in figures like this:



(https://www.symmetrymagazine.org/sites/default/files/images/standard/Inline%201_Speak%20physics%20What%20is%20a%20cross%20section.jpg)
Jorge G. Morf´?n , Juan Nievesb , Jan T. Sobczyka

This plot comes from a paper (https://arxiv.org/abs/1209.6586) on interactions between neutrinos and atomic nuclei. The vertical axis represents the chances of the different reactions (measured in square centimeters over giga-electronvolts), and the horizontal axis represents the energy of the incoming neutrinos (measured in giga-electronvolts). An electronvolt is a measure of energy based on the amount of energy an electron gains after being accelerated by 1 volt of electricity.

The above image is telling us, for instance, that at an energy of 10 giga-electronvolts the most probable result would be a deep inelastic scattering (green line), followed by a resonance state (red line), and lastly by a quasi-elastic event (blue line). The black curve represents the total cross section. The error bars (thin lines that go sideways and upside-down) indicate the estimated accuracy of each measurement.

“What you see in this figure are attempts to find a common way to display complex experimental results. This plot is showing how we divide up events that we find in our detectors,” says Jorge Morfín, a senior scientist at Fermilab and one of the main authors of the paper.

Cross sections are used to communicate results among researchers with common interests, Morfín says. The previous cross section serves, then, as a way to compare data obtained from labs that use different measurement techniques and nuclear targets, such as NOMAD (CERN), SciBooNE (Fermilab) and T2K (Japan).

Scientists studying astrophysics, quantum chromodynamics, physical chemistry and even nanoscience use these kinds of plots in order to understand how particles decay, absorb energy and interact with one another.

Inline 3_ Speak physics What is a cross section_2
Resonace state
“They make so many connections with different scientific fields and current research that’s going on,” says Tom Abel, a computational cosmologist at SLAC National Accelerator Laboratory and Stanford University.

In the hunt for dark matter, for example, researchers investigate whether particles interact in the way theorists predict.

“We are looking for interactions between dark matter particles and heavy nuclei, or dark matter particles interacting with one another,” Abel says. “All of this is expressed in cross-sections.”

If they see different interactions than they expect, it could be a sign of the influence of something unseen—like dark matter.

In a world where probability and uncertainty reign, Herrera notes that concepts in quantum mechanics can be difficult to grasp. “But cross sections are a very tangible element,” he says, “and one of the most important measurements in high-energy physics.”

Read More... (https://www.symmetrymagazine.org/article/speak-physics-what-is-a-cross-section?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Scientists make rare achievement in study of antimatter (https://www.symmetrymagazine.org/article/scientists-make-rare-achievement-in-study-of-antimatter?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Oct 19, 2017

Through hard work, ingenuity and a little cooperation from nature, scientists on the BASE experiment vastly improved their measurement of a property of protons and antiprotons.

Scientists at CERN are celebrating a recent, rare achievement in precision physics: Collaborators on the BASE experiment measured a property of antimatter 350 times as precisely as it had ever been measured before.

The BASE experiment looks for undiscovered differences between protons and their antimatter counterparts, antiprotons. The result (https://www.nature.com/nature/journal/v550/n7676/full/nature24048.html), published in the journal *Nature*, uncovered no such difference, but BASE scientists say they are hopeful the leap in the effectiveness of their measurement has potentially brought them closer to a discovery.

“According to our understanding of the Standard Model [of particle physics], the Big Bang should have created exactly the same amount of matter and antimatter, but [for the most part] only matter remains,” says BASE Spokesperson Stefan Ulmer. This is strange because when matter and antimatter meet, they annihilate one another. Scientists want to know how matter came to dominate our universe.

“One strategy to try to get hints to understand the mechanisms behind this matter-antimatter symmetry is to compare the fundamental properties of matter and antimatter particles with ultra-high precision,” Ulmer says.

Scientists on the BASE experiment study a property called the magnetic moment. The magnetic moment is an intrinsic value of particles such as protons and antiprotons that determines how they will orient in a magnetic field, like a compass. Protons and antiprotons should behave exactly the same, other than their charge and direction of orientation; any differences in how they respond to the laws of physics could help explain why our universe is made mostly of matter.

This is a challenging measurement to make with a proton. Measuring the magnetic moment of an antiproton is an even bigger task. To prevent antiprotons from coming into contact with matter and annihilating, scientists need to house them in special electromagnetic traps.

While antiprotons generally last less than a second, the ones used in this study were placed in a unique reservoir trap in 2015 and used one by one, as needed, for experiments. The trapped antimatter survived for more than 400 days.

During the last year, Ulmer and his team worked to improve the precision of the most sophisticated technqiues developed for this measurement in the last decade.

They did this by improving thier cooling methods. Antiprotons at temperatures close to absolute zero move less than room-temperature ones, making them easier to measure.

Previously, BASE scientists had cooled each individual antiproton before measuring it and moving on to the next. With the improved trap, the antiprotons stayed cool long enough for the scientists to swap an antiproton for a new one as soon as it became too hot.

“Developing an instrument stable enough to keep the antiproton close to absolute zero for 4-5 days was the major goal,” says Christian Smorra, the first author of the study.

This allowed them to collect data more rapidly than ever before. Combining this instrument with a new technique that measures two particles simultaneously allowed them to break their own record from last year’s measurement by a longshot.

“This is very rare in precision physics, where experimental efforts report on factors of greater than 100 magnitude in improvement,” Ulmer says.

The results confirm that the two particles behave exactly the same, as the laws of physics would predict. So the mystery of the imbalance between matter and antimatter remains.

Ulmer says that the group will continue to improve the precision of their work. He says that, in five to 10 years, they should be able to make a measurement at least twice as precise as this latest one. It could be within this range that they will be able to detect subtle differences between protons and antiprotons.

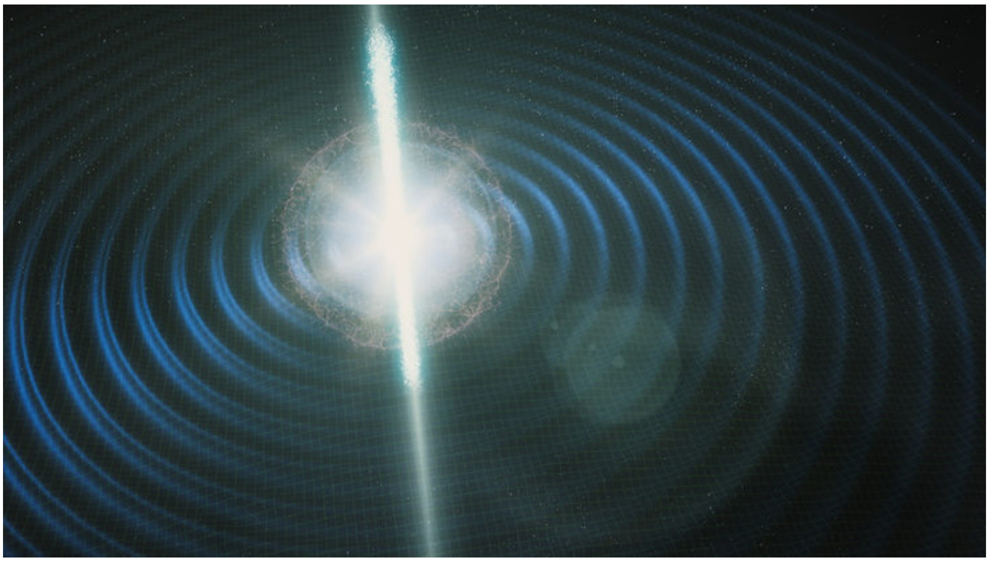
“Antimatter is a very unique probe,” Ulmer says. “It kind of watches the universe through very different glasses than any matter experiments. With antimatter research, we may be the only ones to uncover physics treasures that would help explain why we don’t have antimatter anymore.”

Read More... (https://www.symmetrymagazine.org/article/scientists-make-rare-achievement-in-study-of-antimatter?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Scientists observe first verified neutron-star collision (https://www.symmetrymagazine.org/article/scientists-observe-first-verified-neutron-star-collision?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Oct 16, 2017

For the first time, experiments have seen both light and gravitational waves released by a single celestial crash.



Today scientists announced the first verified observation of a neutron star collision. LIGO detected gravitational waves radiating from two neutron stars as they circled and merged, triggering 50 additional observational groups to jump into action and find the glimmer of this ancient explosion.

This observation represents the first time experiments have seen both light and gravitational waves from a single celestial crash, unlocking a new era of multi-messenger astronomy.

On August 17 at 7:41 a.m. Eastern Time, NASA astronomer Julie McEnery had just returned from an early morning row on the Anacostia River when her experiment, the Fermi Gamma Ray Space Telescope, sent out an automatic alert that it had just recorded a burst of gamma rays coming from the southern constellation Hydra. By itself, this wasn’t novel; the Gamma-ray Burst Monitor instrument on Fermi has seen approximately 2 gamma-ray outbursts per day since its launch in 2008.

“Forty minutes later, I got an email from a colleague at LIGO saying that our trigger has a friend and that we should buckle up,” McEnery says.

Most astronomy experiments, including the Fermi Gamma Ray Space Telescope, watch for light or other particles emanating from distant stars and galaxies. The LIGO experiment, on the other hand, listens for gravitational waves. Gravitational waves are the equivalent of cosmic tremors, but instead of rippling through layers of rock and dirt, they stretch and compress space-time itself.

Exactly 1.7 seconds before Fermi noticed the gamma ray burst, a set of extremely loud gravitational waves had shaken LIGO’s dual detectors.

“The sky positions overlapped, strongly suggesting the two signals were coming from the same astronomical event,” says Daniel Holz, a professor at the University of Chicago and member of LIGO collaboration and the Dark Energy Survey Gravitational Wave group.

LIGO reconstructed the location and distance of the event and sent an alert to their allied astronomers. About 12 hours later, right after sunset, multiple astronomical surveys found a glowing blue dot just above the horizon in the area LIGO predicted.

“It lasted for two weeks, and we observed it for about an hour every night,” says Jim Annis, a researcher at the US Department of Energy’s Fermi National Accelerator Laboratory, the lead institution on the Dark Energy Survey. “We used telescopes that could see everything from low-energy radio waves all the way to high-energy X-rays, giving us a detailed image of what happened immediately after the initial collision.”

Neutron stars are roughly the size of the island of Nantucket but have more mass than the sun. They have such a strong gravitational pull that all their matter has been squeezed and transformed into a single, giant atomic nucleus consisting entirely of neutrons.

“Right before two neutron stars collide, they circle each other about 100 times a second,” Annis says. “As they collide, huge electromagnetic tornados erupt at the poles and material is sprayed out in all directions at close to the speed of light.”

As they merge, neutron stars release a quick burst of gamma radiation and then a spray of decompressing neutron star matter. Exotic heavy elements form and decay, dumping enough energy that the surface reaches temperatures of 20,000 degrees Kelvin. That's almost four times hotter than the surface of the sun and much brighter. Scientists theorize that a good portion of the heavy elements in our universe, such as gold, originated in neutron star collisions and other massively energetic events.

Since coming online in September 2015, the US-based LIGO collaboration and their Italy-based partners, the Virgo collaboration, have reported detecting five bursts of gravitational waves. Up until now, each of these observations has come from a collision of black holes.

“When two black holes collide, they emit gravitational waves but no light,” Holz says. “But this event released an enormous amount of light and numerous astronomical surveys saw it. Hearing and seeing the event provides a goldmine of information, and we will be mining the data for years to come.”

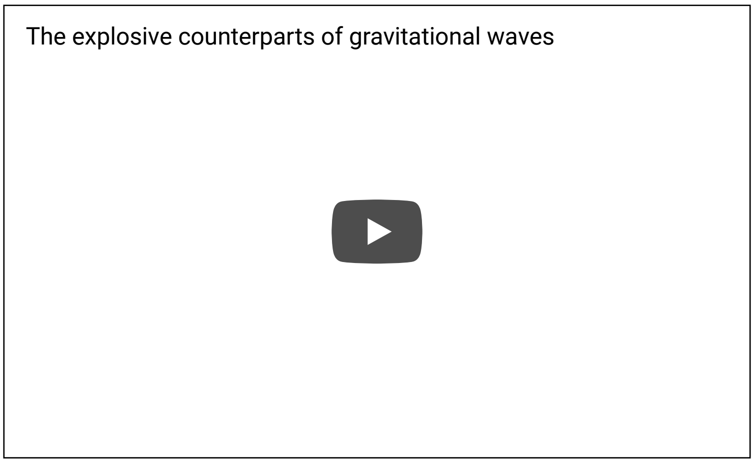
This is a Rosetta Stone-type discovery, Holz says. “We’ve learned about the processes that neutron stars are undergoing as they fling out matter and how this matter synthesizes into some of the elements we find on Earth, such as gold and platinum,” he says. “In addition to teaching us about mysterious gamma-ray bursts, we can use this event to calculate the expansion rate of the universe. We will be able to estimate the age and composition of the universe in an entirely new way.”

For McEnery, the discovery ushers in a new age of cooperation between gravitational-wave experiments and experiments like her own.

“The light and gravitational waves from this collision raced each other across the cosmos for 130 million years and hit earth 1.7 seconds apart,” she says. “This shows that both are moving at the speed of light, as predicted by Einstein. This is what we’ve been hoping to see.”

Editor's note: See LIGO scientific publications here (https://www.ligo.caltech.edu/page/detection-companion-papers).

The explosive counterparts of gravitational waves (/file/the-explosive-counterparts-of-gravitational-waves)

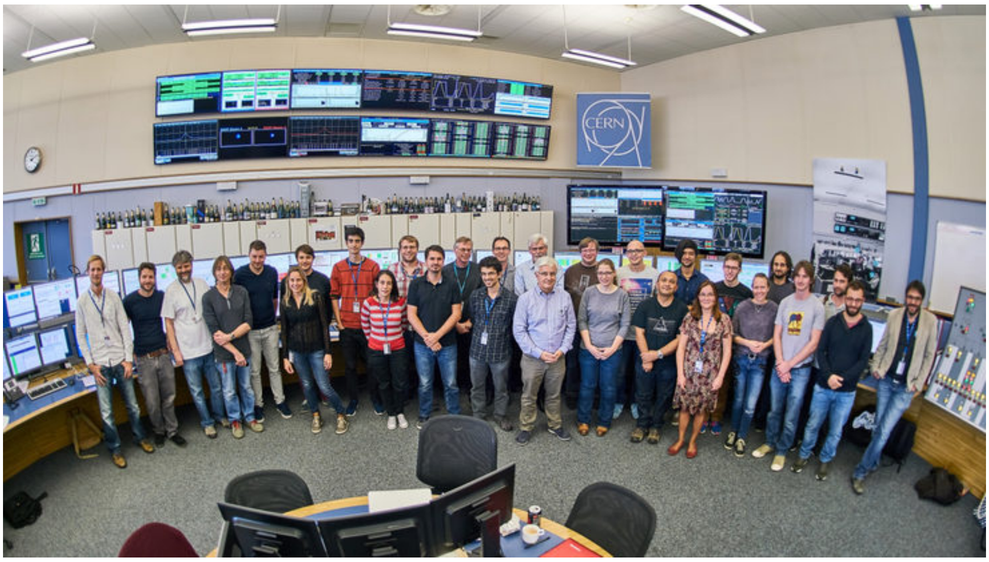


Read More... (https://www.symmetrymagazine.org/article/scientists-observe-first-verified-neutron-star-collision?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Xenon takes a turn in the LHC (https://www.symmetrymagazine.org/article/xenon-takes-a-turn-in-the-lhc?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Oct 12, 2017

For the first time, the Large Hadron Collider is accelerating xenon nuclei for experiments.



Most of the year, the Large Hadron Collider at CERN collides protons. LHC scientists have also accelerated lead nuclei stripped of their electrons. Today, for just about eight hours, they are experimenting with a different kind of nucleus: xenon.

Xenon is a heavy noble gas that exists in trace quantities in the air. Xenon nuclei are about 40 percent lighter than lead nuclei, so xenon-xenon collisions have a different geometry and energy distribution than lead-lead collisions.

“When two high-energy nuclei collide, they can momentarily form a droplet of quark gluon plasma, the primordial matter that filled our universe just after the big bang,” says Peter Steinberg, a physicist at the US Department of Energy’s Brookhaven National Laboratory and a heavy-ion coordinator for the ATLAS experiment at CERN. “The shape of the colliding nuclei influences the initial shape of this droplet, which in turn influences how the plasma flows and finally shows up in the angles of the particles we measure. We’re hoping that these smaller droplets from xenon-xenon collisions give us deeper insight into how this still-mysterious process works at truly subatomic length scales.”

Not all particles that travel through CERN’s long chain of interconnected accelerators wind up in the LHC. Earlier this year, scientists were loading xenon ions into the accelerator and firing them at a fixed-target experiment instead.

“We can have particles from two different sources feeding into CERN’s accelerator complex,” says Michaela Schaumann, a physicist in LHC operation working on the heavy-ion program. “The LHC’s injectors are so flexible that, once everything is set up properly, they can alternate between accelerating protons and accelerating ions a few times a minute.”

Having the xenon beam already available provided an opportunity to send xenon into the LHC for first (and potentially only) time. It took some serious additional work to bring the beam quality up to collider levels, Schaumann says, but today it was ready to go.

“We are keeping the intensities very low in order to fulfil machine protection requirements and be able to use the same accelerator configuration we apply during the proton-proton runs with xenon beams,” Schaumann says. “We needed to adjust the frequency of the accelerator cavities [because more massive xenon ions circulate more slowly than protons], but many of the other machine settings stayed roughly the same.”

This novel run tests scientists’ knowledge of beam physics and shows the flexibility of the LHC. Scientists say they are hopeful it could reveal something new.

“We can learn a lot about the properties of the hot, dense matter from smaller collision systems,” Steinberg says. “They are a valuable bridge to connect what we observe in lead-lead collisions to strikingly similar observations in proton-proton interactions.”

(https://www.symmetrymagazine.org/sites/default/files/images/standard/xenon_run2_0.jpg)

A crowd at CERN stays up through the night to watch the xenon-xenon collisions begin.

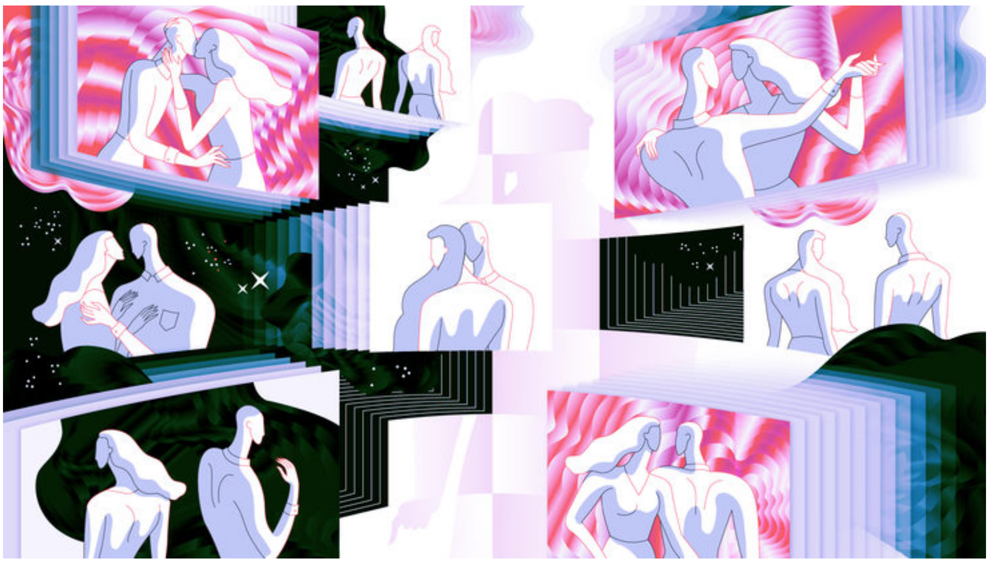
James Beacham, The Ohio State University, CERN

Read More... (https://www.symmetrymagazine.org/article/xenon-takes-a-turn-in-the-lhc?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

A play in parallel universes (https://www.symmetrymagazine.org/article/a-play-in-parallel-universes?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Oct 10, 2017

Constellations illustrates the many-worlds interpretation of quantum mechanics—with a love story.



The play *Constellations* begins with two people, Roland and Marianne, meeting for the first time. It's a short scene, and it doesn't go well. Then the lights go down, come back up, and it's as if the scene has reset itself. The characters meet for the first time, again, but with slightly different (still unfortunate) results.

The entire play progresses this way, showing multiple versions of different scenes between Roland, a beekeeper, and Marianne, an astrophysicist.

In the script, each scene is divided from the next by an indented line. As the stage notes explain: "An indented rule indicates a change in universe."

To scientist Richard Partridge, who recently served as a consultant for a production of *Constellations* at TheatreWorks Silicon Valley, it's a play about quantum mechanics.

"Quantum mechanics is about everything happening at once," he says.

We don't experience our lives this way, but atoms and particles do.

In 1927, physicists Niels Bohr and Werner Heisenberg wrote that, on the scale of atoms and smaller, the properties of physical systems remain undefined until they are measured. Light, for example, can behave as a particle or a wave. But until someone observes it to be one or the other, it exists in a state of quantum superposition: It is both a particle and a wave at the same time. When a scientist takes a measurement, the two possibilities collapse into a single truth.

Physicist Erwin Schrodinger illustrated this with a cat. He created a thought experiment in which the decay of an atom—an event ruled by quantum mechanics—would trigger toxic gas to be released in a steel chamber with a cat inside. By the rules of quantum mechanics, until someone opened the chamber, the cat existed in a state of superposition: simultaneously alive and dead.

Some interpretations of quantum mechanics dispute the idea that observing a system can determine its true state. In the many-worlds interpretation, every possibility exists in a giant collection of parallel realities. In some, the cat lives. In others, it does not.

In some *Constellations* universes, the astrophysicist and the beekeeper fall in love. In others, they do not. "So it's not really about physics," Partridge says.

Constellations director Robert Kelley, who founded TheatreWorks in 1970, agrees. He says he was intimidated by the physics concepts in the play at first but that he was eventually drawn to the relationship at its core.

"With all of these things swirling around in the play, what really counts is the relationship between two people and the love that grows between them," he says. "I found that a very charming message for Silicon Valley. We're surrounded by a whole lot of technology, but probably for most people what counts is when you get home and you're on the couch and your one-and-a-half-year-old shows up."

TheatreWorks in Silicon Valley production of *Constellations*

Cosmologist Marianne (Carie Kawa) and beekeeper Roland (Robert Gilbert) explore the ever-changing mystery of "what ifs" in the regional premiere of *Constellations* presented by TheatreWorks Silicon Valley, August 23-September 17, at the Mountain View Center for the Performing Arts.

Photo by Kevin Berne

Kelley says that he found something familiar in the many timelines of the play. "It's really kind of fun to see all that happen because it's common ground for us as human beings: You hang up the phone and think, 'If only I'd said that or hadn't said that.' It's a fascinating thought that every single thing that happens will then determine every single other thing that happens."

Constantly resetting and replaying the same scenes "was very acrobatic," says Los Angeles-based actress Carie Kawa, who played Marianne in the TheatreWorks production, which concluded in September. "And there were emotional acrobatics—just jumping into different emotional states. Usually you get a little longer arc; this play is just all middles, almost like shooting a film."

To her, the repeats and jumps were familiar in a different way: They were an encapsulation of the experience of acting.

"We do the play over and over again," she says. "It's the same scene, but it's different every single time. And if we're doing it right, we're not thinking about the scene that just happened or the scene that's to come, we're in the moment."

The play will mean different things to different people, Kawa says.

"A teacher once told me a story about theater and a perspective that he had," she says. "At first he said, 'Theater is important because everybody can come together and feel the same feeling at the same time and know that we're all okay.'

"But as he progressed in this artistry he realized that, no, what's happening is everybody is feeling a slightly different feeling at the same time. And that's OK. That's what helps us experience our humanity and the humanity of the other people around us. We're all alone in this together."

Read More... (https://www.symmetrymagazine.org/article/a-play-in-parallel-universes?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

A radio for dark matter (https://www.symmetrymagazine.org/article/a-radio-for-dark-matter?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Oct 5, 2017

Instead of searching for dark matter particles, a new device will search for dark matter waves.

Researchers are testing a prototype “radio” that could let them listen to the tune of mysterious dark matter particles.

Dark matter is an invisible substance thought to be five times more prevalent in the universe than regular matter. According to theory, billions of dark matter particles pass through the Earth each second. We don’t notice them because they interact with regular matter only very weakly, through gravity.

So far, researchers have mostly been looking for dark matter particles. But with the dark matter radio, they want to look for dark matter waves.

Direct detection experiments for dark matter particles use large underground detectors. Researchers hope to see signals from dark matter particles colliding with the detector material. However, this only works if dark matter particles are heavy enough to deposit a detectable amount energy in the collision.

“If dark matter particles were very light, we might have a better chance of detecting them as waves rather than particles,” says Peter Graham, a theoretical physicist at the Kavli Institute for Particle Astrophysics and Cosmology, a joint institute of Stanford University and the Department of Energy’s SLAC National Accelerator Laboratory. “Our device will take the search in that direction.”

The dark matter radio makes use of a bizarre concept of quantum mechanics known as wave-particle duality: Every particle can also behave like a wave.

Take, for example, the photon: the massless fundamental particle that carries the electromagnetic force. Streams of them make up electromagnetic radiation, or light, which we typically describe as waves—including radio waves.

The dark matter radio will search for dark matter waves associated with two particular dark matter candidates. It could find hidden photons—hypothetical cousins of photons with a small mass. Or it could find axions, which scientists think can be produced out of light and transform back into it in the presence of a magnetic field.

“The search for hidden photons will be completely unexplored territory,” says Saptarshi Chaudhuri, a Stanford graduate student on the project. “As for axions, the dark matter radio will close gaps in the searches of existing experiments.”

Intercepting dark matter vibes

A regular radio intercepts radio waves with an antenna and converts them into sound. What sound depends on the station. A listener chooses a station by adjusting an electric circuit, in which electricity can oscillate with a certain resonant frequency. If the circuit’s resonant frequency matches the station’s frequency, the radio is tuned in and the listener can hear the broadcast.

The dark matter radio works the same way. At its heart is an electric circuit with an adjustable resonant frequency. If the device were tuned to a frequency that matched the frequency of a dark matter particle wave, the circuit would resonate. Scientists could measure the frequency of the resonance, which would reveal the mass of the dark matter particle.

The idea is to do a frequency sweep by slowly moving through the different frequencies, as if tuning a radio from one end of the dial to the other.

The electric signal from dark matter waves is expected to be very weak. Therefore, Graham has partnered with a team led by another KIPAC researcher, Kent Irwin. Irwin’s group is developing highly sensitive magnetometers known as superconducting quantum interference devices, or SQUIDs, which they’ll pair with extremely low-noise amplifiers to hunt for potential signals.

In its final design, the dark matter radio will search for particles in a mass range of trillionths to millionths of an electronvolt. (One electronvolt is about a billionth of the mass of a proton.) This is somewhat problematic because this range includes kilohertz to gigahertz frequencies—frequencies used for over-the-air broadcasting.

“Shielding the radio from unwanted radiation is very important and also quite challenging,” Irwin says. “In fact, we would need a several-yards-thick layer of copper to do so. Fortunately we can achieve the same effect with a thin layer of superconducting metal.”

One advantage of the dark matter radio is that it does not need to be shielded from cosmic rays. Whereas direct detection searches for dark matter particles must operate deep underground to block out particles falling from space, the dark matter radio can operate in a university basement.

The researchers are now testing a small-scale prototype at Stanford that will scan a relatively narrow frequency range. They plan on eventually operating two independent, full-size instruments at Stanford and SLAC.

“This is exciting new science,” says Arran Phipps, a KIPAC postdoc on the project. “It’s great that we get to try out a new detection concept with a device that is relatively low-budget and low-risk.”

The dark matter disc jockeys are taking the first steps now and plan to conduct their dark matter searches over the next few years. Stay tuned for future results.

Layers of thermal barriers (top) are used to block heat from the laboratory and keep the radio cold. A cable inside the center rod brings signals from inside the shield to the outside world.

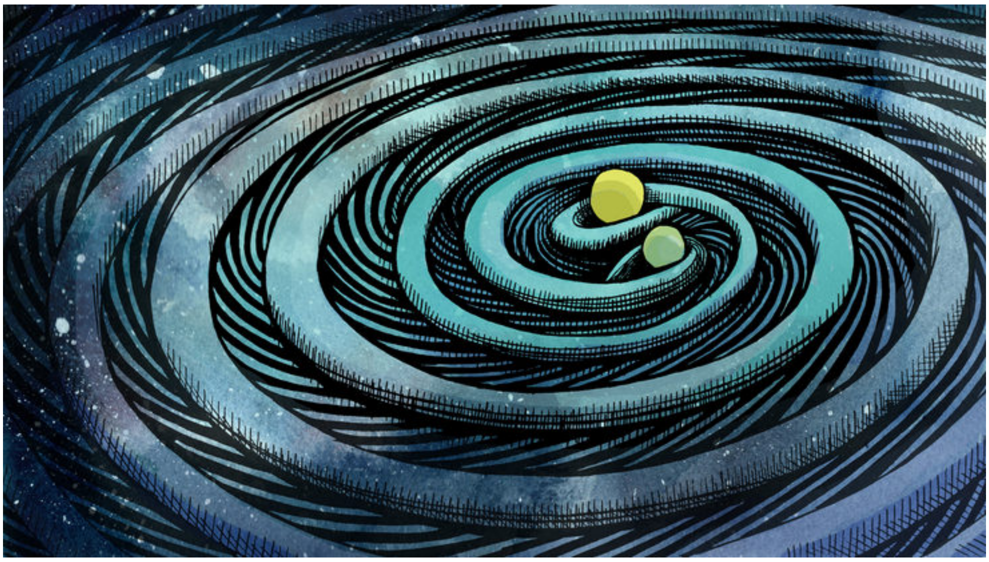
Dawn Harmer/SLAC

Read More... (https://www.symmetrymagazine.org/article/a-radio-for-dark-matter?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Nobel recognizes gravitational wave discovery (http://www.symmetrymagazine.org/article/nobel-recognizes-gravitational-wave-discovery?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Oct 3, 2017

Scientists Rainer Weiss, Kip Thorne and Barry Barish won the 2017 Nobel Prize in Physics for their roles in creating the LIGO experiment.



Three scientists who made essential contributions to the LIGO collaboration have been awarded the 2017 Nobel Prize in Physics.

Rainer Weiss will share the prize with Kip Thorne and Barry Barish for their roles in the discovery of gravitational waves, ripples in space-time predicted by Albert Einstein. Weiss and Thorne conceived of LIGO, and Barish is credited with reviving the struggling experiment and making it happen.

“I view this more as a thing that recognizes the work of about 1000 people,” Weiss said during a Q&A after the announcement this morning. “It’s really a dedicated effort that has been going on, I hate to tell you, for as long as 40 years, people trying to make a detection in the early days and then slowly but surely getting the technology together to do it.”

Another founder of LIGO, scientist Ronald Drever, died in March. Nobel Prizes are not awarded posthumously.

According to Einstein's general theory of relativity, powerful cosmic events release energy in the form of waves traveling through the fabric of existence at the speed of light. LIGO detects these disturbances when they disrupt the symmetry between the passages of identical laser beams traveling identical distances.

The setup for the LIGO experiment looks like a giant L, with each side stretching about 2.5 miles long. Scientists split a laser beam and shine the two halves down the two sides of the L. When each half of the beam reaches the end, it reflects off a mirror and heads back to the place where its journey began.

Normally, the two halves of the beam return at the same time. When there's a mismatch, scientists know something is going on. Gravitational waves compress space-time in one direction and stretch it in another, giving one half of the beam a shortcut and sending the other on a longer trip. LIGO is sensitive enough to notice a difference between the arms as small as 1000^{th} the diameter of an atomic nucleus.

Scientists on LIGO and their partner collaboration, called Virgo, reported the first detection of gravitational waves in February 2016. The waves were generated in the collision of two black holes with 29 and 36 times the mass of the sun 1.3 billion years ago. They reached the LIGO experiment as scientists were conducting an engineering test.

"It took us a long time, something like two months, to convince ourselves that we had seen something from outside that was truly a gravitational wave," Weiss said.

LIGO, which stands for Laser Interferometer Gravitational-Wave Observatory, consists of two of these pieces of equipment, one located in Louisiana and another in Washington state.

The experiment is operated jointly by Weiss's home institution, MIT, and Barish and Thorne's home institution, Caltech. The experiment has collaborators from more than 80 institutions from more than 20 countries. A third interferometer, operated by the Virgo collaboration, recently joined LIGO to make the first joint observation of gravitational waves.

Read More... (http://www.symmetrymagazine.org/article/nobel-recognizes-gravitational-wave-discovery?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Conjuring ghost trains for safety (http://www.symmetrymagazine.org/article/conjuring-ghost-trains-for-safety?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Sep 28, 2017

A Fermilab technical specialist recently invented a device that could help alert oncoming trains to large vehicles stuck on the tracks.

Browsing YouTube late at night, Fermilab Technical Specialist Derek Plant stumbled on a series of videos that all begin the same way: a large vehicle—a bus, semi or other low-clearance vehicle—is stuck on a railroad crossing. In the end, the train crashes into the stuck vehicle, destroying it and sometimes even derailing the train. According to the Federal Railroad Administration, every year hundreds of vehicles meet this fate by trains, which can take over a mile to stop.

"I was just surprised at the number of these that I found," Plant says. "For every accident that's videotaped, there are probably many more."

Inspired by a workplace safety class that preached a principle of minimizing the impact of accidents, Derek set about looking for solutions to the problem of trains hitting stuck vehicles.

Railroad tracks are elevated for proper drainage, and the humped profile of many crossings can cause a vehicle to bottom out. "Theoretically, we could lower all the crossings so that they're no longer a hump. But there are 200,000 crossings in the United States," Plant says. "Railroads and local governments are trying hard to minimize the number of these crossings by creating overpasses, or elevating roadways. That's cost-prohibitive, and it's not going to happen soon."

Other solutions, such as re-engineering the suspension on vehicles likely to get stuck, seemed equally improbable.

After studying how railroad signaling systems work, Plant came up with an idea: to fake the presence of a train. His invention was developed in his spare time using techniques and principles he learned over his almost two decades at Fermilab. It is currently in the patent application process and being prosecuted by Fermilab's Office of Technology Transfer.

"If you cross over a railroad track and you look down the tracks, you'll see red or yellow or green lights," he says. "Trains have traffic signals too."

These signals are tied to signal blocks—segments of the tracks that range from a mile to several miles in length. When a train is on the tracks, its metal wheels and axle connect both rails, forming an electric circuit through the tracks to trigger the signals. These signals inform other trains not to proceed while one train occupies a block, avoiding pileups.

Plant thought, “What if other vehicles could trigger the same signal in an emergency?” By faking the presence of a train, a vehicle stuck on the tracks could give advanced warning for oncoming trains to stop and stall for time. Hence the name of Plant’s invention: the Ghost Train Generator.

To replicate the train’s presence, Plant knew he had to create a very strong electric current between the rails. The most straightforward way to do this is with massive amounts of metal, as a train does. But for the Ghost Train Generator to be useful in a pinch, it needs to be small, portable and easily applied. The answer to achieving these features lies in strong magnets and special wire.

“Put one magnet on one rail and one magnet on the other and the device itself mimics—electrically—what a train would look like to the signaling system,” he says. “In theory, this could be carried in vehicles that are at high risk for getting stuck on a crossing: semis, tour buses and first-response vehicles,” Plant says. “Keep it just like you would a fire extinguisher—just behind the seat or in an emergency compartment.”

Once the device is deployed, the train would receive the signal that the tracks were obstructed and stop. Then the driver of the stuck vehicle could call for emergency help using the hotline posted on all crossings.

Plant compares the invention to a seatbelt.

“Is it going to save your life 100 percent of the time? Nope, but smart people wear them,” he says. “It’s designed to prevent a collision when a train is more than two minutes from the crossing.”

And like a seatbelt, part of what makes Plant’s invention so appealing is its simplicity.

“The first thing I thought was that this is a clever invention,” says Aaron Sauers from Fermilab’s technology transfer office, who works with lab staff to develop new technologies for market. “It’s an elegant solution to an existing problem. I thought, ‘This technology could have legs.’”

The organizers of the National Innovation Summit seem to agree. In May, Fermilab received an Innovation Award from TechConnect for the Ghost Train Generator. The invention will also be featured as a showcase technology in the upcoming Defense Innovation Summit in October.

The Ghost Train Generator is currently in the pipeline to receive a patent with help from Fermilab, and its prospects are promising, according to Sauers. It is a nonprovisional patent, which has specific claims and can be licensed. After that, if the generator passes muster and is granted a patent, Plant will receive a portion of the royalties that it generates for Fermilab.

Fermilab encourages a culture of scientific innovation and exploration beyond the field of particle physics, according to Sauers, who noted that Plant’s invention is just one of a number of technology transfer initiatives at the lab.

Plant agrees—Fermilab’s environment helped motivate his efforts to find a solution for railroad crossing accidents.

“It’s just a general problem-solving state of mind,” he says. “That’s the philosophy we have here at the lab.”

Editor's note: A version of this article was originally published by Fermilab (http://news.fnal.gov/2017/09/invention-help-avert-disaster-railroad-crossings/).

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Fermilab on display (http://www.symmetrymagazine.org/article/fermilab-on-display?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Sep 28, 2017

The national laboratory opened usually inaccessible areas of its campus to thousands of visitors to celebrate 50 years of discovery.

Fermi National Accelerator Laboratory’s yearlong 50th anniversary celebration culminated on Saturday with an Open House that drew thousands of visitors despite the unseasonable heat.

On display were areas of the lab not normally open to guests, including neutrino and muon experiments, a portion of the accelerator complex, lab spaces and magnet and accelerator fabrication and testing areas, to name a few. There were also live links to labs around the world, including CERN, a mountaintop observatory in Chile, and the mile-deep Sanford Underground Research Facility that will house the international neutrino experiment, DUNE.

But it wasn’t all physics. In addition to hands-on demos and a STEM fair, visitors could also learn about Fermilab’s art and history, walk the prairie trails or hang out with the ever-popular bison. In all, some 10,000 visitors got to go behind-the-scenes at Fermilab, shuttled around on 80 buses and welcomed by 900 Fermilab workers eager to explain their roles at the lab. Below, see a few of the photos captured as Fermilab celebrated 50 years of discovery.

Part of the volunteer team at the neutrino campus breaks from sharing science for an exuberant group photo.

Fermilab photo archives

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Shining with possibility (http://www.symmetrymagazine.org/article/shining-with-possibility?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Sep 26, 2017

As Jordan-based SESAME nears its first experiments, member nations are connecting in new ways.

Early in the morning, physicist Roy Beck Barkai boards a bus in Tel Aviv bound for Jordan. By 10:30 a.m., he is on site at SESAME, a new scientific facility where scientists plan to use light to study everything from biology to archaeology. He is back home by 7 p.m., in time to have dinner with his children.

Before SESAME opened, the closest facility like it was in Italy. Beck Barkai often traveled for two days by airplane, train and taxi for a day or two of work—an inefficient and expensive process that limited his ability to work with specialized equipment from his home lab and required him to spend days away from his family.

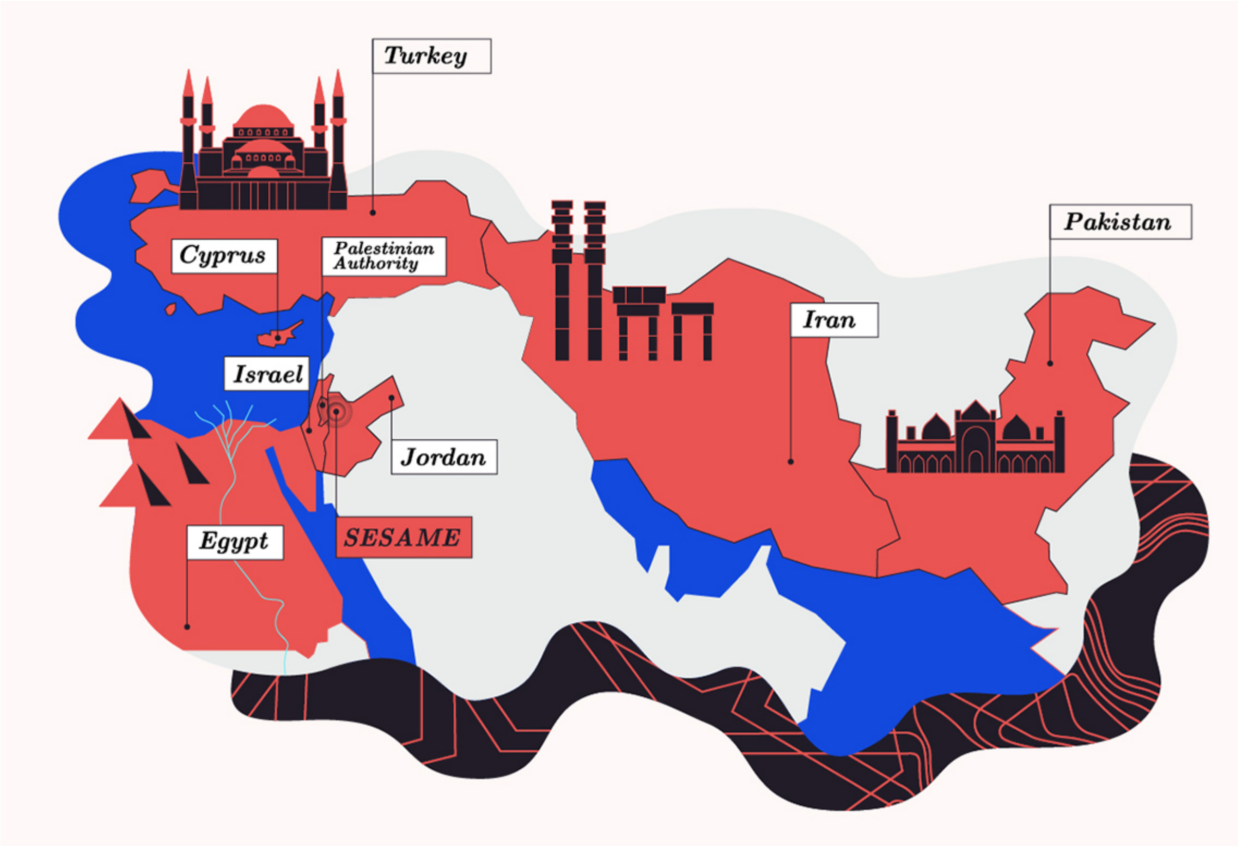
“For me, having the ability to kiss them goodbye in the morning and just before they went to sleep at night is a miracle,” Beck Barkai says. “It felt like a dream come true. Having SESAME at our doorstep is a big plus."

SESAME, also known as the International Centre for Synchrotron-Light for Experimental Science and Applications in the Middle East, opened its doors in May and is expected to host its first beams of particles this year. Scientists from around the world will be able to apply for time to use the facility’s powerful light source for their experiments. It’s the first synchrotron in the region and the first international research center in the Middle East.

Beck Barkai says SESAME provides a welcome dose of convenience, as scientists in the region can now drive to a research center instead of flying with sensitive equipment to another country. It’s also more cost-effective.

Located in Jordan to the northwest of the city of Amman, SESAME was built by a collaboration made up of the countries of Cyprus, Egypt, Iran, Israel, Jordan, Pakistan, Turkey and the Palestinian Authority—a partnership members hope will improve relations among the eight neighbors.

"SESAME is a very important step in the region," says SESAME Scientific Advisory Committee Chair Zehra Sayers. "The language of science is objective. It's based on curiosity. It doesn't need to be affected by the differences in cultural and social backgrounds in these countries. I hope it is something that we will leave the next generations as a positive step toward stability."



(http://www.symmetrymagazine.org/sites/default/files/images/standard/Inline_1_A%20new%20light.jpg)
Artwork by Ana Kova

Protein researcher and a University of Jordan professor Areej Abuhammad says she hopes SESAME will provide an environment that encourages collaboration.

"I think through having the chance to interact, the scientists from around this region will learn to trust and respect each other," she says. "I don't think that this will result in solving all the problems in the region from one day to the next, but it will be a big step forward."

The $100 million center is a state-of-the-art research facility that should provide some relief to scientists seeking time at other, overbooked facilities. SESAME plans to eventually host 100 to 200 users at a time.

SESAME's first two beamlines will open later this year. About twice per year, SESAME will announce calls for research proposals, the next of which is expected for this fall. Sayers says proposals will be evaluated for originality, preparedness and scientific quality.

Groups of researchers hoping to join the first round of experiments submitted more than 50 applications. Once the lab is at full operation, Sayers says, the selection committee expects to receive four to five times more than that.

Opening up a synchrotron in the Middle East means that more people will learn about these facilities and have a chance to use them. Because some scientists in the region are new to using synchrotrons or writing the style of applications SESAME requires, Sayers asked the selection committee to provide feedback with any rejections.

Abuhammad is excited for the learning opportunity SESAME presents for her students—and for the possibility that experiences at SESAME will spark future careers in science.

She plans to apply for beam time at SESAME to conduct protein crystallography, a field that involves peering inside proteins to learn about their function and aid in pharmaceutical drug discovery.

Another scientist vying for a spot at SESAME is Iranian chemist Maedeh Darzi, who studies the materials of ancient manuscripts and how they degrade. Synchrotrons are of great value to archaeologists because they minimize the damage to irreplaceable artifacts. Instead of cutting them apart, scientists can take a less damaging approach by probing them with particles.

Darzi sees SESAME as a chance to collaborate with scientists from other Middle Eastern countries and promote science, peace and friendship. For her and others, SESAME could be a place where particles put things back together.

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Concrete applications for accelerator science (http://www.symmetrymagazine.org/article/concrete-applications-for-accelerator-science?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Sep 21, 2017

A project called A2D2 will explore new applications for compact linear accelerators.

Particle accelerators are the engines of particle physics research at Fermi National Accelerator Laboratory. They generate nearly light-speed, subatomic particles that scientists study to get to the bottom of what makes our universe tick. Fermilab experiments rely on a number of different accelerators, including a powerful, 500-foot-long linear accelerator that kick-starts the process of sending particle beams to various destinations.

But if you're not doing physics research, what's an accelerator good for?

It turns out, quite a lot: Electron beams generated by linear accelerators have all kinds of practical uses, such as making the wires used in cars melt-resistant or purifying water.

A project called Accelerator Application Development and Demonstration (A2D2) at Fermilab's Illinois Accelerator Research Center will help Fermilab and its partners to explore new applications for compact linear accelerators, which are only a few feet long rather than a few hundred. These compact accelerators are of special interest because of their small size—they're cheaper and more practical to build in an industrial setting than particle physics research accelerators—and they can be more powerful than ever.

"A2D2 has two aspects: One is to investigate new applications of how electron beams might be used to change, modify or process different materials," says Fermilab's Tom Kroc, an A2D2 physicist. "The second is to contribute a little more to the understanding of how these processes happen."

To develop these aspects of accelerator applications, A2D2 will employ a compact linear accelerator that was once used in a hospital to treat tumors with electron beams. With a few upgrades to increase its power, the A2D2 accelerator will be ready to embark on a new venture: exploring and benchmarking other possible uses of electron beams, which will help specify the design of a new, industrial-grade, high-power machine under development by IARC and its partners.

It won't be just Fermilab scientists using the A2D2 accelerator: As part of IARC, the accelerator will be available for use (typically through a formal CRADA or SPP agreement) by anyone who has a novel idea for electron beam applications. IARC's purpose is to partner with industry to explore ways to translate basic research and tools, including accelerator research, into commercial applications.

"I already have a lot of people from industry asking me, 'When can I use A2D2?'" says Charlie Cooper, general manager of IARC. "A2D2 will allow us to directly contribute to industrial applications—it's something concrete that IARC now offers."

Speaking of concrete, one of the first applications in mind for compact linear accelerators is creating durable pavement for roads that won't crack in the cold or spread out in the heat. This could be achieved by replacing traditional asphalt with a material that could be strengthened using an accelerator. The extra strength would come from crosslinking, a process that creates bonds between layers of material, almost like applying glue between sheets of paper. A single sheet of paper tears easily, but when two or more layers are linked by glue, the paper becomes stronger.

"Using accelerators, you could have pavement that lasts longer, is tougher and has a bigger temperature range," says Bob Kephart, director of IARC. Kephart holds two patents for the process of curing cement through crosslinking. "Basically, you'd put the road down like you do right now, and you'd pass an accelerator over it, and suddenly you'd turn it into really tough stuff—like the bed liner in the back of your pickup truck."

This process has already caught the eye of the U.S. Army Corps of Engineers, which will be one of A2D2's first partners. Another partner will be the Chicago Metropolitan Water Reclamation District, which will test the utility of compact accelerators for water purification. Many other potential customers are lining up to use the A2D2 technology platform.

"You can basically drive chemical reactions with electron beams—and in many cases those can be more efficient than conventional technology, so there are a variety of applications," Kephart says. "Usually what you have to do is make a batch of something and heat it up in order for a reaction to occur. An electron beam can make a reaction happen by breaking a bond with a single electron."

In other words, instead of having to cook a material for a long time to reach a specific heat that would induce a chemical reaction, you could zap it with an electron beam to get the same effect in a fraction of the time.

In addition to exploring the new electron-beam applications with the A2D2 accelerator, scientists and engineers at IARC are using cutting-edge accelerator technology to design and build a new kind of portable, compact accelerator, one that will take applications uncovered with A2D2 out of the lab and into the field. The A2D2 accelerator is already small compared to most accelerators, but the latest R&D allows IARC experts to shrink the size while increasing the power of their proposed accelerator even further.

"The new, compact accelerator that we're developing will be high-power and high-energy for industry," Cooper says. "This will enable some things that weren't possible in the past. For something such as environmental cleanup, you could take the accelerator directly to the site."

While the IARC team develops this portable accelerator, which should be able to fit on a standard trailer, the A2D2 accelerator will continue to be a place to experiment with how to use electron beams—and study what happens when you do.

"The point of this facility is more development than research, however there will be some research on irradiated samples," says Fermilab's Mike Geelhoed, one of the A2D2 project leads. "We're all excited—at least I am. We and our partners have been anticipating this machine for some time now. We all want to see how well it can perform."

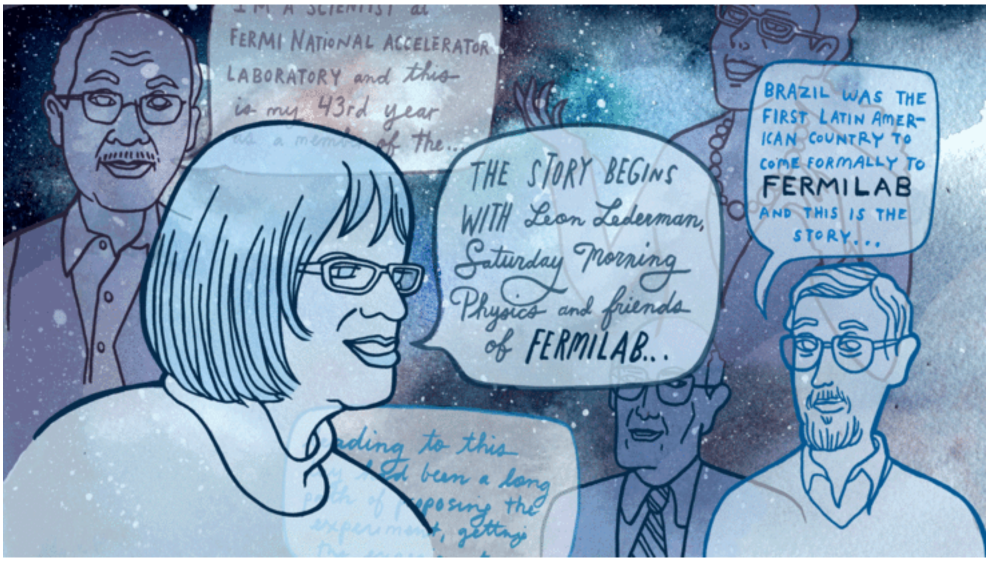
Editor's note: This article was originally published by Fermilab (http://news.fnal.gov/2017/09/concrete-applications-accelerator-science/).

Read More... (http://www.symmetrymagazine.org/article/concrete-applications-for-accelerator-science?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

50 years of stories (http://www.symmetrymagazine.org/article/50-years-of-stories?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Sep 19, 2017

To celebrate a half-century of discovery, Fermilab has been gathering tales of life at the lab.



Science stories usually catch the eye when there's big news: the discovery of gravitational waves, the appearance of a new particle. But behind the blockbusters are the thousands of smaller stories of science behind the scenes and daily life at a research institution.

As the Department of Energy's Fermi National Accelerator Laboratory celebrates its 50th anniversary year, employees past and present have shared memories of building a lab dedicated to particle physics.

Some shared personal memories: keeping an accelerator running during a massive snowstorm (https://youtu.be/3WPczm4X93A); being too impatient for the arrival of an important piece of detector equipment (https://youtu.be/NBci-sWMM1E) to stay put and wait for it to arrive; accidentally complaining about the lab to the lab's director (https://youtu.be/f0exO-IltHs).

Others focused on milestones and accomplishments: the first daycare (https://youtu.be/UC20NW3c4Zc) at a national lab, the Saturday Morning Physics Program (https://youtu.be/hBrVbYIcbkc) built by Nobel laureate Leon Lederman, the birth of the web (https://youtu.be/zSzkKl092YU) at Fermilab.

People shared memories of big names that built the lab: charismatic founding director Robert R. Wilson (http://news.fnal.gov/2017/04/working-for-wilson/), fiery head of accelerator development Helen Edwards (http://news.fnal.gov/2017/04/ball-of-fire/), talented lab artist Angela Gonzales (http://news.fnal.gov/2017/08/50th-memories-three-short-stories-fermilab-colors/).

And or course, employees told stories about Fermilab's resident herd of bison (http://news.fnal.gov/2017/08/bison-tales/).

There are many more stories to peruse. You can watch a playlist (https://www.youtube.com/playlist?list=PLCfRa7MXBEspzm_h0h3qmOD6crVWDq1G5) of the video anecdotes or find all of the stories (both written and video) collected on Fermilab's 50th anniversary website (http://50.fnal.gov/fifty-years-stories/).

Read More... (http://www.symmetrymagazine.org/article/50-years-of-stories?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

SENSEI searches for light dark matter (http://www.symmetrymagazine.org/article/sensei-searches-for-light-dark-matter?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Sep 15, 2017

Technology proposed 30 years ago to search for dark matter is finally seeing the light.

In a project called SENSEI, scientists are using innovative sensors developed over three decades to look for the lightest dark matter particles anyone has ever tried to detect.

Dark matter—so named because it doesn't absorb, reflect or emit light—constitutes 27 percent of the universe, but the jury is still out on what it's made of. The primary theoretical suspect for the main component of dark matter is a particle scientists have descriptively named the weakly interactive massive particle, or WIMP.

But since none of these heavy particles, which are expected to have a mass 100 times that of a proton, have shown up in experiments, it might be time for researchers to think small.

"There is a growing interest in looking for different kinds of dark matter that are additives to the standard WIMP model," says Fermi National Accelerator Laboratory scientist Javier Tiffenberg, a leader of the SENSEI collaboration. "Lightweight, or low-mass, dark matter is a very compelling possibility, and for the first time, the technology is there to explore these candidates."

Sensing the unseen

In traditional dark matter experiments, scientists look for a transfer of energy that would occur if dark matter particles collided with an ordinary nucleus. But SENSEI is different; it looks for direct interactions of dark matter particles colliding with electrons.

"That is a big difference—you get a lot more energy transferred in this case because an electron is so light compared to a nucleus," Tiffenberg says.

If dark matter had low mass—much smaller than the WIMP model suggests—then it would be many times lighter than an atomic nucleus. So if it were to collide with a nucleus, the resulting energy transfer would be far too small to tell us anything. It would be like throwing a ping-pong ball at a boulder: The heavy object wouldn't go anywhere, and there would be no sign the two had come into contact.

An electron is nowhere near as heavy as an atomic nucleus. In fact, a single proton has about 1836 times more mass than an electron. So the collision of a low-mass dark matter particle with an electron has a much better chance of leaving a mark—it's more bowling ball than boulder.

Bowling balls aren't exactly light, though. An energy transfer between a low-mass dark matter particle and an electron would leave only a blip of energy, one either too small for most detectors to pick up or easily overshadowed by noise in the data.

"The bowling ball will move a very tiny amount," says Fermilab scientist Juan Estrada, a SENSEI collaborator. "You need a very precise detector to see this interaction of lightweight particles with something that is much heavier."

That's where SENSEI's sensitive sensors come in.

SENSEI will use skipper charge-couple devices, also called skipper CCDs. CCDs have been used for other dark matter detection experiments, such as the Dark Matter in CCDs (or DAMIC) experiment operating at SNOLAB in Canada. These CCDs were a spinoff from sensors developed for use in the Dark Energy Camera in Chile and other dark energy search projects.

CCDs are typically made of silicon divided into pixels. When a dark matter particle passes through the CCD, it collides with the silicon's electrons, knocking them free, leaving a net electric charge in each pixel the particle passes through. The electrons then flow through adjacent pixels and are ultimately read as a current in a device that measures the number of electrons freed from each CCD pixel. That measurement tells scientists about the mass and energy of the particle that got the chain reaction going. A massive particle, like a WIMP, would free a gusher of electrons, but a low-mass particle might free only one or two.

Typical CCDs can measure the charge left behind only once, which makes it difficult to decide if a tiny energy signal from one or two electrons is real or an error.

Skipper CCDs are a new generation of the technology that helps eliminate the "iffiness" of a measurement that has a one- or two-electron margin of error. "The big step forward for the skipper CCD is that we are able to measure this charge as many times as we want," Tiffenberg says.

The charge left behind in the skipper CCD can be sampled multiple times and then averaged, a method that yields a more precise measurement of the charge deposited in each pixel than the measure-one-and-done technique. That's the rule of statistics: With more data, you get closer to a property's true value.

SENSEI scientists take advantage of the skipper CCD architecture, measuring the number of electrons in a single pixel a whopping 4000 times.

"This is a simple idea, but it took us 30 years to get it to work," Estrada says.

From idea to reality to beyond

A small SENSEI prototype is currently running at Fermilab in a detector hall 385 feet below ground, and it has demonstrated that this detector design will work in the hunt for dark matter.

Skipper CCD technology and SENSEI were brought to life by Laboratory Directed Research and Development (LDRD) funds at Fermilab and Lawrence Berkeley National Laboratory (Berkeley Lab). LDRD programs are intended to provide funding for development of novel, cutting-edge ideas for scientific discovery.

The Fermilab LDRDs were awarded only recently—less than two years ago—but close collaboration between the two laboratories has already yielded SENSEI's promising design, partially thanks to Berkeley lab's previous work in skipper CCD design.

Fermilab LDRD funds allow researchers to test the sensors and develop detectors based on the science, and the Berkeley Lab LDRD funds support the sensor design, which was originally proposed by Berkeley Lab scientist Steve Holland.

"It is the combination of the two LDRDs that really make SENSEI possible," Estrada says.

Future SENSEI research will also receive a boost thanks to a recent grant from the Heising-Simons Foundation.

"SENSEI is very cool, but what's really impressive is that the skipper CCD will allow the SENSEI science and a lot of other applications," Estrada says. "Astronomical studies are limited by the sensitivity of their experimental measurements, and having sensors without noise is the equivalent of making your telescope bigger—more sensitive."

SENSEI technology may also be critical in the hunt for a fourth type of neutrino, called the sterile neutrino, which seems to be even more shy than its three notoriously elusive neutrino family members.

A larger SENSEI detector equipped with more skipper CCDs will be deployed within the year. It's possible it might not detect anything, sending researchers back to the drawing board in the hunt for dark matter. Or SENSEI might finally make contact with dark matter—and that would be SENSEI-tional.

Editor's note: This article is based on an article (http://news.fnal.gov/2017/09/hunt-light-dark-matter/) published by Fermilab.

Read More... (http://www.symmetrymagazine.org/article/sensei-searches-for-light-dark-matter?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Clearing a path to the stars (http://www.symmetrymagazine.org/article/clearing-a-path-to-the-stars?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Sep 12, 2017

Astronomers are at the forefront of the fight against light pollution, which can obscure our view of the cosmos.

More than a mile up in the San Gabriel Mountains in Los Angeles County sits the Mount Wilson Observatory, once one of the cornerstones of groundbreaking astronomy.

Founded in 1904, it was twice home to the largest telescope on the planet, first with its 60-inch telescope in 1908, followed by its 100-inch telescope in 1917. In 1929, Edwin Hubble revolutionized our understanding of the shape of the universe when he discovered on Mt. Wilson that it was expanding.

But a problem was radiating from below. As the city of Los Angeles grew, so did the reach and brightness of its skyglow, otherwise known as light pollution. The city light overpowered the photons coming from faint, distant objects, making deep-sky cosmology all but impossible. In 1983, the Carnegies, who had owned the observatory since its inception, abandoned Mt. Wilson to build telescopes in Chile instead.

"They decided that if they were going to do greater, more detailed and groundbreaking science in astronomy, they would have to move to a dark place in the world," says Tom Meneghini, the observatory's executive director. "They took their money and ran."

(Meneghini harbors no hard feelings: "I would have made the same decision," he says.)

Beyond being a problem for astronomers, light pollution is also known to harm and kill wildlife, waste energy and cause disease in humans around the globe. For their part, astronomers have worked to convince local governments to adopt better lighting ordinances, including requiring the installation of fixtures that prevent light from seeping into the sky.

(http://www.symmetrymagazine.org/sites/default/files/images/standard/Inline_1_%20Clearing%20a%20path%20to%20the%20stars.gif)

Artwork by Corinne Mucha

Many towns and cities are already reexamining their lighting systems as the industry standard shifts from sodium lights to light-emitting diodes, or LEDs, which last longer and use far less energy, providing both cost-saving and environmental benefits. But not all LEDs are created equal. Different bulbs emit different colors, which correspond to different temperatures. The higher the temperature, the bluer the color.

The creation of energy-efficient blue LEDs was so profound that its inventors were awarded the 2014 Nobel Prize in Physics. But that blue light turns out to be particularly detrimental to astronomers, for the same reason that the daytime sky is blue: Blue light scatters more than any other color. (Blue lights have also been found to be more harmful to human health than more warmly colored, amber LEDs. In 2016, the American Medical Association issued guidance (https://www.ama-assn.org/ama-adopts-guidance-reduce-harm-high-intensity-street-lights) to minimize blue-rich light, stating that it disrupts circadian rhythms and leads to sleep problems, impaired functioning and other issues.)

The effort to darken the skies has expanded to include a focus on LEDs, as well as an attempt to get ahead of the next industry trend.

At a January workshop at the annual American Astronomical Society (AAS) meeting, astronomer John Barentine sought to share stories of towns and cities that had successfully battled light pollution. Barentine is a program manager for the International Dark-Sky Association (IDA), a nonprofit founded in 1988 to combat light pollution. He pointed to the city of Phoenix, Arizona.

Arizona is a leader in reducing light pollution. The state is home to four of the 10 IDA-recognized “Dark Sky Communities” in the United States. “You can stand in the middle of downtown Flagstaff and see the Milky Way,” says James Lowenthal, an astronomy professor at Smith College.

But it’s not immune to light pollution. Arizona’s Grand Canyon National Park is designated by the IDA as an International Dark Sky Park, and yet, on a clear night, Barentine says, the horizon is stained by the glow of Las Vegas 170 miles away.

(http://www.symmetrymagazine.org/sites/default/files/images/standard/Inline_2_%20Clearing%20a%20path%20to%20the%20stars.gif)

Artwork by Corinne Mucha

In 2015, Phoenix began testing the replacement of some of its 100,000 or so old streetlights with LEDs, which the city estimated would save $2.8 million a year in energy bills. But they were using high-temperature blue LEDs, which would have bathed the city in a harsh white light.

Through grassroots work, the local IDA chapter delayed the installation for six months, giving the council time to brush up on light pollution and hear astronomers' concerns. In the end, the city went beyond IDA's "best expectations," Barentine says, opting for lights that burn at a temperature well under IDA's maximum recommendations.

"All the way around, it was a success to have an outcome arguably influenced by this really small group of people, maybe 10 people in a city of 2 million," he says. "People at the workshop found that inspiring."

Just getting ordinances on the books does not necessarily solve the problem, though. Despite enacting similar ordinances to Phoenix, the city of Northampton, Massachusetts, does not have enough building inspectors to enforce them. "We have this great law, but developers just put their lights in the wrong way and nobody does anything about it," Lowenthal says.

For many cities, a major part of the challenge of combating light pollution is simply convincing people that it is a problem. This is particularly tricky for kids who have never seen a clear night sky bursting with bright stars and streaked by the glow of the Milky Way, says Connie Walker, a scientist at the National Optical Astronomy Observatory who is also on the board of the IDA. "It's hard to teach somebody who doesn't know what they've lost," Walker says.

Walker is focused on making light pollution an innate concern of the next generation, the way campaigns in the 1950s made littering unacceptable to a previous generation of kids.

In addition to creating interactive light-pollution kits for children, the NOAO operates a citizen-science initiative called Globe at Night (https://www.globeatnight.org/), which allows anyone to take measurements of brightness in their area and upload them to a database. To date, Globe at Night has collected more than 160,000 observations from 180 countries.

It's already produced success stories. In Norman, Oklahoma, for example, a group of high school students, with the assistance of amateur astronomers, used Globe at Night to map light pollution in their town. They took the data to the city council. Within two years, the town had passed stricter lighting ordinances.

"Light pollution is foremost on our minds because our observatories are at risk," Walker says. "We should really be concentrating on the next generation."

Read More... (http://www.symmetrymagazine.org/article/clearing-a-path-to-the-stars?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Detectors in the dirt (http://www.symmetrymagazine.org/article/detectors-in-the-dirt?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Sep 8, 2017

A humidity and temperature monitor developed for CMS finds a new home in Lebanon.

People who tend crops in Lebanon and people who tend particle detectors on the border of France and Switzerland have a need in common: large-scale humidity and temperature monitoring. A scientist who noticed this connection is working with farmers to try to use a particle physics solution to solve an agricultural problem.

Farmers, especially those in dry areas found in the Middle East, need to produce as much food as possible without using too much water. Scientists on experiments at the Large Hadron Collider want to track the health of their detectors—a sudden change in humidity or temperature can indicate a problem.

To monitor humidity and temperature in their detector, members of the CMS experiment at the LHC developed a fiber-optic system. Fiber optics are wires made from glass that can carry light. Etching small mirrors into the core of a fiber creates a "Bragg grating," a system that either lets light through or reflects it back, based on its wavelength and the distance between the mirrors.

"Temperature will naturally have an impact on the distance between the mirrors because of the contraction and dilation of the material," says Martin Gastal, a member of the CMS collaboration at the LHC. "By default, a Bragg grating sensor is a temperature sensor."

Scientists at the University of Sannio and INFN Naples developed a material for the CMS experiment that could turn the temperature sensors into humidity monitors as well. The material expands when it comes into contact with water, and the expansion pulls the mirrors apart. The sensors were tested by a team from the Experimental Physics Department at CERN.

In December 2015, Lebanon signed an International Cooperation Agreement with CERN, and the Lebanese University joined CMS. As Professor Haitham Zaraket, a theoretical physicist at the Lebanese University and member of the CMS experiment, recalls, they picked fiber optic monitoring from a list of CMS projects for one of their engineers to work on. Martin then approached them about the possibility of applying the technology elsewhere.

With Lebanon's water resources under increasing pressure from a growing population and agricultural needs, irrigation control seemed like a natural application. "Agriculture consumes quite a high amount of water, of fresh water, and this is the target of this project," says Ihab Jomaa, the Department Head of Irrigation and Agrometeorology at the Lebanese Agricultural Research Institute. "We are trying to raise what we call in agriculture lately 'water productivity.'"

The first step after formally establishing the Fiber Optic Sensor Systems for Irrigation (FOSS4I) collaboration was to make sure that the sensors could work at all in Lebanon's clay-heavy soil. The Lebanese University shipped 10 kilograms of soil from Lebanon to Naples, where collaborators at University of Sannio adjusted the sensor design to increase the measurement range.

During phase one, which lasted from March to June, 40 of the sensors were used to monitor a small field in Lebanon. It was found that, contrary to the laboratory findings, they could not in practice sense the full range of soil moisture content that they needed to. Based on this feedback, "we are working on a new concept which is not just a simple modification of the initial architecture," Haitham says. The new design concept is to use fiber optics to monitor an absorbing material planted in the soil rather than having a material wrapped around the fiber.

"We are reinventing the concept," he says. "This should take some time and hopefully at the end of it we will be able to go for field tests again." At the same time, they are incorporating parts of phase three, looking for soil parameters such as pesticide or chemicals inside the soil or other bacterial effects.

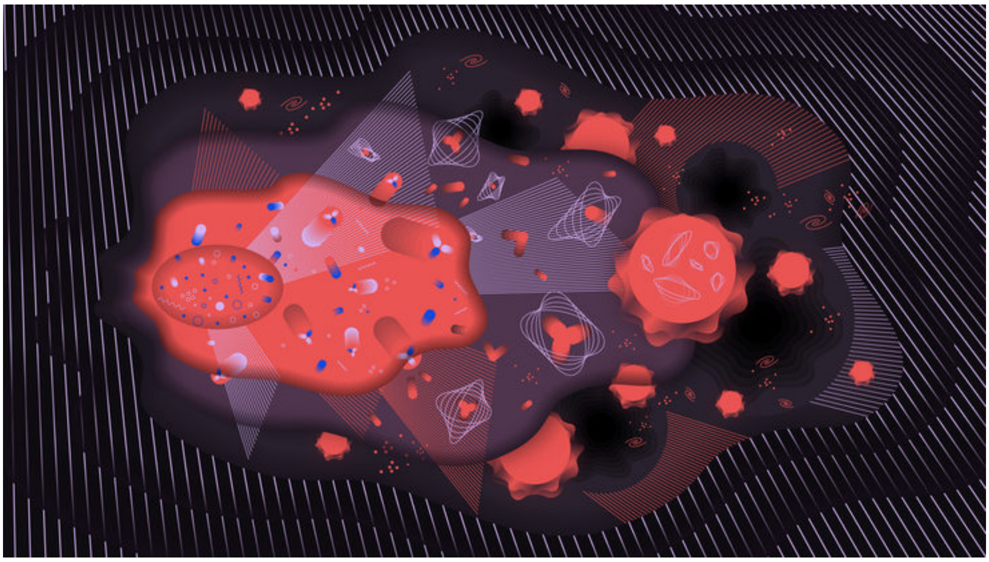
If the new concept is successfully validated, the collaboration will move on to testing more fields and more crops. Research and development always involves setbacks, but the FOSS4I collaboration has taken this one as an opportunity to pivot to a potentially even more powerful technology.

Read More... (http://www.symmetrymagazine.org/article/detectors-in-the-dirt?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

What can particles tell us about the cosmos? (http://www.symmetrymagazine.org/article/what-can-particles-tell-us-about-the-cosmos?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Sep 5, 2017

The minuscule and the immense can reveal quite a bit about each other.



In particle physics, scientists study the properties of the smallest bits of matter and how they interact. Another branch of physics—astrophysics—creates and tests theories about what's happening across our vast universe.

While particle physics and astrophysics appear to focus on opposite ends of a spectrum, scientists in the two fields actually depend on one another. Several current lines of inquiry link the very large to the very small.

The seeds of cosmic structure

For one, particle physicists and astrophysicists both ask questions about the growth of the early universe.

In her office at Stanford University, Eva Silverstein explains her work parsing the mathematical details of the fastest period of that growth, called cosmic inflation.

"To me, the subject is particularly interesting because you can understand the origin of structure in the universe," says Silverstein, a professor of physics at Stanford and the Kavli Institute for Particle Astrophysics and Cosmology. "This paradigm known as inflation accounts for the origin of structure in the most simple and beautiful way a physicist can imagine."

Scientists think that after the Big Bang, the universe cooled, and particles began to combine into hydrogen atoms. This process released previously trapped photons—elementary particles of light.

The glow from that light, called the cosmic microwave background, lingers in the sky today. Scientists measure different characteristics of the cosmic microwave background to learn more about what happened in those first moments after the Big Bang.

According to scientists' models, a pattern that first formed on the subatomic level eventually became the underpinning of the structure of the entire universe. Places that were dense with subatomic particles—or even just virtual fluctuations of subatomic particles—attracted more and more matter. As the universe grew, these areas of density became the locations where galaxies and galaxy clusters formed. The very small grew up to be the very large.

Scientists studying the cosmic microwave background hope to learn about more than just how the universe grew—it could also offer insight into dark matter, dark energy and the mass of the neutrino (http://www.symmetrymagazine.org/article/how-heavy-is-a-neutrino).

“It’s amazing that we can probe what was going on almost 14 billion years ago,” Silverstein says. “We can’t learn everything that was going on, but we can still learn an incredible amount about the contents and interactions.”

For many scientists, “the urge to trace the history of the universe back to its beginnings is irresistible,” wrote theoretical physicist Stephen Weinberg in his 1977 book *The First Three Minutes*. The Nobel laureate added, “From the start of modern science in the sixteenth and seventeenth centuries, physicists and astronomers have returned again and again to the problem of the origin of the universe.”

Searching in the dark

Particle physicists and astrophysicists both think about dark matter and dark energy. Astrophysicists want to know what made up the early universe and what makes up our universe today. Particle physicists want to know whether there are undiscovered particles and forces out there for the finding.

“Dark matter makes up most of the matter in the universe, yet no known particles in the Standard Model [of particle physics] have the properties that it should possess,” says Michael Peskin, a professor of theoretical physics at SLAC. “Dark matter should be very weakly interacting, heavy or slow-moving, and stable over the lifetime of the universe.”

There is strong evidence for dark matter through its gravitational effects on ordinary matter in galaxies and clusters. These observations indicate that the universe is made up of roughly 5 percent normal matter, 25 percent dark matter and 70 percent dark energy. But to date, scientists have not directly observed dark energy or dark matter.

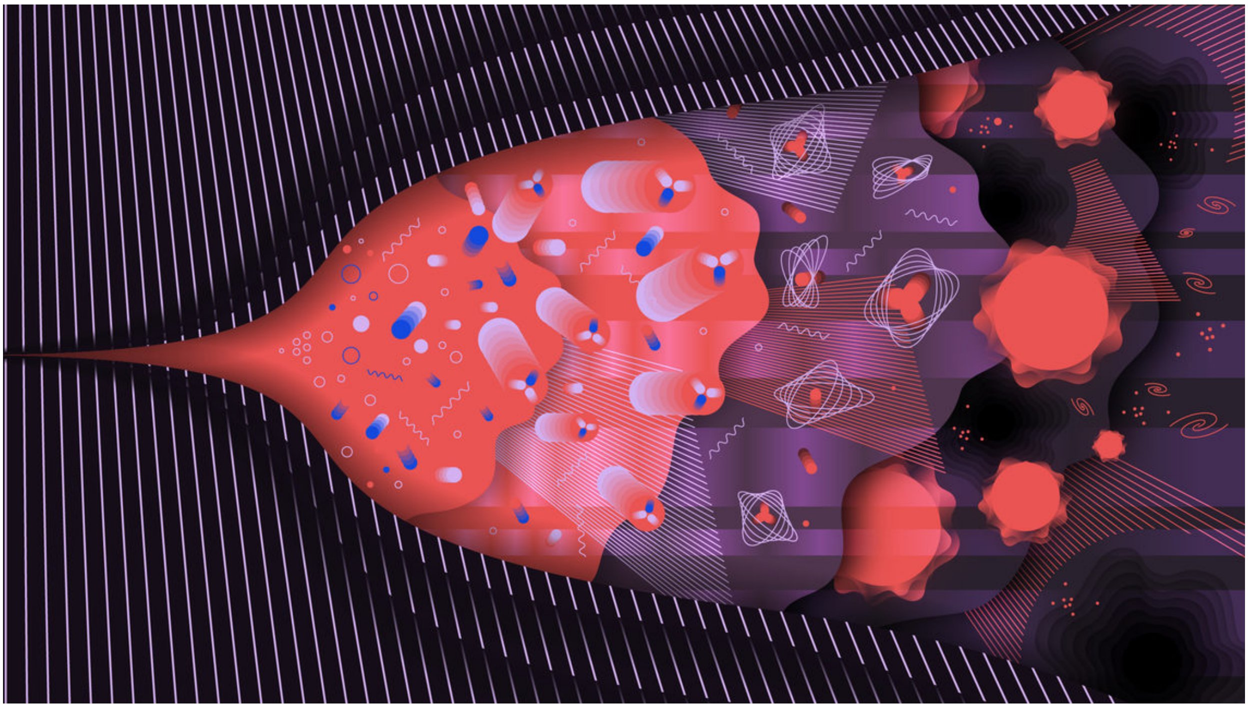
“This is really the biggest embarrassment for particle physics,” Peskin says. “However much atomic matter we see in the universe, there’s five times more dark matter, and we have no idea what it is.”

But scientists have powerful tools to try to understand some of these unknowns. Over the past several years, the number of models of dark matter has been expanding, along with the number of ways to detect it, says Tom Rizzo, a senior scientist at SLAC and head of the theory group.

Some experiments search for direct evidence of a dark matter particle colliding with a matter particle in a detector. Others look for indirect evidence of dark matter particles interfering in other processes or hiding in the cosmic microwave background. If dark matter has the right properties, scientists could potentially create it in a particle accelerator such as the Large Hadron Collider.

Physicists are also actively hunting for signs of dark energy. It is possible to measure the properties of dark energy by observing the motion of clusters of galaxies at the largest distances that we can see in the universe.

“Every time that we learn a new technique to observe the universe, we typically get lots of surprises,” says Marcelle Soares-Santos, a Brandeis University professor and a researcher on the Dark Energy Survey. “And we can capitalize on these new ways of observing the universe to learn more about cosmology and other sides of physics.”



(http://www.symmetrymagazine.org/sites/default/files/images/standard/Inline_Particle_astro.jpg)
Artwork by Ana Kova

Forces at play

Particle physicists and astrophysicists find their interests also align in the study of gravity. For particle physicists, gravity is the one basic force of nature that the Standard Model does not quite explain. Astrophysicists want to understand the important role gravity played and continues to play in the formation of the universe.

In the Standard Model, each force has what’s called a force-carrier particle or a boson. Electromagnetism has photons. The strong force has gluons. The weak force has W and Z bosons. When particles interact through a force, they exchange these force-carriers, transferring small amounts of information called quanta, which scientists describe through quantum mechanics.

General relativity explains how the gravitational force works on large scales: Earth pulls on our own bodies, and planetary objects pull on each other. But it is not understood how gravity is transmitted by quantum particles.

Discovering a subatomic force-carrier particle for gravity would help explain how gravity works on small scales and inform a quantum theory of gravity (https://www6.slac.stanford.edu/news/2015-11-18-qa-slac-theorist-lance-dixon-explains-quantum-gravity.aspx) that would connect general relativity and quantum mechanics.

Compared to the other fundamental forces, gravity interacts with matter very weakly, but the strength of the interaction quickly becomes larger with higher energies. Theorists predict that at high enough energies, such as those seen in the early universe, quantum gravity effects are as strong as the other forces. Gravity played an essential role in transferring the small-scale pattern of the cosmic microwave background into the large-scale pattern of our universe today.

“Another way that these effects can become important for gravity is if there’s some process that lasts a long time,” Silverstein says. “Even if the energies aren’t as high as they would need to be to be sensitive to effects like quantum gravity instantaneously.”

Physicists are modeling gravity over lengthy time scales in an effort to reveal these effects.

Our understanding of gravity is also key in the search for dark matter. Some scientists think that dark matter does not actually exist; they say the evidence we’ve found so far is actually just a sign that we don’t fully understand the force of gravity.

Big ideas, tiny details

Learning more about gravity could tell us about the dark universe, which could also reveal new insight into how structure in the universe first formed.

Scientists are trying to “close the loop” between particle physics and the early universe, Peskin says. As scientists probe space and go back further in time, they can learn more about the rules that govern physics at high energies, which also tells us something about the smallest components of our world.

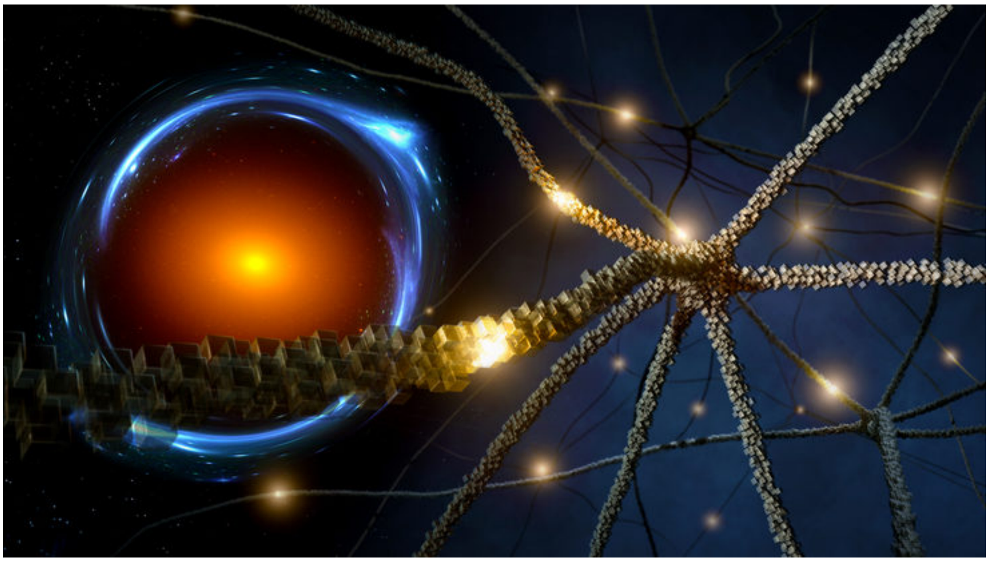
Artwork for this article is available as a printable poster (/sites/default/files/images/hi-res/Symmetry_expansion_rate_poster.jpg).

Read More... (http://www.symmetrymagazine.org/article/what-can-particles-tell-us-about-the-cosmos?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Neural networks meet space (http://www.symmetrymagazine.org/article/neural-networks-meet-space?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Aug 30, 2017

Artificial intelligence analyzes gravitational lenses 10 million times faster.



Researchers from the Department of Energy’s SLAC National Accelerator Laboratory and Stanford University have for the first time shown that neural networks—a form of artificial intelligence—can accurately analyze the complex distortions in spacetime known as gravitational lenses 10 million times faster than traditional methods.

“Analyses that typically take weeks to months to complete, that require the input of experts and that are computationally demanding, can be done by neural nets within a fraction of a second, in a fully automated way and, in principle, on a cell phone’s computer chip,” says postdoctoral fellow Laurence Perreault Levasseur, a co-author of a study published today in *Nature* (https://www.nature.com/nature/journal/v548/n7669/full/nature23463.html).

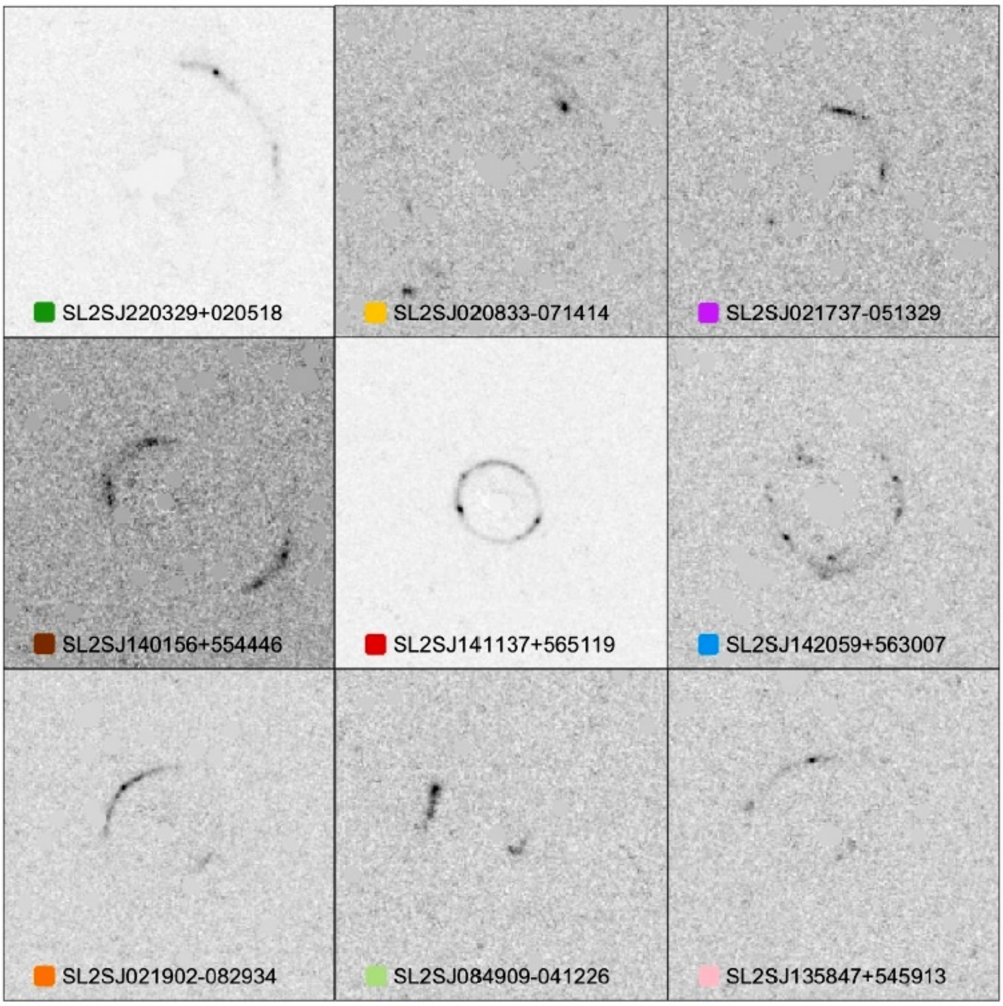
Lightning-fast complex analysis

The team at the Kavli Institute for Particle Astrophysics and Cosmology (KIPAC), a joint institute of SLAC and Stanford, used neural networks to analyze images of strong gravitational lensing (https://www.youtube.com/watch?v=PviYbX7cUUg&list=PL8BCE8824BFF1BB4B&index=41&t=15s), where the image of a faraway galaxy is multiplied and distorted into rings and arcs by the gravity of a massive object, such as a galaxy cluster, that’s closer to us. The distortions provide important clues about how mass is distributed in space and how that distribution changes over time – properties linked to invisible dark matter that makes up 85 percent of all matter in the universe and to dark energy that’s accelerating the expansion of the universe.

Until now this type of analysis has been a tedious process that involves comparing actual images of lenses with a large number of computer simulations of mathematical lensing models. This can take weeks to months for a single lens.

But with the neural networks, the researchers were able to do the same analysis in a few seconds, which they demonstrated using real images from NASA’s Hubble Space Telescope and simulated ones.

To train the neural networks in what to look for, the researchers showed them about half a million simulated images of gravitational lenses for about a day. Once trained, the networks were able to analyze new lenses almost instantaneously with a precision that was comparable to traditional analysis methods. In a separate paper (https://arxiv.org/abs/1708.08843), submitted to *The Astrophysical Journal Letters*, the team reports how these networks can also determine the uncertainties of their analyses.



(http://www.symmetrymagazine.org/sites/default/files/images/standard/Hubble%20Lenses%202.jpg)

KIPAC researchers used images of strongly lensed galaxies taken with the Hubble Space Telescope to test the performance of neural networks, which promise to speed up complex astrophysical analyses tremendously.

Yashar Hezaveh/Laurence Perreault Levasseur/Phil Marshall/Stanford/SLAC National Accelerator Laboratory; NASA/ESA

Prepared for the data floods of the future

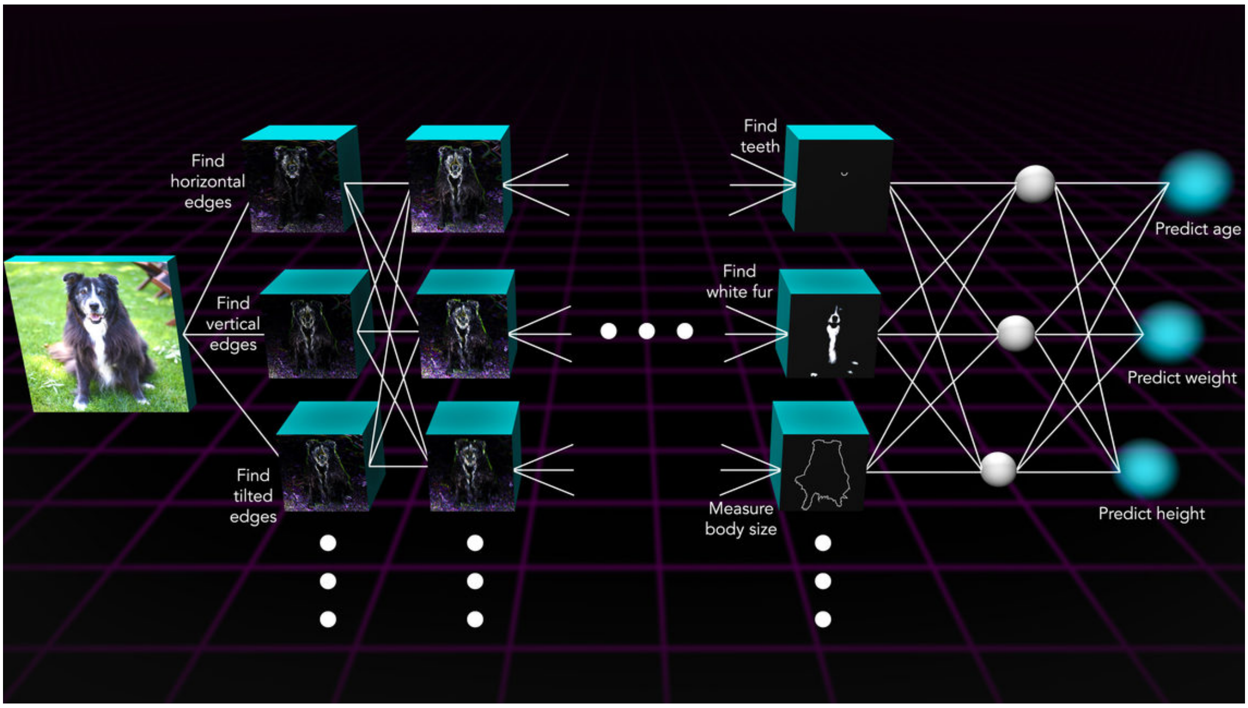
“The neural networks we tested—three publicly available neural nets and one that we developed ourselves—were able to determine the properties of each lens, including how its mass was distributed and how much it magnified the image of the background galaxy,” says the study’s lead author Yashar Hezaveh, a NASA Hubble postdoctoral fellow at KIPAC.

This goes far beyond recent applications of neural networks in astrophysics, which were limited to solving classification problems, such as determining whether an image shows a gravitational lens or not.

The ability to sift through large amounts of data and perform complex analyses very quickly and in a fully automated fashion could transform astrophysics in a way that is much needed for future sky surveys that will look deeper into the universe—and produce more data—than ever before.

The Large Synoptic Survey Telescope (LSST) (https://www.lsst.org/), for example, whose 3.2-gigapixel camera (https://lsst.slac.stanford.edu/) is currently under construction at SLAC, will provide unparalleled views of the universe and is expected to increase the number of known strong gravitational lenses from a few hundred today to tens of thousands.

“We won’t have enough people to analyze all these data in a timely manner with the traditional methods,” Perreault Levasseur says. “Neural networks will help us identify interesting objects and analyze them quickly. This will give us more time to ask the right questions about the universe.”



(http://www.symmetrymagazine.org/sites/default/files/images/standard/neural_network_visual_final.jpg)

Scheme of an artificial neural network, with individual computational units organized into hundreds of layers. Each layer searches for certain features in the input image (at left). The last layer provides the result of the analysis. The researchers used particular kinds of neural networks, called convolutional neural networks, in which individual computational units (neurons, gray spheres) of each layer are also organized into 2-D slabs that bundle information about the original image into larger computational units.

Greg Stewart, SLAC National Accelerator Laboratory

A revolutionary approach

Neural networks are inspired by the architecture of the human brain, in which a dense network of neurons quickly processes and analyzes information.

In the artificial version, the "neurons" are single computational units that are associated with the pixels of the image being analyzed. The neurons are organized into layers, up to hundreds of layers deep. Each layer searches for features in the image. Once the first layer has found a certain feature, it transmits the information to the next layer, which then searches for another feature within that feature, and so on.

"The amazing thing is that neural networks learn by themselves what features to look for," says KIPAC staff scientist Phil Marshall, a co-author of the paper. "This is comparable to the way small children learn to recognize objects. You don't tell them exactly what a dog is; you just show them pictures of dogs."

But in this case, Hezaveh says, "It's as if they not only picked photos of dogs from a pile of photos, but also returned information about the dogs' weight, height and age."

Although the KIPAC scientists ran their tests on the Sherlock high-performance computing cluster at the Stanford Research Computing Center, they could have done their computations on a laptop or even on a cell phone, they said. In fact, one of the neural networks they tested was designed to work on iPhones.

"Neural nets have been applied to astrophysical problems in the past with mixed outcomes," says KIPAC faculty member Roger Blandford, who was not a co-author on the paper. "But new algorithms combined with modern graphics processing units, or GPUs, can produce extremely fast and reliable results, as the gravitational lens problem tackled in this paper dramatically demonstrates. There is considerable optimism that this will become the approach of choice for many more data processing and analysis problems in astrophysics and other fields."

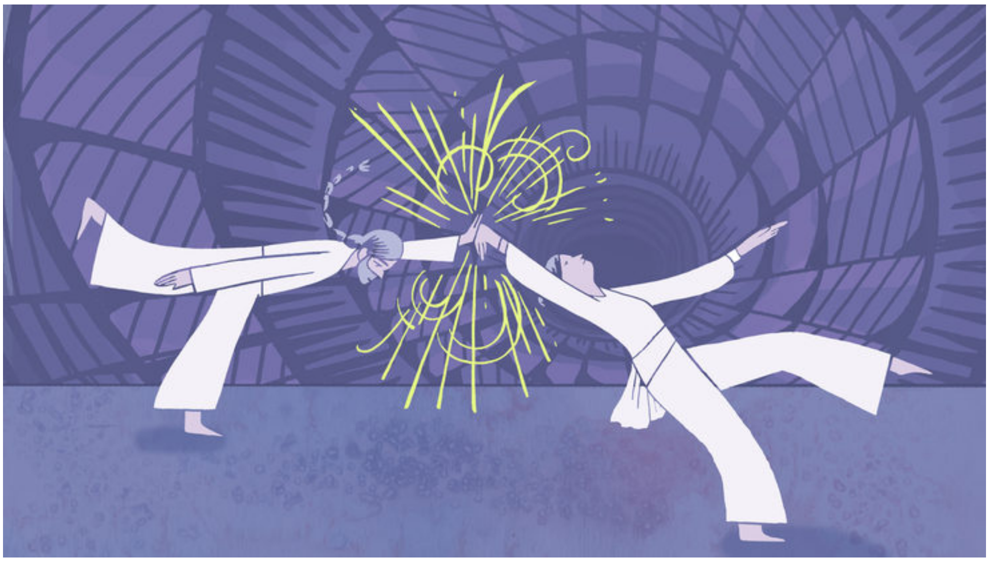
Editor's note: This article originally appeared as a SLAC press release (https://www6.slac.stanford.edu/news/2017-08-30-artificial-intelligence-analyzes-gravitational-lenses-10-million-times-faster.aspx).

Read More... (http://www.symmetrymagazine.org/article/neural-networks-meet-space?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

The dance of the particles (http://www.symmetrymagazine.org/article/the-dance-of-the-particles?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Aug 29, 2017

In collaboration with a scientist, an Iranian dancer is working to communicate the beauty of particle physics through dance.



Although CERN physicist Andrea Latina had always been interested in the arts, he had never really thought about dance before.

While at a local film festival in 2015, he happened upon a flyer that quoted Persian poet Rumi about the “dance of particles.” Curious, he reached out to its author, Iranian dancer and choreographer Sahar Dehghan, to learn more.

Dehghan says that even as a child she was fascinated by both physics and dance.

When she moved to France at a young age, she started taking dance classes, focusing on a meditative form called Sufi dancing and later concentrating on contemporary dance. But she also kept her fascination with physics, reading books and articles and having conversations with scientists she befriended in Paris as a young adult.

“I became interested in quantum mechanics and its relation to physics, and I really started experimenting physically in my dance with a lot of these concepts,” she says.

Dehghan and Latina developed a friendship, meeting to chat about physics and dance.

Virtual particles

Dehghan says that she was inspired by ideas such as the confinement of quarks via the strong force.

“If you try to separate quarks, this force will be so strong that new particles will be created to prevent separation,” Latina says. “The density of energy is so high that a new pair of quark and antiquark will form so that the new quarks pair up with the original ones, just to avoid there being a single quark isolated in nature.”

In the winter of 2016, Dehghan visited CERN to learn more about its goals and how scientists are working to achieve them. One of the most inspiring things, she says, was seeing thousands of scientists from different backgrounds uniting to further our understanding of the universe.

“There are more than 11,000 people of more than 110 nationalities coming together with a common goal,” she says. “Instead of seeing superficial differences caused by cultural, religious, political or sexual preference, they respect and collaborate with each other, learning from each other for a greater purpose.”

Latina says that conversations with Dehghan gave him insight into physics as well.

“I’m very enthusiastic about CERN and my work,” he says. “In drawing parallels between ancient philosophies, Sahar reminded me that what we are doing is the same thing humans have been doing for millennia: questioning where we come from, where we are going and what our role in the universe is. She was able to evoke this ancestral wonder and help me rediscover the poetry of what we do at CERN. We are incessantly trying to answer the same questions; we just use different tools and the language of mathematics.”

Dehghan says she would love to communicate these themes through dance. Through artistic mediums, she says, new ideas can be heard, seen and felt in a deeper, more meaningful way.

“It would be great if we could all see beyond our own illusions into the fascinating particle interactions happening in everything and everyone at all times and the true unity that connects us in this great quantum dance, whirling at all times in rhythm with the music of the entire cosmos,” she says.

She has begun to choreograph a show called WHIRL Quantum Dance. Through scenes in her show, she tries to illustrate concepts such as quantum chromodynamics (with colored lights) or quantum entanglement (with pairs of dancers). She is even trying to create a collision scene with spinning dancers in a large circle representing an accelerator.

“I am not a scientific expert in anything so I am not trying to teach anyone,” she says. “What I want to do with this show is open some doors for the audience to go out there and search for more and learn about not just about quantum and particle physics, but also go out there and physically experiment and see how we’re all connected.

“Even if I open just one door for one person in the audience to go in that direction, I will have achieved my goal.”

WHIRL: Quantum Dance, which is being presented by Sangram Arts, will premiere in the San Francisco Bay Area at the School of Arts & Culture at Mexican Heritage Plaza on September 22 and 23, with dancers Shahrokh Moshkin Ghalam and Rakesh Sukesh. Dehghan says that she hopes to make a film of the show to tour at different venues in cities around the world.

For more information, visit Dehghan's Facebook page (https://www.facebook.com/sahar.dehghandance).

Read More... (http://www.symmetrymagazine.org/article/the-dance-of-the-particles?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Mega-collaborations for scientific discovery (http://www.symmetrymagazine.org/article/mega-collaborations-for-scientific-discovery?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

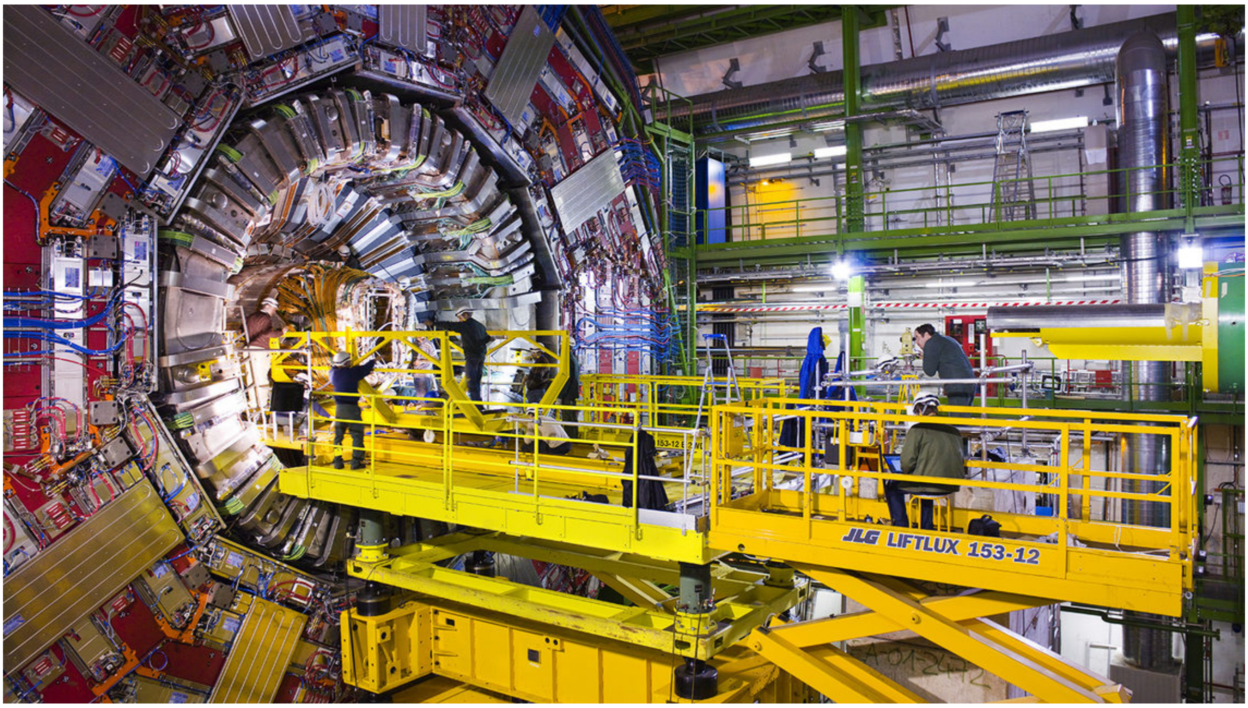
Aug 24, 2017

DUNE joins the elite club of physics collaborations with more than 1000 members.

Sometimes it takes lot of people working together to make discovery possible. More than 7000 scientists, engineers and technicians worked on designing and constructing the Large Hadron Collider at CERN, and thousands of scientists now run each of the LHC's four major experiments.

Not many experiments garner such numbers. On August 15, the Deep Underground Neutrino Experiment (DUNE) became the latest member of the exclusive clique of particle physics experiments with more than a thousand collaborators.

Meet them all:



(http://www.symmetrymagazine.org/sites/default/files/images/standard/CMS_work-s.jpg)

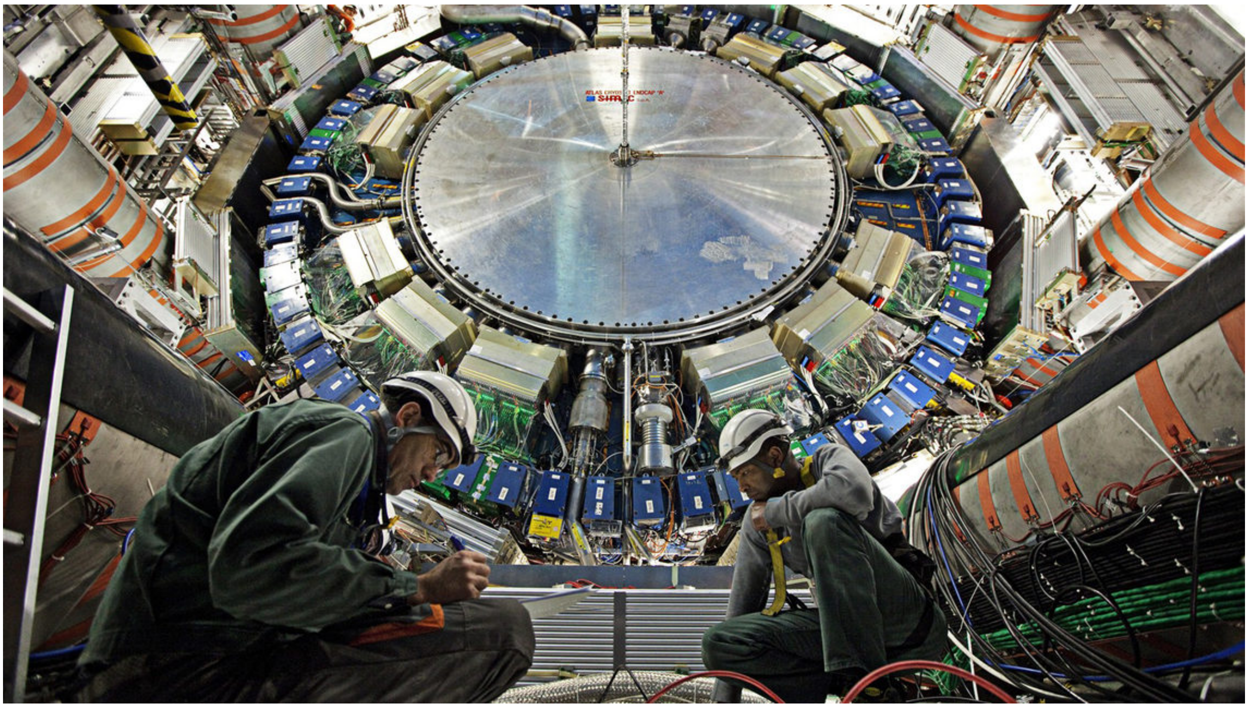
Photo by Maximilien Brice, CERN

4,000+: Compact Muon Solenoid Detector (CMS) Experiment

CMS is one of the two largest experiments at the LHC. It is best known for its role in the discovery of the Higgs boson.

The "C" in CMS stands for compact, but there's nothing compact about the CMS collaboration. It is one of the largest scientific collaborations in history. More than 4000 people from 200 institutions around the world work on the CMS detector and use its data for research.

About 30 percent of the CMS collaboration hail from US institutions. A remote operations center at the Department of Energy's Fermi National Accelerator Laboratory in Batavia, Illinois, serves as a base for CMS research in the United States.



(http://www.symmetrymagazine.org/sites/default/files/images/standard/ATLAS-s_0.jpg)
Claudia Marcelloni, CERN

3,000+: A Toroidal LHC ApparatuS (ATLAS) Experiment

The ATLAS experiment, the other large experiment responsible for discovering the Higgs boson at the LHC, ranks number two in number of collaborators. The ATLAS collaboration has more than 3000 members from 182 institutions in 38 countries. ATLAS and CMS ask similar questions about the building blocks of the universe, but they look for the answers with different detector designs.

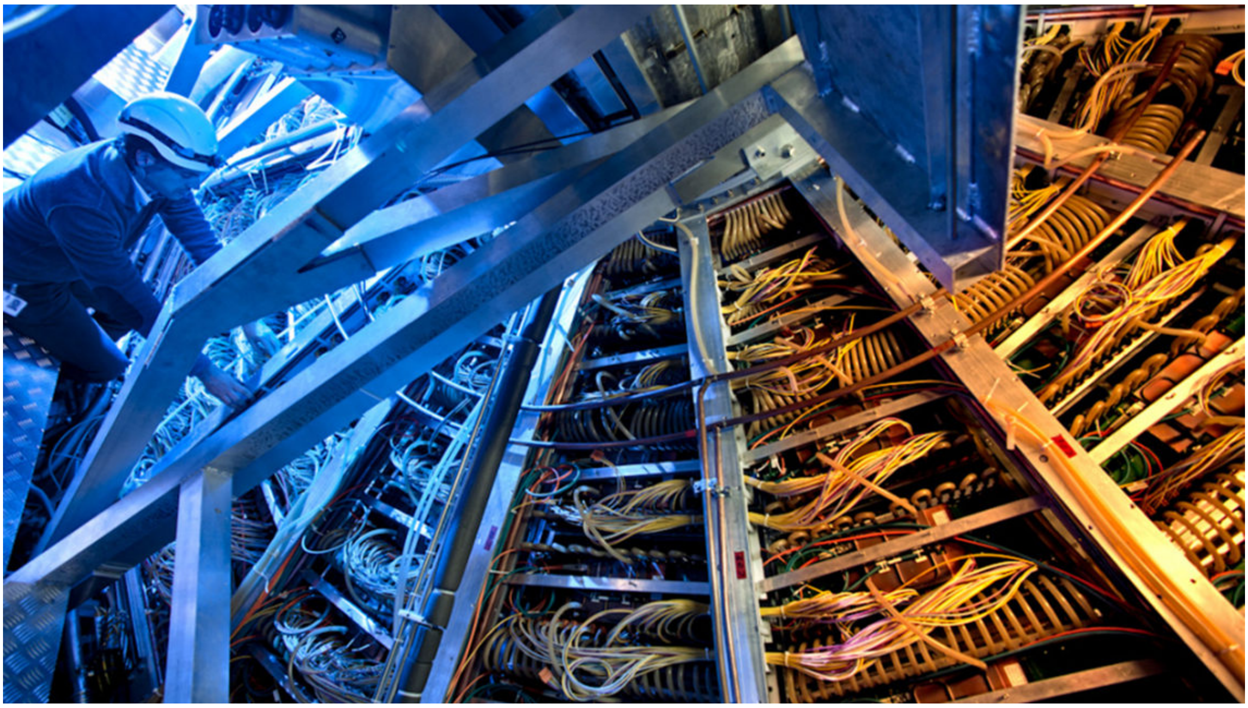
About 30 percent of the ATLAS collaboration are from institutions in the United States. Brookhaven National Laboratory in Upton, New York, serves as the US host.

2,000+: Linear Collider Collaboration

The Linear Collider Collaboration (LCC) is different from CMS and ATLAS in that the collaboration's experiment is still a proposed project and has not yet been built. LCC has around 2000 members who are working to develop and build a particle collider that can produce different kinds of collisions than those seen at the LHC.

LCC members are working on two potential linear collider projects: the compact linear collider study (CLIC) at CERN and the International Linear Collider (ILC) in Japan. CLIC and the ILC originally began as separate projects, but the scientists working on both joined forces in 2013.

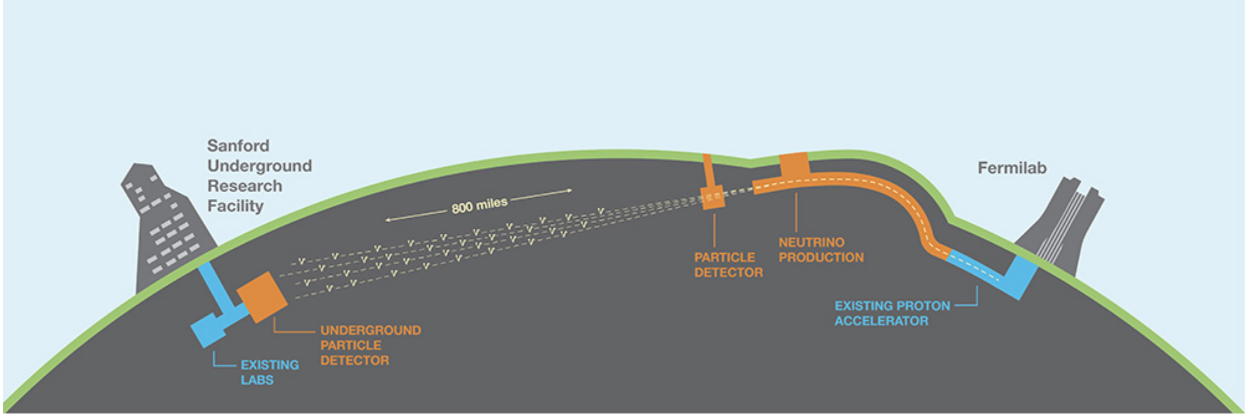
Either CLIC or the ILC would complement the LHC by colliding electrons and positrons to explore the Higgs particle interactions and the nature of subatomic forces in greater detail.



(http://www.symmetrymagazine.org/sites/default/files/images/standard/ALICE-s.jpg)
Antonio Saba, CERN

1,500+; A Large Ion Collider Experiment (ALICE)

ALICE is part of LHC's family of particle detectors, and, like ATLAS and CMS, it too has a large, international collaboration, counting 1500 members from 154 physics institutes in 37 countries. Research using ALICE is focused on quarks, the sub-atomic particles that make up protons and neutrons, and the strong force responsible for holding quarks together.



(http://www.symmetrymagazine.org/sites/default/files/images/standard/DUNE-s.jpg)
Courtesy of Fermilab

1,000+: Deep Underground Neutrino Experiment (DUNE)

The Deep Underground Neutrino Experiment is the newest member of the club. This month, the DUNE collaboration surpassed 1000 collaborators from 30 countries.

From its place a mile beneath the earth at the Sanford Underground Research Facility in South Dakota, DUNE will investigate the behavior of neutrinos, which are invisible, nearly massless particles that rarely interact with other matter. The neutrinos will come from Fermilab, 800 miles away.

Neutrino research could help scientists answer the question of why there is an imbalance between matter and antimatter in the universe. Groundbreaking for DUNE occurred on July 21, and the experiment will start taking data in around 2025.

Honorable mentions

A few notable collaborations have made it close to 1000 but didn't quite make the list. LHCb, the fourth major detector at LHC, boasts a collaboration 800 strong. Over 700 collaborators work on the Belle II experiment at KEK in Japan, which will begin taking data in 2018, studying the properties of B mesons, particles that contain a bottom quark. The 600-member BaBar collaboration at SLAC National Accelerator Laboratory also studies B mesons. STAR, a detector at Brookhaven National Laboratory that probes the conditions of the early universe, has more than 600 collaborators from 55 institutions. The CDF and DZero collaborations at Fermilab, best known for their co-discovery of the top quark in 1995, had about 700 collaborators at their peak.

Read More... (http://www.symmetrymagazine.org/article/mega-collaborations-for-scientific-discovery?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Expanding the search for dark matter (http://www.symmetrymagazine.org/article/expanding-the-search-for-dark-matter?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Aug 22, 2017

At a recent meeting, scientists shared ideas for searching for dark matter on the (relative) cheap.

Thirty-one years ago, scientists made their first attempt to find dark matter with a particle detector in a South Dakota mine.

Since then, researchers have uncovered enough clues to think dark matter makes up approximately 26.8 percent of all the matter and energy in the universe. They think it forms a sort of gravitational scaffolding for the galaxies and galaxy clusters our telescopes do reveal, shaping the structure of our universe while remaining unseen.

These conclusions are based on indirect evidence such as the behavior of galaxies and galaxy clusters. Direct detection experiments—ones designed to actually sense a dark matter particle pinging off the nucleus of an atom—have yet to find what they're looking for. Nor has dark matter been seen at the Large Hadron Collider. That invisible, enigmatic material, that Greta Garbo of particle physics, still wants to be alone.

It could be that researchers are just looking in the wrong place. Much of the search for dark matter has focused on particles called WIMPs, weakly interacting massive particles. But interest in WIMP alternatives has been growing, prompting the development of a variety of small-scale research projects to investigate some of the most promising prospects.

In March more than 100 scientists met at the University of Maryland for "Cosmic Visions: New Ideas in Dark Matter," a gathering to take the pulse of the post-WIMP dark matter landscape for the Department of Energy. That pulse was surprisingly strong. Organizers recently published a white paper (https://inspirehep.net/record/1610250/)detailing the results.

The conference came about partly because, "it seemed a good time to get everyone together to see what each experiment was doing, where they reinforced each other and where they did something new," says Natalia Toro, a theorist at SLAC National Accelerator Laboratory and a member of the Cosmic Visions Scientific Advisory Committee. What she and many other participants didn't expect, Toro says, was just how many good ideas would be presented.

Almost 50 experiments in various stages of development were presented during three days of talks, and a similar number of potential experiments were discussed.

Some of the experiments presented would be designed to look for dark matter particles that are lighter than traditional WIMPs, or for the new fundamental forces through which such particles could interact. Others would look for oscillating forces produced by dark matter particles trillions of times lighter than the electron. Still others would look for different dark matter candidates, such as primordial black holes.

The scientists at the workshop were surprised by how small and relatively inexpensive many of the experiments could be, says Philip Schuster, a particle theorist at SLAC National Accelerator Laboratory.

"'Small' and 'inexpensive' depend on what technology you're using, of course," Schuster says. DOE is prepared to provide funding to the tune of $10 million (still a fraction of the cost of a current WIMP experiment), and many of the experiments could cost in the $1 to $2 million range.

Several factors work together to lessen the cost. For example, advances in detector technology and quantum sensors have made technology cheaper. Then there are small detectors that can be placed at already-existing large facilities like the Heavy Photon Search, a dark-sector search at Jefferson Lab. "It's basically a table-top detector, as opposed to CMS and ATLAS at the Large Hadron Collider, which took years to build and weigh as much as a battleship," Schuster says.

Experimentalist Joe Incandela of the University of California, Santa Barbara and one of the coordinators of the Cosmic Visions effort, has a simple explanation for this current explosion of ideas. "There's a good synergy between the technology and interest in dark matter," he says.

Incandela says he is feeling the synergy himself. He is a former spokesperson for CMS, a battleship-class experiment in which he continues to play an active role while also developing the Light Dark Matter Experiment, which would use a high-resolution silicon-based calorimeter that he originally helped develop for CMS to search for an alternative to WIMPs.

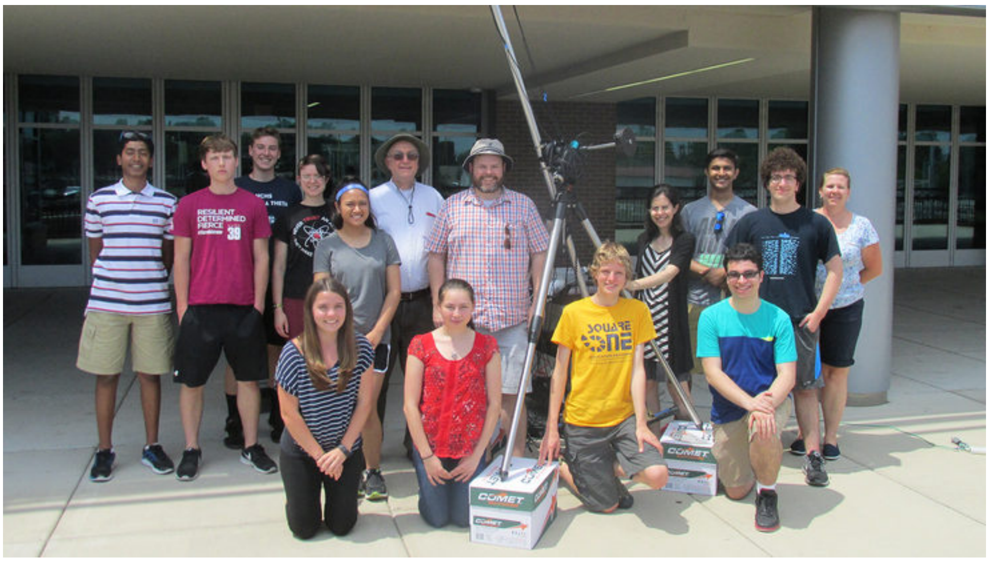
"It occurred to me that this calorimeter technology could very useful for low-mass dark matter searches," he says. "My hope is that, starting soon, and spanning roughly five years, the funding—and not very much is needed—will be available to support experiments that can cover a lot more of the landscape where dark matter may be hiding. It's very exciting."

Read More... (http://www.symmetrymagazine.org/article/expanding-the-search-for-dark-matter?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

QuarkNet takes on solar eclipse science (http://www.symmetrymagazine.org/article/quarknet-takes-on-solar-eclipse-science?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Aug 16, 2017

High school students nationwide will study the effects of the solar eclipse on cosmic rays.



While most people are marveling at Monday's eclipse, a group of researchers will be measuring its effects on cosmic rays—particles from space that collide with the earth's atmosphere to produce muons, heavy cousins of the electron. But these researchers aren't the usual PhD-holding suspects: They're still in high school.

More than 25 groups of high school students and teachers nationwide will use small-scale detectors to find out whether the number of cosmic rays raining down on Earth changes during an eclipse. Although the eclipse event will last only three hours, this student experiment has been a months-long collaboration.

The cosmic ray detectors used for this experiment were provided as kits by QuarkNet, an outreach program that gives teachers and students opportunities to try their hands at high-energy physics research. Through QuarkNet, high school classrooms can participate in a whole range of physics activities, such as analyzing real data from the CMS experiment at CERN and creating their own experiments with detectors.

“Really active QuarkNet groups run detectors all year and measure all sorts of things that would sound crazy to a physicist,” says Mark Adams, QuarkNet’s cosmic ray studies coordinator. “It doesn’t really matter what the question is as long as it allows them to do science.”

And this year’s solar eclipse will give students a rare chance to answer a cosmic question: Is the sun a major producer of the cosmic rays that bombard Earth, or do they come from somewhere else?

“We wanted to show that, if the rate of cosmic rays changes a lot during the eclipse, then the sun is a big source of cosmic rays,” Adams says. “We sort of know that the sun is not the main source, but it’s a really neat experiment. As far as we know, no one has ever done this with cosmic ray muons at the surface.”

Adams and QuarkNet teacher Nate Unterman will be leading a group of nine students and five adults to Missouri to the heart of the path of totality—where the moon will completely cover the sun—to take measurements of the event. Other QuarkNet groups will stay put, measuring what effect a partial eclipse might have on cosmic rays in their area.

Most cosmic rays are likely high-energy particles from exploding stars deep in space, which are picked up via muons in QuarkNet detectors. But the likely result of the experiment—that cosmic rays don’t change their rate when the moon moves in front of the sun—doesn’t eclipse the excitement for the students in the collaboration.

“They’ve been working for months and months to develop the design for the measurements and the detectors,” Adams says. “That’s the great part—they’re not focused on what the answer is but the best way to find it.”

(http://www.symmetrymagazine.org/sites/default/files/images/standard/eclipse-2-s_0.jpg)

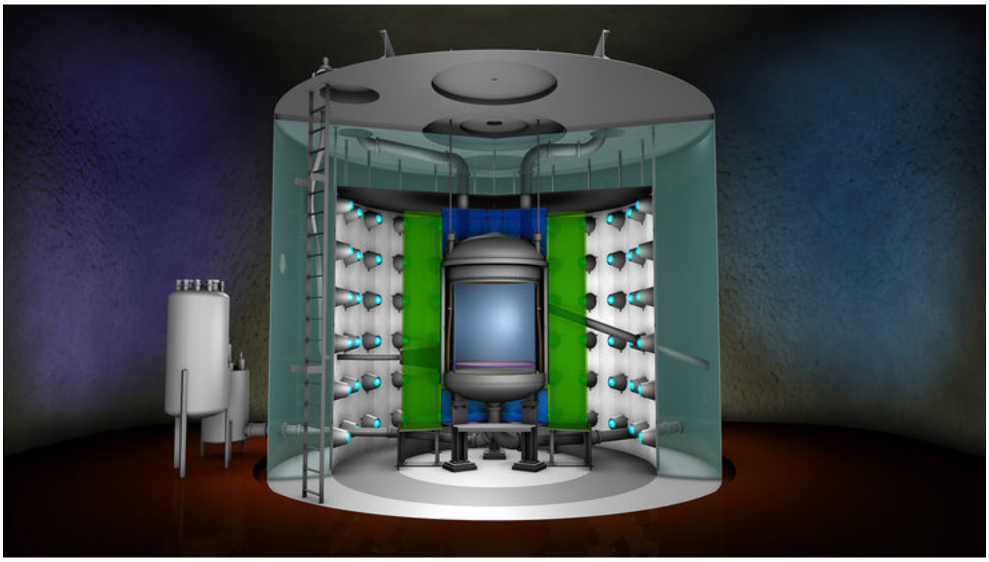
Mark Adams

Read More... (http://www.symmetrymagazine.org/article/quarknet-takes-on-solar-eclipse-science?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Dark matter hunt with LUX-ZEPLIN (http://www.symmetrymagazine.org/article/dark-matter-hunt-with-lux-zeplin?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Aug 15, 2017

A video from SLAC National Accelerator Laboratory explains how the upcoming LZ experiment will search for the missing 85 percent of the matter in the universe.

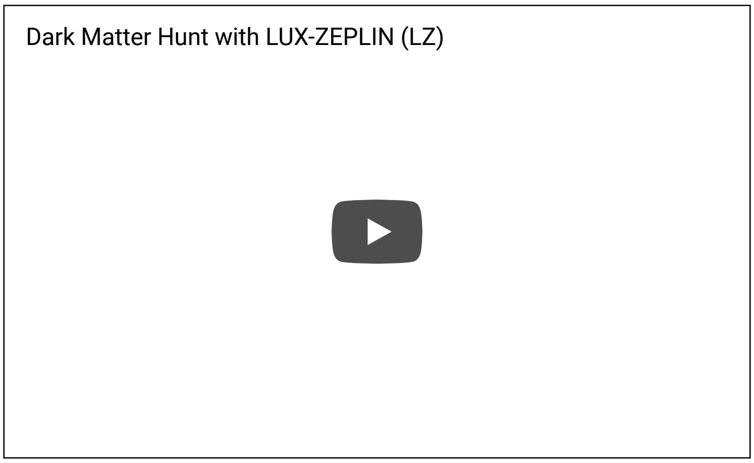


What exactly is dark matter, the invisible substance that accounts for 85 percent of all the matter in the universe but can’t be seen even with our most advanced scientific instruments?

Most scientists believe it's made of ghostly particles that rarely bump into their surroundings. That's why billions of dark matter particles might zip right through our bodies every second without us even noticing. Leading candidates for dark matter particles are WIMPs, or weakly interacting massive particles.

Scientists at SLAC National Accelerator Laboratory are helping to build and test one of the biggest and most sensitive detectors ever designed to catch a WIMP: the LUX-ZEPLIN or LZ detector. The following video explains how it works.

Dark Matter Hunt with LUX-ZEPLIN (LZ) (/file/dark-matter-hunt-with-lux-zeplin-lz)

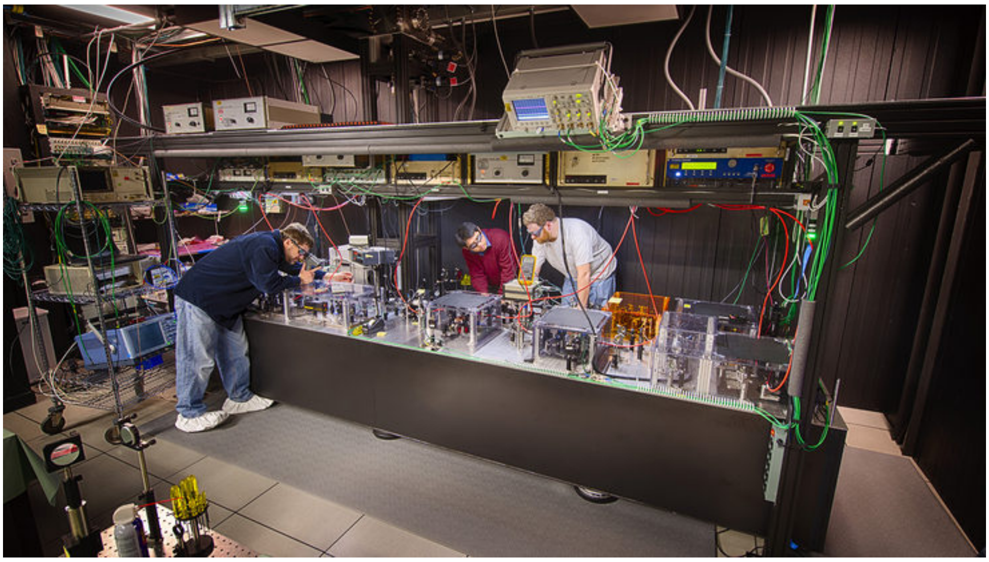


Read More... (http://www.symmetrymagazine.org/article/dark-matter-hunt-with-lux-zeplin?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Think FAST (http://www.symmetrymagazine.org/article/think-fast?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Aug 10, 2017

The new Fermilab Accelerator Science and Technology facility at Fermilab looks to the future of accelerator science.



Unlike most particle physics facilities, the new Fermilab Accelerator Science and Technology facility (FAST) wasn't constructed to find new particles or explain basic physical phenomena. Instead, FAST is a kind of workshop—a space for testing novel ideas that can lead to improved accelerator, beamline and laser technologies.

Historically, accelerator research has taken place on machines that were already in use for experiments, making it difficult to try out new ideas. Tinkering with a physicist's tools mid-search for the secrets of the universe usually isn't a great idea. By contrast, FAST enables researchers to study pieces of future high-intensity and high-energy accelerator technology with ease.

"FAST is specifically aiming to create flexible machines that are easily reconfigurable and that can be accessed on very short notice," says Alexander Valishev, head of department that manages FAST. "You can roll in one experiment and roll the other out in a matter of days, maybe months, without expensive construction and operation costs."

This flexibility is part of what makes FAST a useful place for training up new accelerator scientists. If a student has an idea, or something they want to study, there's plenty of room for experimentation.

"We want students to come and do their thesis research at FAST, and we already have a number of students working." Valishev says. "We have already had a PhD awarded on the basis of work done at FAST, but we want more of that."

(http://www.symmetrymagazine.org/sites/default/files/images/standard/beamline-s.jpg)

This yellow cyromodule will house the superconducting cavities that take the beam's energy from 50 to 300 MeV.

Courtesy of Fermilab

Small ring, bright beam

FAST will eventually include three parts: an electron injector, a proton injector and a particle storage ring called the Integrable Optics Test Accelerator, or IOTA. Although it will be small compared to other rings—only 40 meters long, while Fermilab's Main Injector has a circumference of 3 kilometers—IOTA will be the centerpiece of FAST after its completion in 2019. And it will have a unique feature: the ability to switch from being an electron accelerator to a proton accelerator and back again.

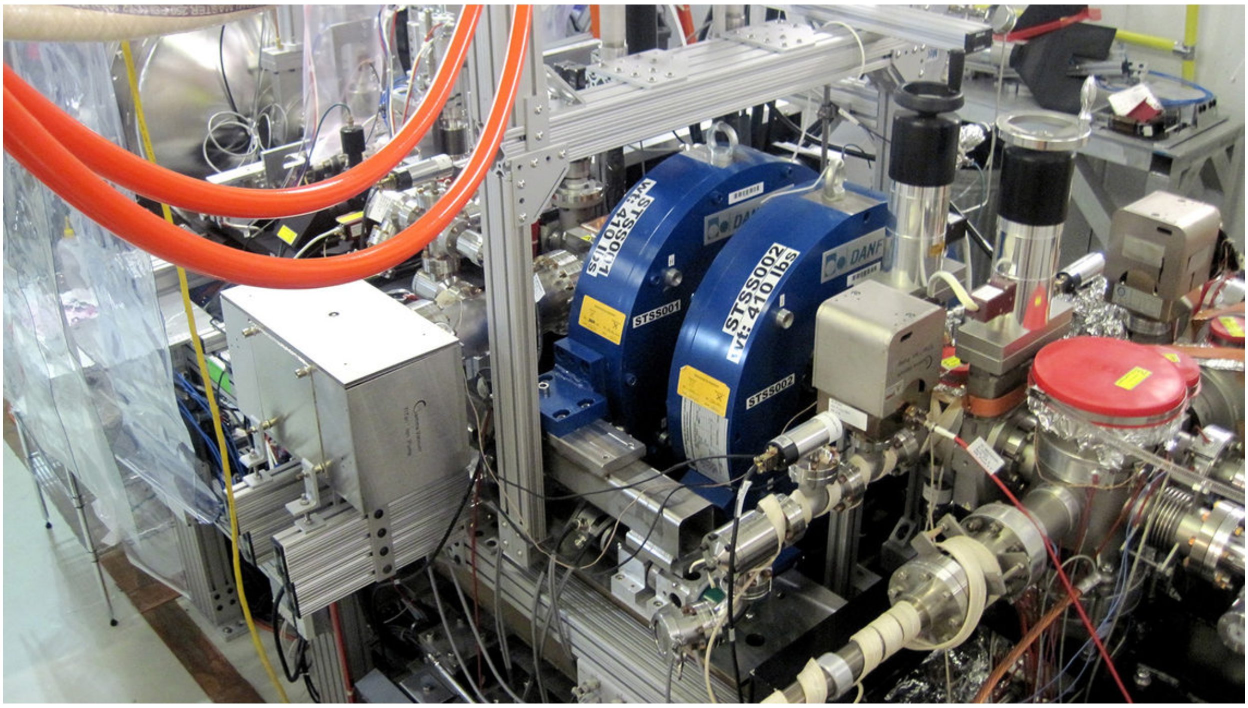
"The sole purpose of this synchrotron is to test accelerator technology and develop that tech to test ideas and theories to improve accelerators everywhere," says Dan Broemmelsiek, a scientist in the IOTA/FAST department.

One aspect of accelerator technology FAST focuses on is creating higher-intensity or "brighter" particle beams.

Brighter beams pack a bigger particle punch. A high-intensity beam could send a detector twice as many particles as is usually possible. Such an experiment could be completed in half the time, shortening the data collection period by several years.

IOTA will test a new concept for accelerators called integrable optics, which is intended to create a more concentrated, stable beam, possibly producing higher intensity beams than ever before.

"If this IOTA thing works, I think it could be revolutionary," says Jamie Santucci, an engineering physicist working on FAST. "It's going to allow all kinds of existing accelerators to pack in way more beam. More beam, more data."



(http://www.symmetrymagazine.org/sites/default/files/images/standard/photoelectron_gun-s.jpg)

The beam starts here: Once electrons are sent down the beamline, they pass through the a set of solenoid magnets—the dark blue rings—before entering the first two superconducting cavities.

Courtesy of Fermilab

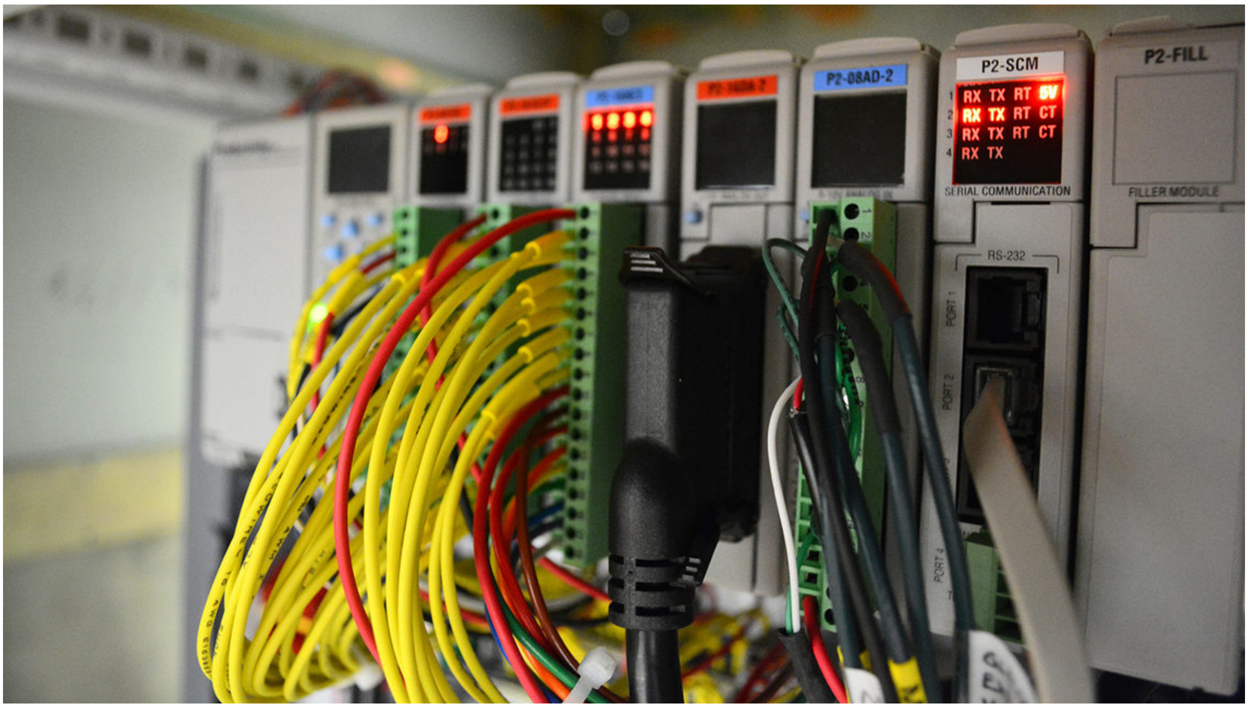
Maximum energy milestone

Although the completion of IOTA is still a few years away, the electron injector will reach a milestone this summer: producing an electron beam with the energy of 300 million electronvolts (MeV).

"The electron injector for IOTA is a research vehicle in its own right," Valishev says. It provides scientists a chance to test superconducting accelerators, a key piece of technology for future physics machines that can produce intense acceleration at relatively low power.

"At this point, we can measure things about the beam, chop it up or focus it," Broemmelsiek says. "We can use cameras to do beam diagnostics, and there's space here in the beamline to put experiments to test novel instrumentation concepts."

The electron beam's previous maximum energy of 50 MeV was achieved by passing the beam through two superconducting accelerator cavities and has already provided opportunities for research. The arrival of the 300 MeV beam this summer—achieved by sending the beam through another eight superconducting cavities—will open up new possibilities for accelerator research, with some experiments already planned to start as soon as the beam is online.



(http://www.symmetrymagazine.org/sites/default/files/images/standard/Proton_injector-s.jpg)

Electronics for IOTA

Chip Edstrom

FAST forward

The third phase of FAST, once IOTA is complete, will be the construction of the proton injector.

"FAST is unique because we will specifically target creating high-intensity proton beams," Valishev says.

This high-intensity proton beam research will directly translate to improving research into elusive particles called neutrinos, Fermilab's current focus.

"In five to 10 years, you'll be talking to a neutrino guy and they'll go, 'I don't know what the accelerator guys did, but it's fabulous. We're getting more neutrinos per hour than we ever thought we would,'" Broemmelsiek says.

Creating new accelerator technology is often an overlooked area in particle physics, but the freedom to try out new ideas and discover how to build better machines for research is inherently rewarding for people who work at FAST.

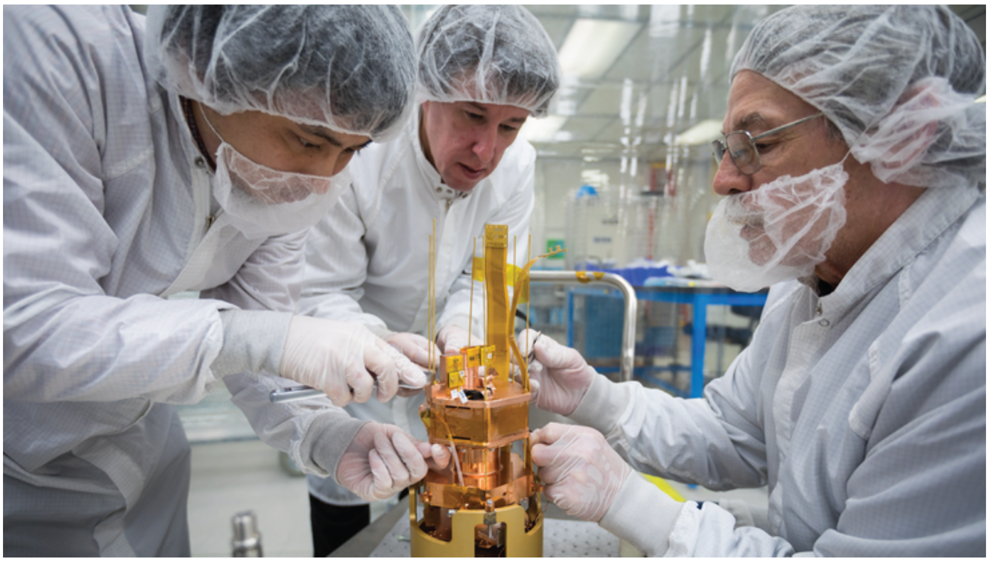
"Our business is science, and we're supposed to make science, and we work really hard to do that," Broemmelsiek says. "But it's also just plain ol' fun."

Read More... (http://www.symmetrymagazine.org/article/think-fast?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

A new search for dark matter 6800 feet underground (http://www.symmetrymagazine.org/article/a-new-search-for-dark-matter-6800-feet-underground?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Aug 8, 2017

Prototype tests of the future SuperCDMS SNOLAB experiment are in full swing.



When an extraordinarily sensitive dark matter experiment goes online at one of the world's deepest underground research labs, the chances are better than ever that it will find evidence for particles of dark matter—a substance that makes up 85 percent of all matter in the universe but whose constituents have never been detected.

The heart of the experiment, called SuperCDMS SNOLAB, will be one of the most sensitive detectors for hypothetical dark matter particles called WIMPs, short for "weakly interacting massive particles." SuperCDMS SNOLAB is one of two next-generation experiments (the other one being an experiment called LZ) selected by the US Department of Energy and the National Science Foundation to take the search for WIMPs to the next level, beginning in the early 2020s.

"The experiment will allow us to enter completely unexplored territory," says Richard Partridge, head of the SuperCDMS SNOLAB group at the Kavli Institute for Particle Astrophysics and Cosmology, a joint institute of Stanford University and SLAC National Accelerator Laboratory. "It'll be the world's most sensitive detector for WIMPs with relatively low mass, complementing LZ, which will look for heavier WIMPs."

The experiment will operate deep underground at Canadian laboratory SNOLAB inside a nickel mine near the city of Sudbury, where 6800 feet of rock provide a natural shield from high-energy particles from space, called cosmic rays. This radiation would not only cause unwanted background in the detector; it would also create radioactive isotopes in the experiment's silicon and germanium sensors, making them useless for the WIMP search. That's also why the experiment will be assembled from major parts at its underground location.

A detector prototype is currently being tested at SLAC, which oversees the efforts of the SuperCDMS SNOLAB project.

Colder than the universe

The only reason we know dark matter exists is that its gravity pulls on regular matter, affecting how galaxies rotate and light propagates. But researchers believe that if WIMPs exist, they could occasionally bump into normal matter, and these collisions could be picked up by modern detectors.

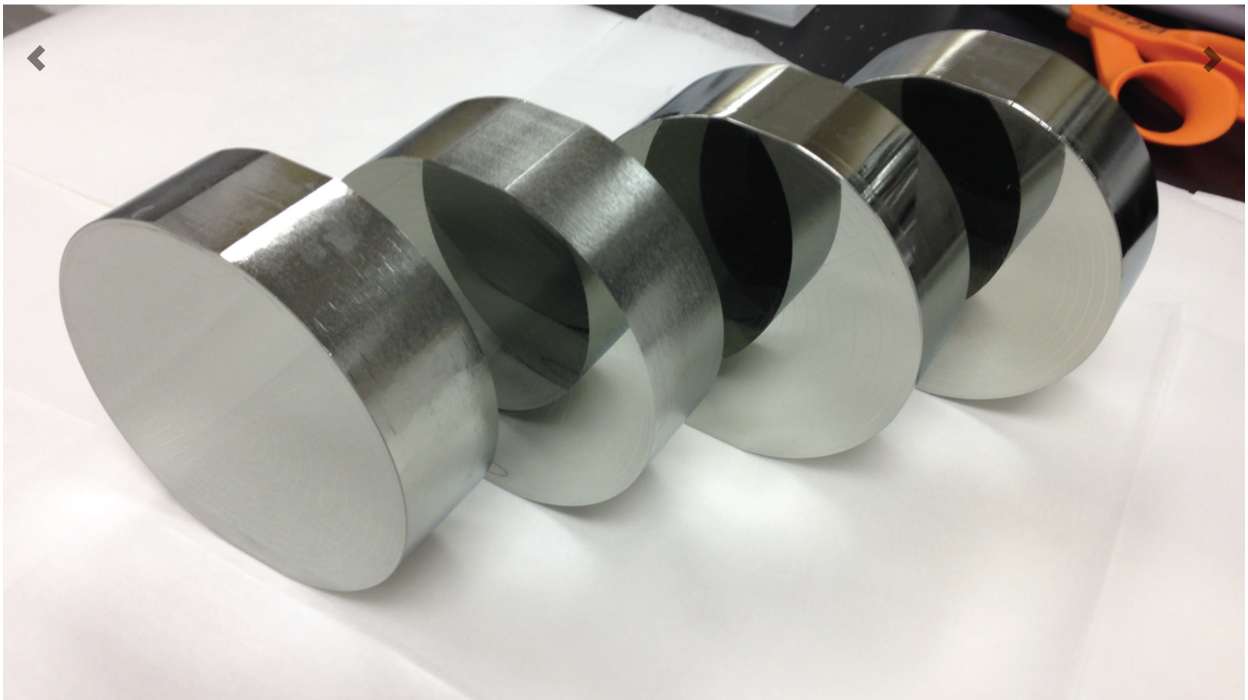
SuperCDMS SNOLAB will use germanium and silicon crystals in the shape of oversized hockey pucks as sensors for these sporadic interactions. If a WIMP hits a germanium or silicon atom inside these crystals, two things will happen: The WIMP will deposit a small amount of energy, causing the crystal lattice to vibrate, and it'll create pairs of electrons and electron deficiencies that move through the crystal and alter its electrical conductivity. The experiment will measure both responses.

"Detecting the vibrations is very challenging," says KIPAC's Paul Brink, who oversees the detector fabrication at Stanford. "Even the smallest amounts of heat cause lattice vibrations that would make it impossible to detect a WIMP signal. Therefore, we'll cool the sensors to about one hundredth of a Kelvin, which is much colder than the average temperature of the universe."

These chilly temperatures give the experiment its name: CDMS stands for "Cryogenic Dark Matter Search." (The prefix "Super" indicates that the experiment is more sensitive than previous detector generations.)

The use of extremely cold temperatures will be paired with sophisticated electronics, such as transition-edge sensors that switch from a superconducting state of zero electrical resistance to a normal-conducting state when a small amount of energy is deposited in the crystal, as well as superconducting quantum interference devices, or SQUIDs, that measure these tiny changes in resistance.

The experiment will initially have four detector towers, each holding six crystals. For each crystal material—silicon and germanium—there will be two different detector types, called high-voltage (HV) and interleaved Z-sensitive ionization phonon (iZIP) detectors. Future upgrades can further boost the experiment's sensitivity by increasing the number of towers to 31, corresponding to a total of 186 sensors.



Four SuperCDMS SNOLAB iZIP detectors at the Stanford Nanofabrication Facility

Matt Cherry

Working hand in hand

The work under way at SLAC serves as a system test for the future SuperCDMS SNOLAB experiment. Researchers are testing the four different detector types, the way they are integrated into towers, their superconducting electrical connectors and the refrigerator unit that cools them down to a temperature of almost absolute zero.

“These tests are absolutely crucial to verify the design of these new detectors before they are integrated in the experiment underground at SNOLAB,” says Ken Fouts, project manager for SuperCDMS SNOLAB at SLAC. “They will prepare us for a critical DOE review next year, which will determine whether the project can move forward as planned.” DOE is expected to cover about half of the project costs, with the other half coming from NSF and a contribution from the Canadian Foundation for Innovation.

Important work is progressing at all partner labs of the SuperCDMS SNOLAB project. Fermi National Accelerator Laboratory is responsible for the cryogenics infrastructure and the detector shielding—both will enable searching for faint WIMP signals in an environment dominated by much stronger unwanted background signals. Pacific Northwest National Laboratory will lend its expertise in understanding background noise in highly sensitive precision experiments. A number of US universities are involved in various aspects of the project, including detector fabrication, tests, data analysis and simulation.

The project also benefits from international partnerships with institutions in Canada, France, the UK and India. The Canadian partners are leading the development of the experiment’s data acquisition and will provide the infrastructure at SNOLAB.

“Strong partnerships create a lot of synergy and make sure that we’ll get the best scientific value out of the project,” says Fermilab’s Dan Bauer, spokesperson of the SuperCDMS collaboration, which consists of 109 scientists from 22 institutions, including numerous universities. “Universities have lots of creative students and principal investigators, and their talents are combined with the expertise of scientists and engineers at the national labs, who are used to successfully manage and build large projects.”

SuperCDMS SNOLAB will be the fourth generation of experiments, following CDMS-I at Stanford, CDMS-II at the Soudan mine in Minnesota, and a first version of SuperCDMS at Soudan, which completed operations in 2015.

“Over the past 20 years we’ve been pushing the limits of our detectors to make them more and more sensitive for our search for dark matter particles,” says KIPAC’s Blas Cabrera, project director of SuperCDMS SNOLAB. “Understanding what constitutes dark matter is as fundamental and important today as it was when we started, because without dark matter none of the known structures in the universe would exist—no galaxies, no solar systems, no planets and no life itself.”

Read More... (http://www.symmetrymagazine.org/article/a-new-search-for-dark-matter-6800-feet-underground?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Our clumpy cosmos (http://www.symmetrymagazine.org/article/our-clumpy-cosmos?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Aug 3, 2017

The Dark Energy Survey reveals the most accurate measurement of dark matter structure in the universe.

Imagine planting a single seed and, with great precision, being able to predict the exact height of the tree that grows from it. Now imagine traveling to the future and snapping photographic proof that you were right.

If you think of the seed as the early universe, and the tree as the universe the way it looks now, you have an idea of what the Dark Energy Survey (DES) collaboration has just done. In a presentation today at the American Physical Society Division of Particles and Fields meeting at the US Department of Energy's (DOE) Fermi National Accelerator Laboratory, DES scientists will unveil the most accurate measurement ever made of the present large-scale structure of the universe.

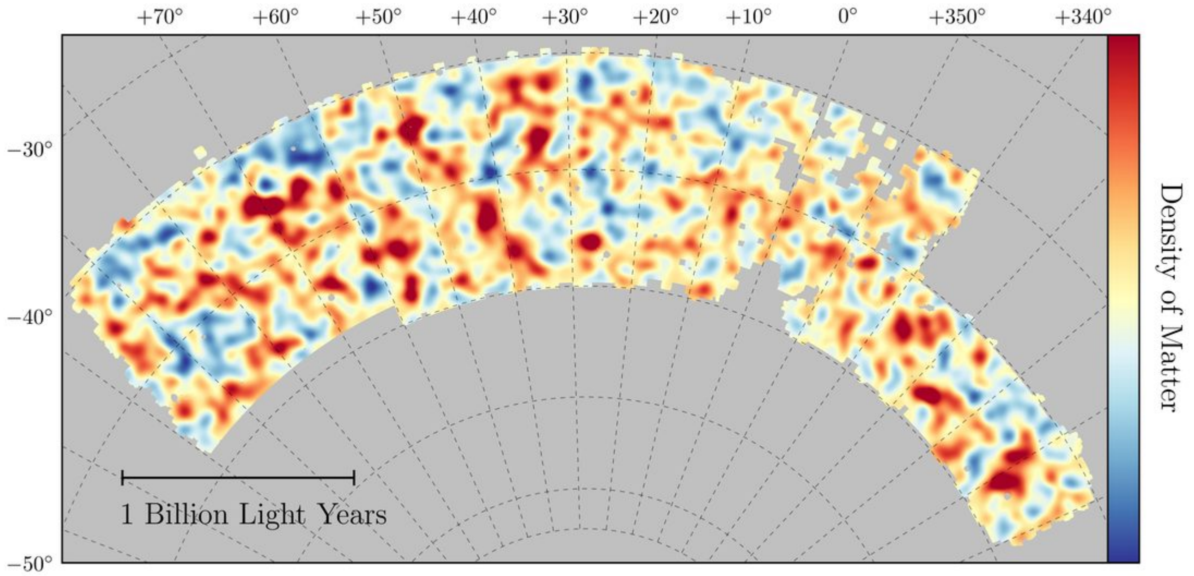
These measurements of the amount and "clumpiness" (or distribution) of dark matter in the present-day cosmos were made with a precision that, for the first time, rivals that of inferences from the early universe by the European Space Agency's orbiting Planck observatory. The new DES result (the tree, in the above metaphor) is close to "forecasts" made from the Planck measurements of the distant past (the seed), allowing scientists to understand more about the ways the universe has evolved over 14 billion years.

"This result is beyond exciting," says Scott Dodelson of Fermilab, one of the lead scientists on this result. "For the first time, we're able to see the current structure of the universe with the same clarity that we can see its infancy, and we can follow the threads from one to the other, confirming many predictions along the way."

Most notably, this result supports the theory that 26 percent of the universe is in the form of mysterious dark matter and that space is filled with an also-unseen dark energy, which is causing the accelerating expansion of the universe and makes up 70 percent.

Paradoxically, it is easier to measure the large-scale clumpiness of the universe in the distant past than it is to measure it today. In the first 400,000 years following the Big Bang, the universe was filled with a glowing gas, the light from which survives to this day. Planck's map of this cosmic microwave background radiation gives us a snapshot of the universe at that very early time. Since then, the gravity of dark matter has pulled mass together and made the universe clumpier over time. But dark energy has been fighting back, pushing matter apart. Using the Planck map as a start, cosmologists can calculate precisely how this battle plays out over 14 billion years.

"The DES measurements, when compared with the Planck map, support the simplest version of the dark matter/dark energy theory," says Joe Zuntz, of the University of Edinburgh, who worked on the analysis. "The moment we realized that our measurement matched the Planck result within 7 percent was thrilling for the entire collaboration."



(http://www.symmetrymagazine.org/sites/default/files/images/standard/DES-year-one-mass-map-full.jpeg)

This map of dark matter is made from gravitational lensing measurements of 26 million galaxies in the Dark Energy Survey. The map covers about 1/30th of the entire sky and spans several billion light-years in extent. Red regions have more dark matter than average, blue regions less dark matter.

Chihway Chang of the Kavli Institute for Cosmological Physics at the University of Chicago and the DES collaboration.
The primary instrument for DES is the 570-megapixel Dark Energy Camera, one of the most powerful in existence, able to capture digital images of light from galaxies eight billion light-years from Earth. The camera was built and tested at Fermilab, the lead laboratory on the Dark Energy Survey, and is mounted on the National Science Foundation's 4-meter Blanco telescope, part of the Cerro Tololo Inter-American Observatory in Chile, a division of the National Optical Astronomy Observatory. The DES data are processed at the National Center for Supercomputing Applications at the University of Illinois at Urbana-Champaign.

Scientists on DES are using the camera to map an eighth of the sky in unprecedented detail over five years. The fifth year of observation will begin in August. The new results released today draw from data collected only during the survey's first year, which covers 1/30th of the sky.

"It is amazing that the team has managed to achieve such precision from only the first year of their survey," says National Science Foundation Program Director Nigel Sharp. "Now that their analysis techniques are developed and tested, we look forward with eager anticipation to breakthrough results as the survey continues."

DES scientists used two methods to measure dark matter. First, they created maps of galaxy positions as tracers, and second, they precisely measured the shapes of 26 million galaxies to directly map the patterns of dark matter over billions of light-years using a technique called gravitational lensing.

To make these ultra-precise measurements, the DES team developed new ways to detect the tiny lensing distortions of galaxy images, an effect not even visible to the eye, enabling revolutionary advances in understanding these cosmic signals. In the process, they created the largest guide to spotting dark matter in the cosmos ever drawn (see image). The new dark matter map is 10 times the size of the one DES released in 2015 and will eventually be three times larger than it is now.

"It's an enormous team effort and the culmination of years of focused work," says Erin Sheldon, a physicist at the DOE's Brookhaven National Laboratory, who co-developed the new method for detecting lensing distortions.

These results and others from the first year of the Dark Energy Survey will be released today online (https://www.darkenergysurvey.org/des-year-1-cosmology-results-papers/) and announced during a talk by Daniel Gruen, NASA Einstein fellow at the Kavli Institute for Particle Astrophysics and Cosmology at DOE's SLAC National Accelerator Laboratory, at 5 pm Central time. The talk is part of the APS Division of Particles and Fields meeting at Fermilab and will be streamed live (http://vms.fnal.gov/asset/livevideo).

The results will also be presented by Kavli fellow Elisabeth Krause of the Kavli Insitute for Particle Astrophysics and Cosmology at SLAC at the TeV Particle Astrophysics Conference in Columbus, Ohio, on Aug. 9; and by Michael Troxel, postdoctoral fellow at the Center for Cosmology and AstroParticle Physics at Ohio State University, at the International Symposium on Lepton Photon Interactions at High Energies in Guanzhou, China, on Aug. 10. All three of these speakers are coordinators of DES science working groups and made key contributions to the analysis.

"The Dark Energy Survey has already delivered some remarkable discoveries and measurements, and they have barely scratched the surface of their data," says Fermilab Director Nigel Lockyer. "Today's world-leading results point forward to the great strides DES will make toward understanding dark energy in the coming years."

A version of this article was published by Fermilab (http://news.fnal.gov/2017/08/dark-energy-survey-reveals-accurate-measurement-dark-matter-structure-universe/).

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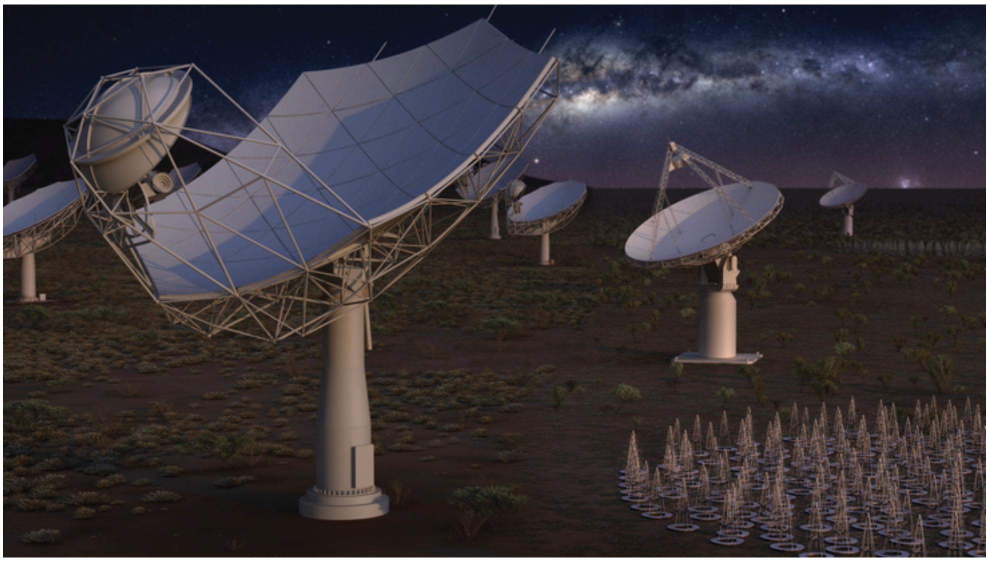
Tuning in for science (http://www.symmetrymagazine.org/article/tuning-in-for-science?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Aug 1, 2017

The sprawling Square Kilometer Array radio telescope hunts signals from one of the quietest places on earth.



When you think of radios, you probably think of noise. But the primary requirement for building the world's largest radio telescope is keeping things almost perfectly quiet.

Radio signals are constantly streaming to Earth from a variety of sources in outer space. Radio telescopes are powerful instruments that can peer into the cosmos—through clouds and dust—to identify those signals, picking them up like a signal from a radio station. To do it, they need to be relatively free from interference emitted by cell phones, TVs, radios and their kin.

That's one reason the Square Kilometer Array is under construction in the Great Karoo, 400,000 square kilometers of arid, sparsely populated South African plain, along with a component in the Outback of Western Australia. The Great Karoo is also a prime location because of its high altitude—radio waves can be absorbed by atmospheric moisture at lower altitudes. SKA currently covers some 1320 square kilometers of the landscape.

Even in the Great Karoo, scientists need careful filtering of environmental noise. Effects from different levels of radio frequency interference (RFI) can range from “blinding” to actually damaging the instruments. Through South Africa’s Astronomy Geographic Advantage Act, SKA is working toward “radio protection,” which would dedicate segments of the bandwidth for radio astronomy while accommodating other private and commercial RF service requirements in the region.

“Interference affects observational data and makes it hard and expensive to remove or filter out the introduced noise,” says Bernard Duah Asabere, Chief Scientist of the Ghana team of the African Very Long Baseline Interferometry Network (African VLBI Network, or AVN), one of the SKA collaboration groups in eight other African nations participating in the project.

SKA “will tackle some of the fundamental questions of our time, ranging from the birth of the universe to the origins of life,” says SKA Director-General Philip Diamond. Among the targets: dark energy, Einstein’s theory of gravity and gravitational waves, and the prevalence of the molecular building blocks of life across the cosmos.

SKA-South Africa can detect radio spectrum frequencies from 350 megahertz to 14 gigahertz. Its partner Australian component will observe the lower-frequency scale, from 50 to 350 megahertz. Visible light, for comparison, has frequencies ranging from 400 to 800 million megahertz. SKA scientists will process radiofrequency waves to form a picture of their source.

A precursor instrument to SKA called MeerKAT (named for the squirrel-sized critters indigenous to the area), is under construction in the Karoo. This array of 16 dishes in South Africa achieved first light on June 19, 2016. MeerKAT focused on 0.01 percent of the sky for 7.5 hours and saw 1300 galaxies—nearly double the number previously known in that segment of the cosmos.

Since then, MeerKAT met another milestone with 32 integrated antennas. MeerKat will also reach its full array of 64 dishes early next year, making it one of the world’s premier radio telescopes. MeerKAT will eventually be integrated into SKA Phase 1, where an additional 133 dishes will be built. That will bring the total number of antennas for SKA Phase I in South Africa to 197 by 2023. So far, 32 dishes are fully integrated and are being commissioned for science operations.

On completion of SKA 2 by 2030, the detection area of the receiver dishes will exceed 1 square kilometer, or about 11,000 square feet. Its huge size will make it 50 times more sensitive than any other radio telescope. It is expected to operate for 50 years.

SKA is managed by a 10-nation consortium, including the UK, China, India and Australia as well as South Africa, and receives support from another 10 countries, including the US. The project is headquartered at Jodrell Bank Observatory in the UK.

The full SKA will use radio dishes across Africa and Australia, and collaboration members say it will have a farther reach and more detailed images than any existing radio telescope.

In preparation for the SKA, South Africa and its partner countries developed AVN to establish a network of radiotelescopes across the African continent. One of its projects is the refurbishing of redundant 30-meter-class antennas, or building new ones across the partner countries, to operate as networked radio telescopes.

The first project of its kind is the AVN Ghana project, where an idle 32-meter diameter dish has been refurbished and revamped with a dual receiver system at 5 and 6.7 gigahertz central frequencies for use as a radio telescope. The dish was previously owned and operated by the government and the company Vodafone Ghana as a telecommunications facility. Now it will explore celestial objects such as extragalactic nebulae, pulsars and other RF sources in space, such as molecular clouds, called masers.

Asabere’s group will be able to tap into areas of SKA’s enormous database (several supercomputers’ worth) over the Internet. So will groups in Botswana, Kenya, Madagascar, Mauritius, Mozambique, Namibia and Zambia. SKA is also offering extensive outreach in participating countries and has already awarded 931 scholarships, fellowships and grants.

Other efforts in Ghana include introducing astronomy in the school curricula, training students in astronomy and related technologies, doing outreach in schools and universities, receiving visiting students at the telescope site and hosting programs such as the West African International Summer School for Young Astronomers taking place this week.

Asabere, who achieved his advanced degrees in Sweden (Chalmers University of Technology) and South Africa (University of Johannesburg), would like to see more students trained in Ghana, and would like get more researchers on board. He also hopes for the construction of the needed infrastructure, more local and foreign partnerships and strong governmental backing.

“I would like the opportunity to practice my profession on my own soil,” he says.

That day might not be far beyond the horizon. The Leverhulme-Royal Society Trust and Newton Fund in the UK are co-funding extensive human capital development programs in the SKA-AVN partner countries. A seven-member Ghanaian team, for example, has undergone training in South Africa and has been instructed in all aspects of the project, including the operation of the telescope.

Several PhD students and one MSc student from Ghana have received SKA-SA grants to pursue further education in astronomy and engineering. The Royal Society has awarded funding in collaboration with Leeds University to train two PhDs and 60 young aspiring scientists in the field of astrophysics.

Based on the success of the Leverhulme-Royal Society program, a joint UK-South Africa Newton Fund intervention (DARA—the Development in Africa with Radio Astronomy) has since been initiated in other partner countries to grow high technology skills that could lead to broader economic development in Africa.

As SKA seeks answers to complex questions over the next five decades, there should be plenty of opportunities for science throughout the Southern Hemisphere. Though it lives in one of the quietest places, SKA hopes to be heard loud and clear.

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An underground groundbreaking (http://www.symmetrymagazine.org/article/an-underground-groundbreaking?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Jul 31, 2017

A physics project kicks off construction a mile underground.

For many government officials, groundbreaking ceremonies are probably old hat—or old hardhat. But how many can say they've been to a groundbreaking that's nearly a mile underground?

A group of dignitaries, including a governor and four members of Congress, now have those bragging rights. On July 21, they joined scientists and engineers 4850 feet beneath the surface at the Sanford Underground Research Facility to break ground on the Long-Baseline Neutrino Facility (LBNF).

LBNF will house massive, four-story-high detectors for the Deep Underground Neutrino Experiment (DUNE) to learn more about neutrinos—invisible, almost massless particles that may hold the key to how the universe works and why matter exists. Fourteen shovels full of dirt marked the beginning of construction for a project that could be, well, groundbreaking.

The Sanford Underground Research Facility in Lead, South Dakota resides in what was once the deepest gold mine in North America, which has been repurposed as a place for discovery of a different kind.

"A hundred years ago, we mined gold out of this hole in the ground. Now we're going to mine knowledge," said US Representative Kristi Noem of South Dakota in an address at the groundbreaking.

Transforming an old mine into a lab is more than just a creative way to reuse space. On the surface, cosmic rays from the sun constantly bombard us, causing cosmic noise in the sensitive detectors scientists use to look for rare particle interactions. But underground, shielded by nearly a mile of rock, there's cosmic quiet. Cosmic rays are rare, making it easier for scientists to see what's going on in their detectors without being clouded by interference.

Going down?

It may be easier to analyze data collected underground, but entering the subterranean science facility can be a chore. Nearly 60 people took a trip underground to the groundbreaking site, requiring some careful elevator choreography.

Before venturing into the deep below, reporters and representatives alike donned safety glasses, hardhats and wearable flashlights. They received two brass tags engraved with their names—one to keep and another to hang on a corkboard—a process called "brassing in." This helps keep track of who's underground in case of emergency.

The first group piled into the open-top elevator, known as a cage, to begin the descent. As the cage glides through a mile of mountain, it's easy to imagine what it must have been like to be a miner back when Sanford Lab was the Homestake Mine. What's waiting below may have changed, but the method of getting there hasn't: The winch lowering the cage at 500-feet-a-minute is 80 years old and still works perfectly.

The ride to the 4850-level takes about 10 minutes in the cramped cage—it fits 35, but even with 20 people it feels tight. Water drips in through the ceiling as the open elevator chugs along, occasionally passing open mouths in the rock face of drifts once mined for gold.

"When you go underground, you start to think 'It has never rained in here. And there's never been daylight,'" says Tim Meyer, Chief Operating Officer of Fermilab, who attended the groundbreaking. "When you start thinking about being a mile below the surface, it just seems weird, like you're walking through a piece of Swiss cheese."

Where the cage stops at the 4850-level would be the destination of most elevator occupants on a normal day, since the shaft ends near the entrance of clean research areas housing Sanford Lab experiments. But for the contingent traveling to the future site of LBNF/DUNE on the other end of the mine, the journey continued, this time in an open-car train. It's almost like a theme-park ride as the motor (as it's usually called by Sanford staff) clips along through a tunnel, but fortunately, no drops or loop-the-loops are involved.

“The same rails now used to transport visitors and scientists were once used by the Homestake miners to remove gold from the underground facility,” says Jim Siegrist, Associate Director of High Energy Physics at the Department of Energy. “During the ride, rock bolts and protective screens attached to the walls were visible by the light of the headlamp mounted on our hardhats.”

After a 15-minute ride, the motor reached its destination and it was business as usual for a groundbreaking ceremony: speeches, shovels and smiling for photos. A fresh coat of white paint (more than 100 gallons worth) covered the wall behind the officials, creating a scene that almost could have been on the surface.

“Celebrating the moment nearly a mile underground brought home the enormity of the task and the dedication required for such precise experiments,” says South Dakota Governor Dennis Daugaard. “I know construction will take some time, but it will be well worth the wait for the Sanford Underground Research Facility to play such a vital role in one of the most significant physics experiments of our time."

What’s the big deal?

The process to reach the groundbreaking site is much more arduous than reaching most symbolic ceremonies, so what would possess two senators, two representatives, a White House representative, a governor and delegates from three international science institutions (to mention a few of the VIPs) to make the trip? Only the beginning of something huge—literally.

“This milestone represents the start of construction of the largest mega-science project in the United States,” said Mike Headley, executive director of Sanford Lab.

The 14 shovelers at the groundbreaking made the first tiny dent in the excavation site for LBNF, which will require the extraction of more than 870,000 tons of rock to create huge caverns for the DUNE detectors. These detectors will catch neutrinos sent 800 miles through the earth from Fermi National Accelerator Laboratory in the hopes that they will tell us something more about these strange particles and the universe we live in.

“We have the opportunity to see truly world-changing discovery,” said US Representative Randy Hultgren of Illinois. “This is unique—this is the picture of incredible discovery and experimentation going into the future.”

Read More... (http://www.symmetrymagazine.org/article/an-underground-groundbreaking?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Angela Fava: studying neutrinos around the globe (http://www.symmetrymagazine.org/article/angela-fava-studying-neutrinos-around-the-globe?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Jul 26, 2017

This experimental physicist has followed the ICARUS neutrino detector from Gran Sasso to Geneva to Chicago.

Physicist Angela Fava has been at the enormous ICARUS detector’s side for over a decade. As an undergraduate student in Italy in 2006, she worked on basic hardware for the neutrino hunting experiment: tightening bolts and screws, connecting and reconnecting cables, learning how the detector worked inside and out.

ICARUS (short for Imaging Cosmic And Rare Underground Signals) first began operating for research in 2010, studying a beam of neutrinos created at European laboratory CERN and launched straight through the earth hundreds of miles to the detector’s underground home at INFN Gran Sasso National Laboratory.

In 2014, the detector moved to CERN for refurbishing, and Fava relocated with it. In June ICARUS began a journey across the ocean to the US Department of Energy’s Fermi National Accelerator Laboratory to take part in a new neutrino experiment. When it arrives today, Fava will be waiting.

Fava will go through the installation process she helped with as a student, this time as an expert.

(http://www.symmetrymagazine.org/sites/default/files/images/standard/ICARUS_1-s_0.jpg)
Caraban Gonzalez, Noemi Ordan, Julien Marius, CERN

Journey to ICARUS

As a child growing up between Venice and the Alps, Fava always thought she would pursue a career in math. But during a one-week summer workshop before her final year of high school in 2000, she was drawn to experimental physics.

At the workshop, she realized she had more in common with physicists. Around the same time, she read about new discoveries related to neutral, rarely interacting particles called neutrinos. Scientists had recently been surprised to find that the extremely light particles actually had mass and that different types of neutrinos could change into one another. And there was still much more to learn about the ghostlike particles.

At the start of college in 2001, Fava immediately joined the University of Padua neutrino group. For her undergraduate thesis research, she focused on the production of hadrons, making measurements essential to studying the production of neutrinos. In 2004, her research advisor Alberto Guglielmi and his group joined the ICARUS collaboration, and she's been a part of it ever since.

Fava jests that the relationship actually started much earlier: "ICARUS was proposed for the first time in 1983, which is the year I was born. So we are linked from birth."

Fava remained at the University of Padua in the same research group for her graduate work. During those years, she spent about half of her time at the ICARUS detector, helping bring it to life at Gran Sasso.

Once all the bolts were tightened and the cables were attached, ICARUS scientists began to pursue their goal of using the detector to study how neutrinos change from one type to another.

During operation, Fava switched gears to create databases to store and log the data. She wrote code to automate the data acquisition system and triggering, which differentiates between neutrino events and background such as passing cosmic rays. "I was trying to take part in whatever activity was going on just to learn as much as possible," she says.

That flexibility is a trait that Claudio Silverio Montanari, the technical director of ICARUS, praises. "She has a very good capability to adapt," he says. "Our job, as physicists, is putting together the pieces and making the detector work."

(http://www.symmetrymagazine.org/sites/default/files/images/standard/ICARUS_2-s.jpg)
Caraban Gonzalez, Noemi Ordan, Julien Marius, CERN

Changing it up

Adapting to changing circumstances is a skill both Fava and ICARUS have in common. When scientists proposed giving the detector an update at CERN and then using it in a suite of neutrino experiments at Fermilab, Fava volunteered to come along for the ride.

Once installed and operating at Fermilab, ICARUS will be used to study neutrinos from a source a few hundred meters away from the detector. In its new iteration, ICARUS will search for sterile neutrinos, a hypothetical kind of neutrino that would interact even more rarely than standard neutrinos. While hints of these low-mass particles have cropped up in some experiments, they have not yet been detected.

At Fermilab, ICARUS also won't be buried below more than half a mile of rock, a feature of the INFN setup that shielded it from cosmic radiation from space. That means the triggering system will play an even bigger role in this new experiment, Fava says.

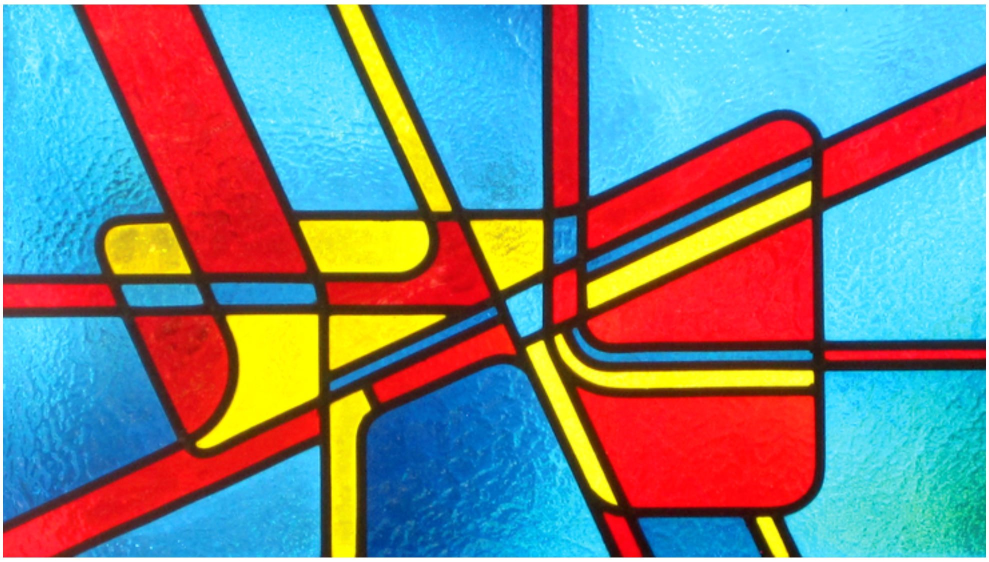
"We have a great challenge ahead of us." She's up to the task.

Read More... (http://www.symmetrymagazine.org/article/angela-fava-studying-neutrinos-around-the-globe?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Turning plots into stained glass (http://www.symmetrymagazine.org/article/turning-plots-into-stained-glass?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Jul 25, 2017

Hubert van Hecke, a heavy-ion physicist, transforms particle physics plots into works of art.



At first glance, particle physicist Hubert van Hecke's stained glass windows simply look like unique pieces of art. But there is much more to them than pretty shapes and colors. A closer look reveals that his creations are actually renditions of plots from particle physics experiments.

Van Hecke learned how to create stained glass during his undergraduate years at Louisiana State University. "I had an artistic background—my father was a painter, so I thought, if I need a humanities credit, I'll just sign up for this," van Hecke recalls. "So in order to get my physics' bachelors, I took stained glass."

Over the course of two semesters, van Hecke learned how to cut pieces of glass from larger sheets, puzzle them together, then solder and caulk the joints. “There were various assignments that gave you an enormous amount of elbow room,” he says. “One of them was to do something with Fibonacci numbers, and one was pick your favorite philosopher and made a window related to their work.”

Van Hecke continued to create windows and mirrors throughout graduate school but stopped for many years while working as a full-time heavy-ion physicist at Los Alamos National Laboratory and raising a family. Only recently did he return to his studio—this time, to create pieces inspired by physics.

“I had been thinking about designs for a long time—then it struck me that occasionally, you see plots that are interesting, beautiful shapes,” van Hecke says. “So I started collecting pictures as I saw them.”

Hubert van Hecke

His first plot-based window, a rectangle-shaped piece with red, orange and yellow glass, was inspired by the results of a neutrino flavor oscillation study from the MiniBooNE experiment at Fermi National Accelerator Laboratory. He created two pieces after that, one from a plot generated during the hunt for the Higgs boson at the Tevatron, also at Fermilab and the other based on an experiment with quarks and gluons.

According to van Hecke, what inspires him about these plots is “purely the shapes.”

“In terms of the physics, it's what I run across—for example, I see talks about heavy ion physics, elementary particle physics, and neutrinos, [but] I haven't really gone out and searched in other fields,” he says. “Maybe there are nice plots in biology or astronomy.”

Although van Hecke has not yet displayed his pieces publicly, if he does one day, he plans to include explanations for the phenomena the plots illustrate, such as neutrinos and the Standard Model, as a unique way to communicate science.

But before that, van Hecke plans to create more stained glass windows. As of two months ago, he is semiretired—and in between runs to Fermilab, where he is helping with the effort to use Argonne National Laboratory's SeaQuest experiment to search for dark photons, he hopes to spend more time in the studio creating the pieces left on the drawing board, which include plots found in experiments investigating the Standard Model, neutrinoless double decay and dark matter interactions.

“I hope to make a dozen or more,” he says. “As I bump into plots, I'll collect them and hopefully, turn them all into windows.”

Hubert van Hecke

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Watch the underground groundbreaking (http://www.symmetrymagazine.org/article/watch-the-underground-groundbreaking?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Jul 21, 2017

This afternoon, watch a livestream of the start of excavation for the future home of the Deep Underground Neutrino Experiment.

Today in South Dakota, dignitaries, scientists and engineers will mark the start of construction of the future home of America's flagship neutrino experiment with a groundbreaking ceremony.

Participants will hold shovels and give speeches. But this will be no ordinary groundbreaking. It will take place a mile under the earth at Sanford Underground Research Facility, the deepest underground physics lab in the United States.

The groundbreaking will celebrate the beginning of excavation for the Long-Baseline Neutrino Facility, which will house the Deep Underground Neutrino Experiment. When complete, LBNF/DUNE will be the largest experiment ever built in the US to study the properties of mysterious particles called neutrinos. Unlocking the mysteries of these particles could help explain more about how the universe works and why matter exists at all.

Watch the underground groundbreaking at 2:20 p.m. Mountain Time (3:20 p.m. Central) via livestream (http://vms.fnal.gov/w1/groundbreaking.htm).

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Shaking the dark matter paradigm (http://www.symmetrymagazine.org/article/shaking-the-dark-matter-paradigm?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Jul 18, 2017

A theory about gravity challenges our understanding of the universe.

For millennia, humans held a beautiful belief. Our planet, Earth, was at the center of a vast universe, and all of the planets and stars and celestial bodies revolved around us. This geocentric model, though it had floated around since 6th century BCE, was written in its most elegant form by Claudius Ptolemy in 140 AD.

When this model encountered problems, such as the retrograde motions of planets, scientists reworked the data to fit the model by coming up with phenomena such as epicycles, mini orbits.

It wasn't until 1543, 1400 years later, that Nicolaus Copernicus set in motion a paradigm shift that would give way to centuries of new discoveries. According to Copernicus' radical theory, Earth was not the center of the universe but simply one of a long line of planets orbiting around the sun.

But even as evidence that we lived in a heliocentric system piled up and scientists such as Galileo Galilei perfected the model, society held onto the belief that the entire universe orbited around Earth until the early 19th century.

To Erik Verlinde, a theoretical physicist at the University of Amsterdam, the idea of dark matter is the geocentric model of the 21st century.

"What people are doing now is allowing themselves free parameters to sort of fit the data," Verlinde says. "You end up with a theory that has so many free parameters it's hard to disprove."

Dark matter, an as-yet-undetected form of matter that scientists believe makes up more than a quarter of the mass and energy of the universe, was first theorized when scientists noticed that stars at the outer edges of galaxies and galaxy clusters were moving much faster than Newton's theory of gravity said they should. Up until this point, scientists have assumed that the best explanation for this is that there must be missing mass in the universe holding those fast-moving stars in place in the form of dark matter.

But Verlinde has come up with a set of equations that explains these galactic rotation curves by viewing gravity as an emergent force — a result of the quantum structure of space.

The idea is related to dark energy, which scientists think is the cause for the accelerating expansion of our universe. Verlinde thinks that what we see as dark matter is actually just interactions between galaxies and the sea of dark energy in which they're embedded.

"Before I started working on this I never had any doubts about dark matter," Verlinde says. "But then I started thinking about this link with quantum information and I had the idea that dark energy is carrying more of the dynamics of reality than we realize."

Verlinde is not the first theorist to come up with an alternative to dark matter. Many feel that his theory echoes the sentiment of physicist Mordehai Milgrom's equations of "modified Newtonian dynamics," or MOND. Just as Einstein modified Newton's laws of gravity to fit to the scale of planets and solar systems, MOND modifies Einstein's laws of gravity to fit to the scale of galaxies and galaxy clusters.

Verlinde, however, makes the distinction that he's not deriving the equations of MOND, rather he's deriving what he calls a "scaling relation," or a volume effect of space-time that only becomes important at large distances.

Stacy McGaugh, an astrophysicist at Case Western Reserve University, says that while MOND is primarily the notion that the effective force of gravity changes with acceleration, Verlinde's ideas are more of a ground-up theoretical work.

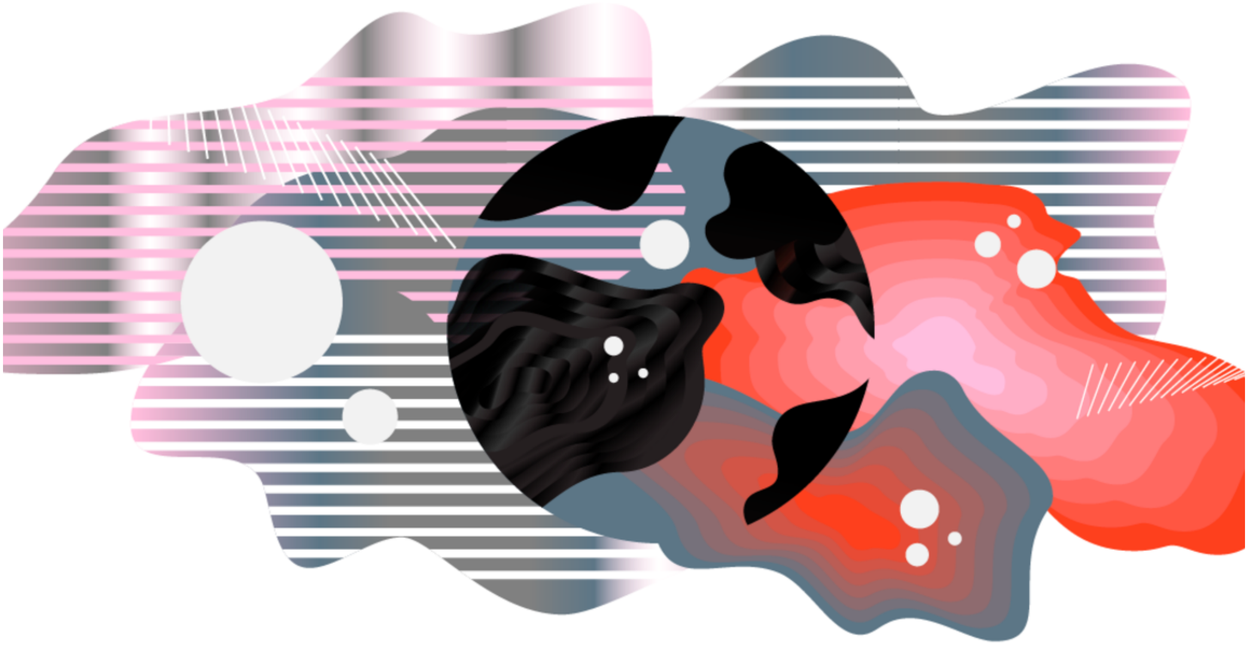
"He's trying to look at the structure of space-time and see if what we call gravity is a property that emerges from that quantum structure, hence the name emergent gravity," McGaugh says. "In principle, it's a very different approach that doesn't necessarily know about MOND or have anything to do with it."

One of the appealing things about Verlinde's theory, McGaugh says, is that it naturally produces evidence of MOND in a way that "just happens."

"That's the sort of thing that one looks for," McGaugh says. "There needs to be some basis of why MOND happens, and this theory might provide it."

Verlinde's ideas have been greeted with a fair amount of skepticism in the scientific community, in part because, according to Kathryn Zurek, a theoretical physicist at the US Department of Energy's Lawrence Berkeley National Laboratory, his theory leaves a lot unexplained.

"Theories of modified gravity only attempt to explain galactic rotation curves [those fast-moving planets]," Zurek says. "As evidence for dark matter, that's only one very small part of the puzzle. Dark matter explains a whole host of observations from the time of the cosmic microwave background when the universe was just a few hundred thousand years old through structure formation all the way until today."



(http://www.symmetrymagazine.org/sites/default/files/images/standard/Inline.png)

Illustration by Ana Kova

Zurek says that in order for scientists to start lending weight to his claims, Verlinde needs to build the case around his theory and show that it accommodates a wider range of observations. But, she says, this doesn't mean that his ideas should be written off.

"One should always poke at the paradigm," Zurek says, "even though the cold dark matter paradigm has been hugely successful, you always want to check your assumptions and make sure that you're not missing something that could be the tip of the iceberg."

McGaugh had a similar crisis of faith in dark matter when he was working on an experiment wherein MOND's predictions were the only ones that came true in his data. He had been making observations of low-surface-brightness galaxies, wherein stars are spread more thinly than galaxies such as the Milky Way where the stars are crowded relatively close together.

McGaugh says his results did not make sense to him in the standard dark matter context, and it turned out that the properties that were confusing to him had already been predicted by Milgrom's MOND equations in 1983, before people had even begun to take seriously the idea of low-surface-brightness galaxies.

Although McGaugh's experience caused him to question the existence of dark matter and instead argue for MOND, others have not been so quick to join the cause.

"We subscribe to a particular paradigm and most of our thinking is constrained within the boundaries of that paradigm, and so if we encounter a situation in which there is a need for a paradigm shift, it's really hard to think outside that box," McGaugh says. "Even though we have rules for the game as to when you're supposed to change your mind and we all in principle try to follow that, in practice there are some changes of mind that are so big that we just can't overcome our human nature."

McGaugh says that many of his colleagues believe that there's so much evidence for dark matter that it's a waste of time to consider any alternatives. But he believes that all of the evidence for dark matter might instead be an indication that there is something wrong with our theories of gravity.

"I kind of worry that we are headed into another thousand years of dark epicycles," McGaugh says.

But according to Zurek, if MOND came up with anywhere near the evidence that has been amassed for the dark matter paradigm, people would be flocking to it. The problem, she says, is that at the moment MOND just does not come anywhere near to passing the number of tests that cold dark matter has. She adds that there are some physicists who argue that the cold dark matter paradigm can, in fact, explain those observations about low-surface-brightness galaxies.

Recently, Case Western held a workshop wherein they gathered together representatives from different communities, including those working on dark matter models, to discuss dwarf galaxies and the external field effect, which is the notion that very low-density objects will be affected by what's around them. MOND predicts that the dynamics of a small satellite galaxy will depend on its proximity to its giant host in a way that doesn't happen with dark matter.

McGaugh says that in attendance at the workshop were a group of more philosophically inclined people who use a set of rules to judge theories, which they've put together by looking back at how theories have developed in the past.

"One of the interesting things that came out of that was that MOND is doing better on that score card," he says. "It's more progressive in the sense that it's making successful predictions for new phenomena whereas in the case of dark matter we've had to repeatedly invoke ad hoc fixes to patch things up."

Verlinde's ideas, however, didn't come up much within the workshop. While McGaugh says that the two theories are closely enough related that he would hope the same people pursuing MOND would be interested in Verlinde's theory, he added that not everyone shares that attitude. Many are waiting for more theoretical development and further observational tests.

"The theory needs to make a clear prediction so that we can then devise a program to go out and test it," he says. "It needs to be further worked out to get beyond where we are now."

Verlinde says he realizes that he still needs to develop his ideas further and extend them to explain things such as the formation of galaxies and galaxy clusters. Although he has mostly been working on this theory on his own, he recognizes the importance of building a community around his ideas.

Over the past few months, he has been giving presentations at different universities, including Princeton, Harvard, Berkeley, Stanford, and Caltech. There is currently a large community of people working on ideas of quantum information and gravity, he says, and his main goal is to get more people, in particular string theorists, to start thinking about his ideas to help him improve them.

“I think that when we understand gravity better and we use those equations to describe the evolution of the universe, we may be able to answer questions more precisely about how the universe started,” Verlinde says. “I really think that the current description is only part of the story and there's a much deeper way of understanding it—maybe an even more beautiful way.”

Read More... (http://www.symmetrymagazine.org/article/shaking-the-dark-matter-paradigm?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

SLAC accelerator plans appear in Smithsonian art exhibit (http://www.symmetrymagazine.org/article/slac-accelerator-plans-appear-in-smithsonian-art-exhibit?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Jul 13, 2017

The late artist June Schwarcz found inspiration in some unusual wrapping paper her husband brought home from the lab.

Leroy Schwarcz, one of the first engineers hired to build SLAC National Accelerator Laboratory’s original 2-mile-long linear accelerator, thought his wife might like to use old mechanical drawings of the project as wrapping paper. So, he brought them home.

His wife, acclaimed enamelist June Schwarcz, had other ideas.

Today, works called *SLAC Drawing III*, *VII* and *VIII*, created in 1974 and 1975 from electroplated copper and enamel, form a unique part of a retrospective at the Smithsonian’s Renwick Gallery in Washington, D.C.

Among the richly formed and boldly textured and colored vessels that make up the majority of June’s oeuvre, the SLAC-inspired panels stand out for their fidelity to the mechanical design of their inspiration.

The description next to the display at the gallery describe the “SLAC Blueprints” as resembling “ancient pictographs drawn on walls of a cave or glyphs carved in stone.” The designs appear to depict accelerator components, such as electromagnets and radio frequency structures.

According to Harold B. Nelson, who curated the exhibit with Bernard N. Jazzar, “The panels are quite unusual in the subtle color palette she chose; in her use of predominantly opaque enamels; in her reliance on a rectilinear, geometric format for her compositions; and in her reference in the work to machines, plans, numbers, and mechanical parts.

“We included them because they are extremely beautiful and visually powerful. Together they form an important group within her body of work.”

Making history

June and Leroy Schwarcz met in the late 1930s and were married in 1943. Two years later they moved to Chicago where Leroy would become chief mechanical engineer for the University of Chicago’s synchrocyclotron, which was at the time the highest-energy proton accelerator in the world.

Having studied art and design at the Pratt Institute in Brooklyn several years earlier, June found her way into a circle of notable artists in Chicago, including Bauhaus legend László Moholy-Nagy, founder of Chicago’s Institute of Design.

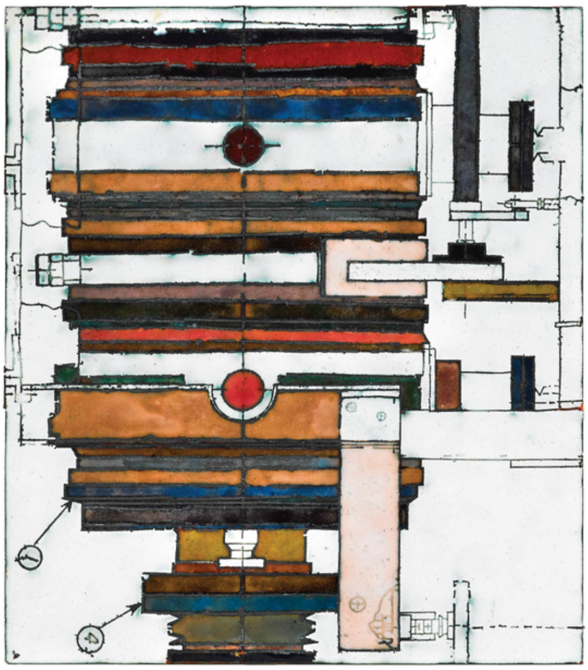
Around 1954, June was introduced to enameling and shortly thereafter began to exhibit her art. She and her husband had two children and relocated several times during the 1950s for Leroy’s work. In 1958 they settled in Sausalito, California, where June set up her studio in the lower level of their hillside home.

In 1961, Leroy became the first mechanical engineer hired by Stanford University to work on “Project M (http://www.slac.stanford.edu/history/projectm.shtml),” which would become the famous 2-mile-long linear accelerator at SLAC. He oversaw the engineers during early design and construction of the linac, which eventually enabled Nobel-winning particle physics research.

June and Leroy’s daughter, Kim Schwarcz, who made a living as a glass blower and textile artist until the mid 1980s and occasionally exhibited with her mother, remembers those early days at the future lab.

"Before SLAC was built, the offices were in Quonset huts, and my father used to bring me down, and I would bicycle all over the campus," she recalled. "Pief was a family friend and so was Bob Mozley. Mom introduced Bob to his future wife…It was a small community and a really nice community."

W.K.H. "Pief" Panofsky was the first director of SLAC; he and Mozley were renowned SLAC physicists and national arms control experts.



June Schwarcz, SLAC Drawing III, 1974, electroplated copper and enamel. (Photo by Cate Hurst)

Finding beauty

Kim was not surprised that her mother made art based on the SLAC drawings. She remembers June photographing the foggy view outside their home and getting inspiration from nature, ethnic art and Japanese clothing.

"She would take anything and make something out of it," Kim said. "She did an enamel of an olive oil can once and a series called *Adam's Pants* that were based on the droopy pants my son wore as a teen."

But the fifteen SLAC-inspired compositions were unique and a family favorite; Kim and her brother Carl both own some of them, and others are at museums.

In a 2001 oral history interview (https://www.aaa.si.edu/collections/interviews/oral-history-interview-june-schwarcz-12744) with the Smithsonian Institution's Archives of American Art, June explained the detailed work involved in creating the SLAC drawings by varnishing, scribing, electroplating and enameling a copper sheet: "I'm primarily interested in having things that are beautiful, and of course, beauty is a complicated thing to devise, to find."

Engineering art

Besides providing inspiration in the form of technical drawings, Leroy was influential in June's career in other ways.

Around 1962 he introduced her to Jimmy Pope at the SLAC machine shop, who showed June how to do electroplating, a signature technique of her work. Electroplating involves using an electric current to deposit a coating of metal onto another material. She used it to create raised surfaces and to transform thin sheets of copper—which she stitched together using copper wire—into substantial, free-standing vessel-like forms. She then embellished these sculptures with colored enamel.

Leroy built a 30-gallon plating bath and other tools for June's art-making at their shared workshop.

"Mom was tiny, 5 feet tall, and she had these wobbly pieces on the end of a fork that she would put into a hot kiln. It was really heavy. Dad made a stand so she could rest her arm and slide the piece in," Kim recalls.

"He was very inventive in that way, and very creative himself," she said. "He did macramé in the 1960s, made wooden spoons and did scrimshaw carvings on bone that were really good."

Kim remembers the lower-level workshop as a chaotic and inventive space. "For the longest time, there was a wooden beam in the middle of the workshop we would trip over. It was meant for a boat dad wanted to build—and eventually did build after he retired," she said.

At SLAC Leroy's work was driven by his "amazingly good intuition," according to a tribute written by Mozley upon his colleague's death in 1993. Even when he favored crude drawings to exact math, "his intuitive designs were almost invariably right," he wrote.

After the accelerator was built, Leroy turned his attention to the design, construction and installation of a streamer chamber scientists at SLAC used as a particle detector. In 1971 he took a leave of absence from the California lab to go back to Chicago and move the synchrocyclotron's 2000-ton magnet from the university to Fermi National Accelerator Laboratory.

"[Leroy] was the only person who could have done this because, although drawings existed, knowledge of the assembly procedures existed only in the minds of Leroy and those who had helped him put the cyclotron together," Mozley wrote.

Beauty on display

June continued making art at her Sausalito home studio up until two weeks before her death in 2015 at the age of 97. A 2007 video (https://www.youtube.com/watch?v=AadcRrCwiy4) shows the artist at work there 10 years prior to her passing.

After Leroy died, her own art collection expanded on the shelves and walls of her home.

“As a kid, the art was just what mom did, and it never changed,” Kim remembers. “She couldn’t wait for us to go to school so she could get to work, and she worked through health challenges in later years.”

The Smithsonian exhibit is a unique collection of June’s celebrated work, with its traces of a shared history with SLAC and one of the lab’s first mechanical engineers.

“June had an exceptionally inquisitive mind, and we think you get a sense of the rich breadth of her vision in this wonderful body of work,” says curator Jazzar.

June Schwarcz: Invention and Variation is the first retrospective of the artist’s work in 15 years and includes almost 60 works. The exhibit (http://americanart.si.edu/exhibitions/archive/2017/schwarcz/) runs through August 27 at the Smithsonian American Art Museum Renwick Gallery.

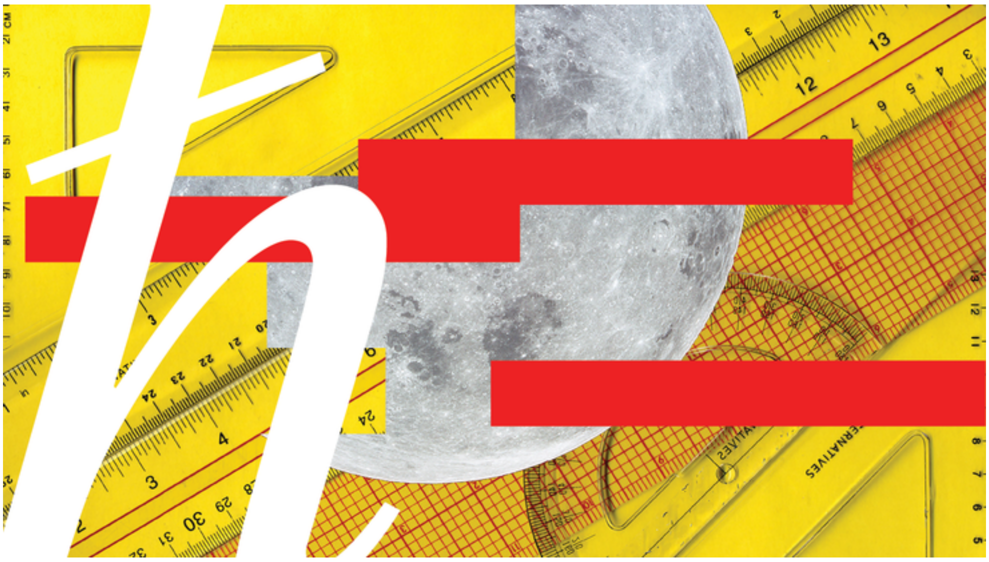
Editor's note: Some of the information from this article was derived from an essay written by Jazzar and Nelson that appears in a book based on the exhibition with the same title.

Read More... (http://www.symmetrymagazine.org/article/slac-accelerator-plans-appear-in-smithsonian-art-exhibit?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

A new model for standards (http://www.symmetrymagazine.org/article/a-new-model-for-standards?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Jul 11, 2017

In an upcoming refresh, particle physics will define units of measurement such as the meter, the kilogram and the second.



While America remains obstinate about using Imperial units such as miles, pounds and degrees Fahrenheit, most of the world has agreed that using units that are actually divisible by 10 is a better idea. The metric system, also known as the International System of Units (SI), is the most comprehensive and precise system for measuring the universe that humans have developed.

In 2018, the 26th General Conference on Weights and Measures will convene and likely adopt revised definitions for the seven base metric system units for measuring: length, mass, time, temperature, electric current, luminosity and quantity.

The modern metric system owes its precision to particle physics, which has the tools to investigate the universe more precisely than any microscope. Measurements made by particle physicists can be used to refine the definitions of metric units. In May, a team of German physicists at the Physikalisch-Technische Bundesanstalt made the most precise measurements yet of the Boltzmann constant, which will be used to define units of temperature.

Since the metric system was established in the 1790s, scientists have attempted to give increasingly precise definitions to these units. The next update will define every base unit using fundamental constants of the universe that have been derived by particle physics.

meter (distance):

Starting in 1799, the meter was defined by a prototype meter bar, which was just a platinum bar. Physicists eventually realized that distance could be defined by the speed of light, which has been measured with an accuracy to one part in a billion using an interferometer (interestingly, the same type of detector the LIGO collaboration used to discover gravitational waves). The meter is currently defined as the distance traveled by light (in a vacuum) for 1/299,792,458 of a second, and will remain effectively unchanged in 2018.

kilogram (mass):

For over a century, the standard kilogram has been a small platinum-iridium cylinder housed at the International Bureau of Weights and Measures in France. But even its precise mass fluctuates due to factors such as accumulation of microscopic dust. Scientists hope to redefine the kilogram in 2018 by setting the value of Planck’s constant to exactly 6.626070040×10^{34} kilograms times meters squared per second. Planck’s constant is the smallest amount of quantized energy possible. This fundamental value, which is represented with the letter h, is integral to calculating energies in particle physics.

second (time):

The earliest seconds were defined as divisions of time between full moons. Later, seconds were defined by solar days, and eventually the time it took Earth to revolve around the sun. Today, seconds are defined by atomic time, which is precise to 1 part in 10 billion. Atomic time is calculated by periods of radiation by atoms, a measurement that relies heavily on particle physics techniques. One second is currently defined as 9,192,631,770 periods of the radiation for a Cesium-133 atom and will remain effectively unchanged.

kelvin (temperature):

Kelvin is the temperature scale that starts at the coldest possible state of matter. Currently, a kelvin is defined by the triple point of water—where water can exist as a solid, liquid and gas. The triple point is 273.16 Kelvin, so a single kelvin is 1/273.16 of the triple point. But because water can never be completely pure, impurities can influence the triple point. In 2018 scientists hope to redefine kelvin by setting the value of Boltzmann's constant to exactly $1.38064852\times10^{?23}$ joules per kelvin. Boltzmann's constant links the movement of particles in a gas (the average kinetic energy) to the temperature of the gas. Denoted by the symbol k, the Boltzmann constant is ubiquitous throughout physics calculations that involve temperature and entropy.

ampere (electric current):

André-Marie Ampère, who is often considered the father of electrodynamics, has the honor of having the basic unit of electric current named after him. Right now, the ampere is defined by the amount of current required to produce of a force of $2\times10^{?7}$ newtons for each meter between two parallel conductors of infinite length. Naturally, it's a bit hard to come by things of infinite length, so the proposed definition is instead to define amperes by the fundamental charge of a particle. This new definition would rely on the charge of the electron, which will be set to $1.6021766208\times10^{?19}$ amperes times seconds.

candela (luminosity):

The last of the base SI units to be established, the candela measures luminosity—what we typically refer to as brightness. Early standards for the candela used a phenomenon from quantum mechanics called "black body radiation." This is the light that all objects radiate as a function of their heat. Currently, the candela is defined more fundamentally as 1/683 watt per square radian at a frequency of 540×10^{12} herz over a certain area, a definition which will remain effectively unchanged. Hard to picture? A candle, conveniently, emits about one candela of luminous intensity.

mole (quantity):

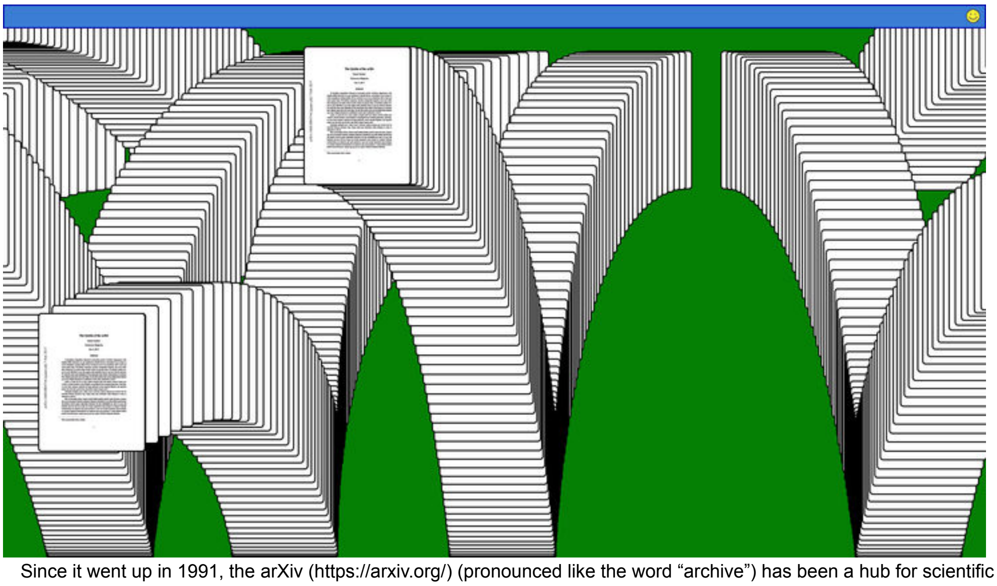
Different from all the other base units, the mole measures quantity alone. Over hundreds of years, scientists starting from Amedeo Avogadro worked to better understand how the number of atoms was related to mass, leading to the current definition of the mole: the number of atoms in 12 grams of carbon-12. This number, which is known as Avogadro's constant and used in many calculations of mass in particle physics, is about 6 x 10^{23}. To make the mole more precise, the new definition would set Avogadro's constant to exactly 6.022140857×10^{23}, decoupling it from the kilogram.

Read More... (http://www.symmetrymagazine.org/article/a-new-model-for-standards?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Quirks of the arXiv (http://www.symmetrymagazine.org/article/quirks-of-the-arxiv?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Jul 7, 2017

Sometimes, physics papers turn funny.



Since it went up in 1991, the arXiv (https://arxiv.org/) (pronounced like the word "archive") has been a hub for scientific papers in quantitative fields such as physics, math and computer science. Many of its million-plus papers are serious products of intense academic work that are later published in peer-reviewed journals. Still, some manage to have a little more character than the rest. For your consideration, we've gathered seven of the quirkiest physics papers on the arXiv.

Can apparent superluminal neutrino speeds be explained as a quantum weak measurement?

M V Berry, N Brunner, S Popescu and P Shukla

Read full paper (PDF) (https://arxiv.org/pdf/1110.2832.pdf)

In 2011, an experiment appeared to find particles traveling faster than the speed of light. To spare readers uninterested in lengthy calculations demonstrating the unlikeliness of this probably impossible phenomenon, the abstract for this analysis cut to the chase.

Paper Thumbnail

Quantum Tokens for Digital Signatures

Shalev Ben-David and Or Sattath

Read full paper (PDF) (https://arxiv.org/pdf/1609.09047.pdf)

Sometimes the best way to explain something is to think about how you might explain it to a child—for example, as a fairy tale.

Paper Thumbnail

A dialog on quantum gravity

Carlo Rovelli

Read full paper (PDF) (https://arxiv.org/pdf/hep-th/0310077v2.pdf)

Unless you're intimately familiar with string theory and quantum loop gravity, this Socratic dialogue is like Plato's *Republic*: It's all Greek to you.

Paper Thumbnail

The Proof of Innocence

Dmitri Krioukov

Read full paper (PDF) (https://arxiv.org/pdf/1204.0162.pdf)

Pulled over after he was apparently observed failing to halt at a stop sign, the author of this paper, Dmitri Krioukov, was determined to prove his innocence—as only a scientist would.

Using math, he demonstrated that, to a police officer measuring the angular speed of Krioukov's car, a brief obstruction from view could cause an illusion that the car did not stop. Krioukov submitted his proof to the arXiv; the judge ruled in his favor (http://articles.latimes.com/2012/apr/23/local/la-me-0423-traffic-fine-20120423).

Paper Thumbnail

Quantum weak coin flipping with arbitrarily small bias

Carlos Mochon

Read full paper (PDF) (https://arxiv.org/pdf/0711.4114.pdf)

Not many papers in the arXiv illustrate their point with a tale involving human sacrifice. There's something about quantum informatics that brings out the weird side of physicists.

Paper Thumbnail

Paper Thumbnail

10 = 6 + 4

Frank D. (Tony) Smith, Jr.

Read full paper (PDF) (https://arxiv.org/pdf/hep-th/9908205.pdf)

A theorist calculated an alternative decomposition of 10 dimensions into 6 spacetime dimensions with local Conformal symmetry and 4-dimensional compact Internal Symmetry Space. For the title of his paper, he decided to go with something a little simpler.

Paper Thumbnail

Would Bohr be born if Bohm were born before Born?

Hrvoje Nikolic

Read full paper (PDF) (https://arxiv.org/pdf/physics/0702069.pdf)

This tricky tongue-twisting treatise theorizes a tangential timeline to testify that taking up quantum theories turns on timeliness.

Paper Thumbnail

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When was the Higgs actually discovered? (http://www.symmetrymagazine.org/article/when-was-the-higgs-actually-discovered?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Jul 3, 2017

The announcement on July 4 was just one part of the story. Take a peek behind the scenes of the discovery of the Higgs boson.

Joe Incandela sat in a conference room at CERN and watched with his arms folded as his colleagues presented the latest results on the hunt for the Higgs boson. It was December 2011, and they had begun to see the very thing they were looking for—an unexplained bump emerging from the data.

“I was far from convinced,” says Incandela, a professor at the University of California, Santa Barbara and the former spokesperson of the CMS experiment at the Large Hadron Collider.

For decades, scientists had searched for the elusive Higgs boson: the holy grail of modern physics and the only piece of the robust and time-tested Standard Model that had yet to be found.

The construction of the LHC was motivated in large part by the absence of this fundamental component from our picture of the universe. Without it, physicists couldn’t explain the origin of mass or the divergent strengths of the fundamental forces.

“Without the Higgs boson, the Standard Model falls apart,” says Matthew McCullough, a theorist at CERN. “The Standard Model was fitting the experimental data so well that most of the theory community was convinced that something playing the role of Higgs boson would be discovered by the LHC.”

The Standard Model predicted the existence of the Higgs but did not predict what the particle’s mass would be. Over the years, scientists had searched for it across a wide range of possible masses. By 2011, there was only a tiny region left to search; everything else had been excluded by previous generations of experimentation. If the predicted Higgs boson were anywhere, it had to be there, right where the LHC scientists were looking.

But Incandela says he was skeptical about these preliminary results. He knew that the Higgs could manifest itself in many different forms, and this particular channel was extremely delicate.

“A tiny mistake or an unfortunate distribution of the background events could make it look like a new particle is emerging from the data when in reality, it’s nothing,” Incandela says.

A common mantra in science is that extraordinary claims require extraordinary evidence. The challenge isn’t just collecting the data and performing the analysis; it’s deciding if every part of the analysis is trustworthy. If the analysis is bulletproof, the next question is whether the evidence is substantial enough to claim a discovery. And if a discovery can be claimed, the final question is what, exactly, has been discovered? Scientists can have complete confidence in their results but remain uncertain about how to interpret them.

In physics, it’s easy to say what something is not but nearly impossible to say what it is. A single piece of corroborated, contradictory evidence can discredit an entire theory and destroy an organization’s credibility.

“We’ll never be able to definitively say if something is exactly what we think it is, because there’s always something we don’t know and cannot test or measure,” Incandela says. “There could always be a very subtle new property or characteristic found in a high-precision experiment that revolutionizes our understanding.”

With all of that in mind, Incandela and his team made a decision: From that point on, everyone would refine their scientific analyses using special data samples and a patch of fake data generated by computer simulations covering the interesting areas of their analyses. Then, when they were sure about their methodology and had enough data to make a significant observation, they would remove the patch and use their algorithms on all the real data in a process called unblinding.

“This is a nice way of providing an unbiased view of the data and helps us build confidence in any unexpected signals that may be appearing, particularly if the same unexpected signal is seen in different types of analyses,” Incandela says.

A few weeks before July 4, all the different analysis groups met with Incandela to present a first look at their unblinded results. This time the bump was very significant and showing up at the same mass in two independent channels.

“At that point, I knew we had something,” Incandela says. “That afternoon we presented the results to the rest of the collaboration. The next few weeks were among the most intense I have ever experienced.”

Meanwhile, the other general-purpose experiment at the LHC, ATLAS, was hot on the trail of the same mysterious bump.

Andrew Hard was a graduate student at The University of Wisconsin, Madison working on the ATLAS Higgs analysis with his PhD thesis advisor Sau Lan Wu.

“Originally, my plan had been to return home to Tennessee and visit my parents over the winter holidays,” Hard says. “Instead, I came to CERN every day for five months—even on Christmas. There were a few days when I didn't see anyone else at CERN. One time I thought some colleagues had come into the office, but it turned out to be two stray cats fighting in the corridor.”

Hard was responsible for writing the code that selected and calibrated the particles of light the ATLAS detector recorded during the LHC’s high-energy collisions. According to predictions from the Standard Model, the Higgs can transform into two of these particles when it decays, so scientists on both experiments knew that this project would be key to the discovery process.

“We all worked harder than we thought we could,” Hard says. “People collaborated well and everyone was excited about what would come next. All in all, it was the most exciting time in my career. I think the best qualities of the community came out during the discovery.”

At the end of June, Hard and his colleagues synthesized all of their work into a single analysis to see what it revealed. And there it was again—that same bump, this time surpassing the statistical threshold the particle physics community generally requires to claim a discovery.

“Soon everyone in the group started running into the office to see the number for the first time,” Hard says. “The Wisconsin group took a bunch of photos with the discovery plot.”

Hard had no idea whether CMS scientists were looking at the same thing. At this point, the experiments were keeping their latest results secret—with the exception of Incandela, Fabiola Gianotti (then ATLAS spokesperson) and a handful of CERN’s senior management, who regularly met to discuss their progress and results.

“I told the collaboration that the most important thing was for each experiment to work independently and not worry about what the other experiment was seeing,” Incandela says. “I did not tell anyone what I knew about ATLAS. It was not relevant to the tasks at hand.”

Still, rumors were circulating around theoretical physics groups both at CERN and abroad. Mccullough, then a postdoc at the Massachusetts Institute of Technology, was avidly following the progress of the two experiments.

“We had an update in December 2011 and then another one a few months later in March, so we knew that both experiments were seeing something,” he says. “When this big excess showed up in July 2012, we were all convinced that it was the guy responsible for curing the ails of the Standard Model, but not necessarily precisely *that* guy predicted by the Standard Model. It could have properties mostly consistent with the Higgs boson but still be not absolutely identical.”

The week before announcing what they’d found, Hard’s analysis group had daily meetings to discuss their results. He says they were excited but also nervous and stressed: Extraordinary claims require extraordinary confidence.

“One of our meetings lasted over 10 hours, not including the dinner break halfway through,” Hard says. “I remember getting in a heated exchange with a colleague who accused me of having a bug in my code.”

After both groups had independently and intensely scrutinized their Higgs-like bump through a series of checks, cross-checks and internal reviews, Incandela and Gianotti decided it was time to tell the world.

“Some people asked me if I was sure we should say something,” Incandela says. “I remember saying that this train has left the station. This is what we’ve been working for, and we need to stand behind our results.”

On July 4, 2012, Incandela and Gianotti stood before an expectant crowd and, one at a time, announced that decades of searching and generations of experiments had finally culminated in the discovery of a particle “compatible with the Higgs boson.”

Science journalists rejoiced and rushed to publish their stories. But was this new particle the long-awaited Higgs boson? Or not?

Discoveries in science rarely happen all at once; rather, they build slowly over time. And even when the evidence overwhelmingly points in a clear direction, scientists will rarely speak with superlatives or make definitive claims.

“There is always a risk of overlooking the details,” Incandela says, “and major revolutions in science are often born in the details.”

Immediately after the July 4 announcement, theorists from around the world issued a flurry of theoretical papers presenting alternative explanations and possible tests to see if this excess really was the Higgs boson predicted by the Standard Model or just something similar.

“A lot of theory papers explored exotic ideas,” McCullough says. “It’s all part of the exercise. These papers act as a straw man so that we can see just how well we understand the particle and what additional tests need to be run.”

For the next several months, scientists continued to examine the particle and its properties. The more data they collected and the more tests they ran, the more the discovery looked like the long-awaited Higgs boson. By March, both experiments had twice as much data and twice as much evidence.

“Amongst ourselves, we called it the Higgs,” Incandela says, “but to the public, we were more careful.”

It was increasingly difficult to keep qualifying their statements about it, though. “It was just getting too complicated,” Incandela says. “We didn’t want to always be in this position where we had to talk about this particle like we didn’t know what it was.”

On March 14, 2013—nine months and 10 days after the original announcement—CERN issued a press release quoting Incandela as saying, “to me, it is clear that we are dealing with a Higgs boson, though we still have a long way to go to know what kind of Higgs boson it is.”?

To this day, scientists are open to the possibility that the Higgs they found is not exactly the Higgs they expected.

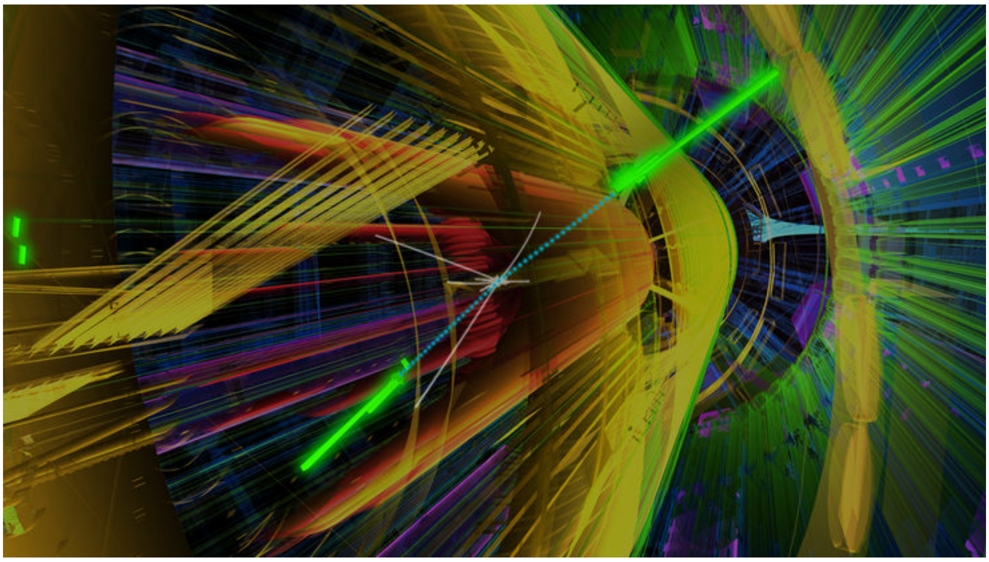
“We are definitely, 100 percent sure that this is a Standard-Model-*like* Higgs boson,” Incandela says. “But we’re hoping that there’s a chink in that armor somewhere. The Higgs is a sign post, and we’re hoping for a slight discrepancy which will point us in the direction of new physics.”

Read More... (http://www.symmetrymagazine.org/article/when-was-the-higgs-actually-discovered?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

What’s really happening during an LHC collision? (http://www.symmetrymagazine.org/article/whats-really-happening-during-an-lhc-collision?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Jun 30, 2017

It’s less of a collision and more of a symphony.



The Large Hadron Collider is definitely large. With a 17-mile circumference, it is the biggest collider on the planet. But the latter fraction of its name is a little misleading. That's because what collides in the LHC are the tiny pieces inside the hadrons, not the hadrons themselves.

Hadrons are composite particles made up of quarks and gluons. The gluons carry the strong force, which enables the quarks to stick together and binds them into a single particle. The main fodder for the LHC are hadrons called protons. Protons are made up of three quarks and an indefinable number of gluons. (Protons in turn make up atoms, which are the building blocks of everything around us.)

If a proton were enlarged to the size of a basketball, it would look empty. Just like atoms, protons are mostly empty space. The individual quarks and gluons inside are known to be extremely small, less than 1/10,000th the size of the entire proton.

"The inside of a proton would look like the atmosphere around you," says Richard Ruiz, a theorist at Durham University. "It's a mixture of empty space and microscopic particles that, for all intents and purposes, have no physical volume.

"But if you put those particles inside a balloon, you'll see the balloon expand. Even though the internal particles are microscopic, they interact with each other and exert a force on their surroundings, inevitably producing something which does have an observable volume."

So how do you collide two objects that are effectively empty space? You can't. But luckily, you don't need a classical collision to unleash a particle's full potential.

In particle physics, the term "collide" can mean that two protons glide through each other, and their fundamental components pass so close together that they can talk to each other. If their voices are loud enough and resonate in just the right way, they can pluck deep hidden fields that will sing their own tune in response—by producing new particles.

"It's a lot like music," Ruiz says. "The entire universe is a symphony of complex harmonies which call and respond to each other. We can easily produce the mid-range tones, which would be like photons and muons, but some of these notes are so high that they require a huge amount of energy and very precise conditions to resonate."

Space is permeated with dormant fields that can briefly pop a particle into existence when vibrated with the right amount of energy. These fields play important roles but almost always work behind the scenes. The Higgs field, for instance, is always interacting with other particles to help them gain mass. But a Higgs particle will only appear if the field is plucked with the right resonance.

When protons meet during an LHC collision, they break apart and the quarks and gluons come spilling out. They interact and pull more quarks and gluons out of space, eventually forming a shower of fast-moving hadrons.

This subatomic symbiosis is facilitated by the LHC and recorded by the experiment, but it's not restricted to the laboratory environment; particles are also accelerated by cosmic sources such as supernova remnants. "This happens everywhere in the universe," Ruiz says. "The LHC and its experiments are not special in that sense. They're more like a big concert hall that provides the energy to pop open and record the symphony inside each proton."

Read More... (http://www.symmetrymagazine.org/article/whats-really-happening-during-an-lhc-collision?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

The rise of LIGO's space-studying super-team (http://www.symmetrymagazine.org/article/the-rise-of-ligos-space-studying-super-team?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Jun 27, 2017

The era of multi-messenger astronomy promises rich rewards—and a steep learning curve.

Sometimes you need more than one perspective to get the full story.

Scientists including astronomers working with the Fermi Large Area Telescope have recorded brief bursts of high-energy photons called gamma rays coming from distant reaches of space. They suspect such eruptions result from the merging of two neutron stars—the collapsed cores of dying stars—or from the collision of a neutron star and a black hole.

But gamma rays alone can't tell them that. The story of the dense, crashing cores would be more convincing if astronomers saw a second signal coming from the same event—for example, the release of ripples in space-time called gravitational waves.

"The Fermi Large Area Telescope detects a few short gamma ray bursts per year already, but detecting one in correspondence to a gravitational-wave event would be the first direct confirmation of this scenario," says postdoctoral researcher Giacomo Vianello of the Kavli Institute for Particle Astrophysics and Cosmology, a joint institution of SLAC National Accelerator Laboratory and Stanford University.

Scientists discovered gravitational waves in 2015 (announced in 2016). Using the Laser Interferometer Gravitational-Wave Observatory, or LIGO, they detected the coalescence of two massive black holes.

LIGO scientists are now sharing their data with a network of fellow space watchers to see if any of their signals match up. Combining multiple signals to create a more complete picture of astronomical events is called multi-messenger astronomy.?

Looking for a match

"We had this dream of finding astronomical events to match up with our gravitational wave triggers," says LIGO scientist Peter Shawhan of the University of Maryland. ?

But LIGO can only narrow down the source of its signals to a region large enough to contain roughly 100,000 galaxies.

Searching for contemporaneous signals within that gigantic volume of space is extremely challenging, especially since most telescopes only view a small part of the sky at a time. So Shawhan and his colleagues developed a plan to send out an automatic alert to other observatories whenever LIGO detected an interesting signal of its own. The alert would contain preliminary calculations and the estimated location of the source of the potential gravitational waves.

"Our early efforts were pretty crude and only involved a small number of partners with telescopes, but it kind of got this idea started," Shawhan says. The LIGO Collaboration and the Virgo Collaboration, its European partner, revamped and expanded the program while upgrading their detectors. Since 2014, 92 groups have signed up to receive alerts from LIGO, and the number is growing.

LIGO is not alone in latching onto the promise of multi-messenger astronomy. The Supernova Early Warning System (SNEWS) also unites multiple experiments to look at the same event in different ways. Neutral, rarely interacting particles called neutrinos escape more quickly from collapsing stars than optical light, so a network of neutrino experiments is prepared to alert optical observatories as soon as they get the first warning of a nearby supernova in the form of a burst of neutrinos.

National Science Foundation Director France Córdova has lauded multi-messenger astronomy, calling it in 2016 a bold research idea that would lead to transformative discoveries.?

The learning curve

Catching gamma ray bursts alongside gravitational waves is no simple feat.

The Fermi Large Area Telescope orbits the earth as the primary instrument on the Fermi Gamma-ray Space Telescope. The telescope is constantly in motion and has a large field of view that surveys the entire sky multiple times per day.

But a gamma-ray burst lasts just a few seconds, and it takes about three hours for LAT to complete its sweep. So even if an event that releases gravitational waves also produces a gamma-ray burst, LAT might not be looking in the right direction at the right time. It would need to catch the afterglow of the event.

Fermi LAT scientist Nicola Omodei of Stanford University acknowledges another challenge: The window to see the burst alongside gravitational waves might not line up with the theoretical predictions. It's never been done before, so the signal could look different or come at a different time than expected.

That doesn't stop him and his colleagues from trying, though. "We want to cover all bases, and we adopt different strategies," he says. "To make sure we are not missing any preceding or delayed signal, we also look on much longer time scales, analyzing the days before and after the trigger."

Scientists using the second instrument on the Fermi Gamma-ray Space Telescope have already found an unconfirmed signal that aligned with the first gravitational waves LIGO detected, says scientist Valerie Connaughton of the Universities Space Research Association, who works on the Gamma-Ray Burst Monitor. "We were surprised to find a transient event 0.4 seconds after the first GW seen by LIGO."

While the event is theoretically unlikely to be connected to the gravitational wave, she says the timing and location “are enough for us to be interested and to challenge the theorists to explain how something that was not expected to produce gamma rays might have done so.”

From the ground up

It’s not just space-based experiments looking for signals that align with LIGO alerts. A working group called DESgw, members of the Dark Energy Survey with independent collaborators, have found a way to use the Dark Energy Camera, a 570-Megapixel digital camera mounted on a telescope in the Chilean Andes, to follow up on gravitational wave detections.?

“We have developed a rapid response system to interrupt the planned observations when a trigger occurs,” says DES scientist Marcelle Soares-Santos of Fermi National Accelerator Laboratory. “The DES is a cosmological survey; following up gravitational wave sources was not originally part of the DES scientific program.”

Once they receive a signal, the DESgw collaborators meet to evaluate the alert and weigh the cost of changing the planned telescope observations against what scientific data they could expect to see—most often how much of the LIGO source location could be covered by DECam observations.

“We could, in principle, put the telescope onto the sky for every event as soon as night falls,” says DES scientist Jim Annis, also of Fermilab. “In practice, our telescope is large and the demand for its time is high, so we wait for the right events in the right part of the sky before we open up and start imaging.”

At an even lower elevation, scientists at the IceCube neutrino experiment—made up of detectors drilled down into Antarctic ice—are following LIGO’s exploits as well.

“The neutrinos IceCube is looking for originate from the most extreme environment in the cosmos,” says IceCube scientist Imre Bartos of Columbia University. “We don't know what these environments are for sure, but we strongly suspect that they are related to black holes.”

LIGO and IceCube are natural partners. Both gravitational waves and neutrinos travel for the most part unimpeded through space. Thus, they carry pure information about where they originate, and the two signals can be monitored together nearly in real time to help refine the calculated location of the source.

The ability to do this is new, Bartos says. Neither gravitational waves nor high-energy neutrinos had been detected from the cosmos when he started working on IceCube in 2008. “During the past few years, both of them were discovered, putting the field on a whole new footing.”

Shawhan and the LIGO collaboration are similarly optimistic about the future of their program and multi-messenger astronomy. More gravitational wave detectors are planned or under construction, including an upgrade to the European detector Virgo, the KAGRA detector in Japan, and a third LIGO detector in India, and that means scientists will home in closer and closer on their targets.?

Read More... (http://www.symmetrymagazine.org/article/the-rise-of-ligos-space-studying-super-team?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

World’s biggest neutrino experiment moves one step closer (http://www.symmetrymagazine.org/article/worlds-biggest-neutrino-experiment-moves-one-step-closer?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Jun 23, 2017

The startup of a 25-ton test detector at CERN advances technology for the Deep Underground Neutrino Experiment.

In a lab at CERN sits a very important box. It covers about three parking spaces and is more than a story tall. Sitting inside is a metal device that tracks energetic cosmic particles.

This is a prototype detector, a stepping-stone on the way to the future Deep Underground Neutrino Experiment (DUNE). On June 21, it recorded its first particle tracks.

So begins the largest ever test of an extremely precise method for measuring elusive particles called neutrinos, which may hold the key to why our universe looks the way it does and how it came into being.

A two-phase detector

The prototype detector is named WA105 3x1x1 (its dimensions in meters) and holds five active tons—3000 liters—of liquid argon. Argon is well suited to interacting with neutrinos then transmitting the subsequent light and electrons for collection. Previous liquid argon neutrino detectors, such as ICARUS and MicroBooNE, detected signals from neutrinos using wires in the liquid argon. But crucially, this new test detector also holds a small amount of gaseous argon, earning it the special status of a two-phase detector.

As particles pass through the detector, they interact with the argon atoms inside. Electrons are stripped off of atoms and drift through the liquid toward an “extraction grid,” which kicks them into the gas. There, large electron multipliers create a cascade of electrons, leading to a stronger signal that scientists can use to reconstruct the particle track in 3D. Previous tests of this method were conducted in small detectors using about 250 active liters of liquid argon.

“This is the first time anyone will demonstrate this technology at this scale,” says Sebastien Murphy, who led the construction of the detector at CERN.

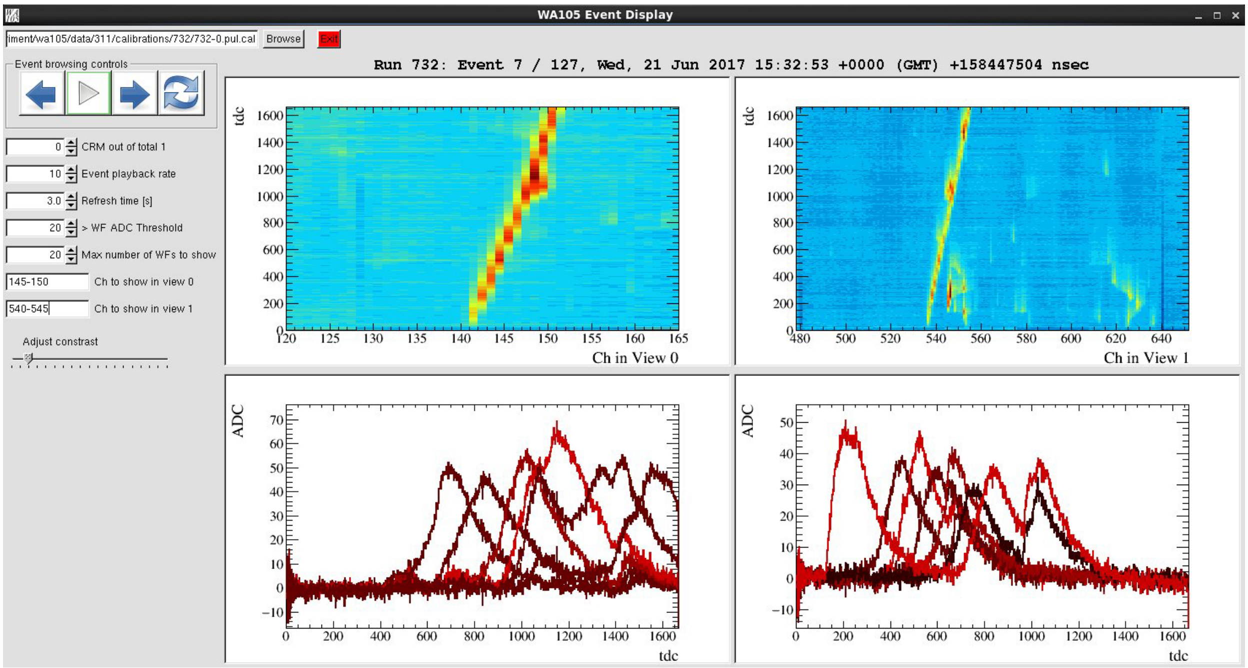
The 3x1x1 test detector represents a big jump in size compared to previous experiments, but it’s small compared to the end goal of DUNE, which will hold 40,000 active tons of liquid argon. Scientists say they will take what they learn and apply it (and some of the actual electronic components) to next-generation single- and dual-phase prototypes, called ProtoDUNE.

The technology used for both types of detectors is a time projection chamber, or TPC. DUNE will stack many large modules snugly together like LEGO blocks to create enormous DUNE detectors, which will catch neutrinos a mile underground at Sanford Underground Research Facility in South Dakota. Overall development for liquid argon TPCs has been going on for close to 40 years, and research and development for the dual-phase for more than a decade. The idea for this particular dual-phase test detector came in 2013.

“The main goal [with WA105 3x1x1] is to demonstrate that we can amplify charges in liquid argon detectors on the same large scale as we do in standard gaseous TPCs,” Murphy says.

By studying neutrinos and antineutrinos that travel 800 miles through the Earth from the US Department of Energy’s Fermi National Accelerator Laboratory to the DUNE detectors, scientists aim to discover differences in the behavior of matter and antimatter. This could point the way toward explaining the abundance of matter over antimatter in the universe. The supersensitive detectors will also be able to capture neutrinos from exploding stars (supernovae), unveiling the formation of neutron stars and black holes. In addition, they allow scientists to hunt for a rare phenomenon called proton decay.

“All the R&D we did for so many years and now want to do with ProtoDUNE is the homework we have to do,” says André Rubbia, the spokesperson for the WA105 3x1x1 experiment and former co-spokesperson for DUNE. “Ultimately, we are all extremely excited by the discovery potential of DUNE itself.”



(http://www.symmetrymagazine.org/sites/default/files/images/standard/DC3qIFcUQAQSEpv.jpg)

One of the first tracks in the prototype detector, caused by a cosmic ray.

André Rubbia

Testing, testing, 3-1-1, check, check

Making sure a dual-phase detector and its electronics work at cryogenic temperatures of minus 184 degrees Celsius (minus 300 degrees Fahrenheit) on a large scale is the primary duty of the prototype detector—but certainly not its only one. The membrane that surrounds the liquid argon and keeps it from spilling out will also undergo a rigorous test. Special cryogenic cameras look for any hot spots where the liquid argon is predisposed to boiling away and might cause voltage breakdowns near electronics.

After many months of hard work, the cryogenic team and those working on the CERN neutrino platform have already successfully corrected issues with the cryostat, resulting in a stable level of incredibly pure liquid argon. The liquid argon has to be pristine and its level just below the large electron multipliers so that the electrons from the liquid will make it into the gaseous argon.

“Adding components to a detector is never trivial, because you’re adding impurities such as water molecules and even dust,” says Laura Manenti, a research associate at the University College London in the UK. “That is why the liquid argon in the 311—and soon to come ProtoDUNEs—has to be recirculated and purified constantly.”

While ultimately the full-scale DUNE detectors will sit in the most intense neutrino beam in the world, scientists are testing the WA105 3x1x1 components using muons from cosmic rays, high-energy particles arriving from space. These efforts are supported by many groups, including the Department of Energy’s Office of Science.

The plan is now to run the experiment, gather as much data as possible, and then move on to even bigger territory.

“The prospect of starting DUNE is very exciting, and we have to deliver the best possible detector,” Rubbia says. “One step at a time, we’re climbing a large mountain. We’re not at the top of Everest yet, but we’re reaching the first chalet.”

Read More... (http://www.symmetrymagazine.org/article/worlds-biggest-neutrino-experiment-moves-one-step-closer?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Howie Day records love song to physics (http://www.symmetrymagazine.org/article/howie-day-records-love-song-to-physics?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Jun 23, 2017

After the musician learned that grad students at CERN had created a parody of his 2004 single "Collide," he flew to Switzerland to sing it at the LHC.

Singer-songwriter Howie Day was sitting in a coffee shop in Denver one morning while on tour when he saw the Twitter notifications: CERN had shared a parody video of his hit song "Collide," sung from the perspective of a proton in the Large Hadron Collider.

Sarah Charley, US communications manager for the LHC experiments, had come up with the idea for the video. She created it with the help of graduate students Jesse Heilman of the University of California, Riverside and Tom Perry and Laser Seymour Kaplan of the University of Wisconsin, Madison.

They spent lunches and coffee breaks workshopping their new version of the lyrics, which were originally about two people falling in love despite their differences. They spent a combined 20 hours in CERN's editing studio recording the vocals and instrumentation of the track. Then they wandered around the laboratory for a full Saturday, filming at various sites. Charley edited the footage together.

"I was flattered, and it was quite funny, too," Day says of seeing the video for the first time. "I immediately retweeted it and then sent a direct message inquiring about a visit. I figured it was a long shot, but why not?"

That started a conversation that led to Day planning a visit to CERN and booking time in his studio to re-record the song from the ground up with the new lyrics. "It was about the most fun I've ever had in the studio," Day says. "We literally laughed all day long. I sent the track off to CERN with the note, 'Should we make another music video?'"

The answer was yes.

While at CERN, Day spent two days visiting the ATLAS and CMS experiments, the CERN Data Centre and the SM18 magnet-testing facility. He also was given the rare opportunity to travel down into the LHC tunnel. CERN's video crew tagged along to film him at the various sites.

"Going down into the LHC tunnel was a once in a lifetime opportunity, and it felt that way. It was like seeing the northern lights, or playing the *Tonight Show*, or bringing a new puppy home."

Day, who says he has always been fascinated by the "why" of things, had been aware of CERN before this project, but he had only a rough idea of what went on there. He says that it wasn't until he got there that things started to make sense.

"Obviously nothing can prepare you for the sheer scale of the place, but also the people who worked there were amazing," Day says. "I felt completely overwhelmed and humbled the entire time. It was truly great to be working at the site where humans may make the most important scientific discoveries of our lifetime."

Heilman, now a postdoctoral researcher at Carleton University, says that he saw the song as a way to reach out to people outside the culture of academia.

“All of us have been steeped in the science for so long that we sort of forget how to speak a language,” he says. “It's always important for academics and researchers to learn different ways to communicate what we’re doing because we’re doing it for people and for society.”

There’s a point in the original song where there’s an emotional build, he says, and Day sings, “I’ve found I’m scared to know, I’m always on your mind.”

The parody uses that part of the song to express the hopes and fears of experimentalists looking for evidence that might not ever appear.

“We're all experimentalists, so we will all spend our careers searching for something,” Heilman says. “The feeling is that [the theory of] supersymmetry, while it's this thing that everybody's been so excited about for a long time, really doesn’t seem that likely to a lot of us anymore because we’re eliminating a lot of the phase space. It's sort of like this white whale hunt. And so our lyrics, ‘Can SUSY still be found?’ is this emotional cry to the physics.”

Charley says she hopes that, through the video, they’re able to “reach and touch people with the science who we normally can't talk to.”

“I think you can appreciate something without fully understanding it,” she says. “As someone who is a professional science communicator, that's always the line I'm walking: trying to find ways that people can appreciate and understand and value something without needing to get a PhD. You can't devote your life to everything, but you can still have an appreciation for things in the world outside your own specific field.”

Read More... (http://www.symmetrymagazine.org/article/howie-day-records-love-song-to-physics?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

African School works to develop local expertise (http://www.symmetrymagazine.org/article/african-school-works-to-develop-local-expertise?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Jun 22, 2017

Universities in sub-Saharan Africa are teaming up to offer free training to students interested in fundamental physics.

Last Feremenga was born in a small town in Zimbabwe. As a high school student in a specialized school in the capital, Harare, he was drawn to the study of physics.

“Physics was at the top of my list of potential academic fields to pursue,” he says.

But with limited opportunities nearby, that was going to require a lot of travel.

With help from the US Education Assistance Center at the American Embassy in Harare, Feremenga was accepted at the University of Chicago in 2007. As an undergraduate, he conducted research for a year at the nearby US Department of Energy’s Fermi National Accelerator Laboratory.

Then, through the University of Texas at Arlington, he became one of just a handful of African nationals to conduct research as a user at European research center CERN. Feremenga joined the ATLAS experiment at the Large Hadron Collider. He spent his grad-school years traveling between CERN and Argonne National Laboratory near Chicago, analyzing hundreds of terabytes of ATLAS data.

“I became interested in solving problems across diverse disciplines, not just physics,” he says.

“At CERN and Argonne, I assisted in developing a system that filters interesting events from large data-sets. I also analyzed these large datasets to find interesting physics patterns.”

(http://www.symmetrymagazine.org/sites/default/files/images/standard/Inline_1.png)
The African School of Fundamental Physics and Applications

In December 2016, he received his PhD. In February 2017, he accepted a job at technology firm Digital Reasoning in Nashville, Tennessee.

To pursue particle physics, Feremenga needed to spend the entirety of his higher education outside Zimbabwe. Only one activity brought him even within the same continent as his home: the African School of Fundamental Physics and Applications. Feremenga attended the school in the program's inaugural year at South Africa's Stellenbosch University.

The ASP received funding for a year from France's Centre National de la Recherche Scientific (CNRS) in 2008. Since then, major supporters among 20 funding institutions have included the International Center for Theoretical Physics (ICTP) in Trieste, Italy; the South African National Research Foundation, and department of Science and Technology; and the South African Institute of Physics. Other major supporters have included CERN, the US National Science Foundation and the University of Rwanda.

The free, three-week ASP has been held bi-annually since 2010. Targeting students in sub-Saharan Africa, the school has been held in South Africa, Ghana, Senegal and Rwanda. The 2018 School is slated to take place in Namibia. Thanks to outreach efforts, applications have risen from 125 in 2010 to 439 in 2016.

(http://www.symmetrymagazine.org/sites/default/files/images/standard/Inline_3.png)

The African School of Fundamental Physics and Applications

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The 50 to 80 students selected for the school must have a minimum of a 3-year university education in math, physics, engineering and/or computer science. The first week of the school focuses on theoretical physics; the second week, experimental physics; the third week, physics applications and high-performance computing.

School organizers stay in touch to support alumni in pursuing higher education, says organizer Ketevi Assamagan. “We maintain contact with the students and help them as much as we can,” Assamagan says. “ASP alumni are pursuing higher education in Africa, Asia, Europe and the US.”

Assamagan, originally from Togo but now a US citizen, worked on the Higgs hunt with the ATLAS experiment. He is currently at Brookhaven National Lab in New York, which supports him devoting 10 percent of his time to the ASP.

While sub-Saharan countries are just beginning to close the gap in physics, there is one well-established accelerator complex in South Africa, operated by the iThemba LABS of Cape Town and Johannesburg. The 30-year-old Separated-Sector Cyclotron, which primarily produces particle beams for nuclear research and for training at the postdoc level, is the largest accelerator of its kind in the southern hemisphere.

Jonathan Dorfan, former Director of SLAC National Accelerator Laboratory and a native of South Africa, attended University of Cape Town. Dorfan recalls that after his Bachelor’s and Master’s degrees, the best PhD opportunities were in the US or Britain. He says he’s hopeful that that outlook could one day change.

Organizers of the African School of Fundamental Physics and Applications continue reaching out to students on the continent in the hopes that one day, someone like Feremenga won’t have to travel across the world to pursue particle physics.

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A speed trap for dark matter, revisited (http://www.symmetrymagazine.org/article/a-speed-trap-for-dark-matter-revisited?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Jun 20, 2017

A NASA rocket experiment could use the Doppler effect to look for signs of dark matter in mysterious X-ray emissions from space.

Researchers who hoped to look for signs of dark matter particles in data from the Japanese ASTRO-H/Hitomi satellite suffered a setback last year when the satellite malfunctioned and died just a month after launch.

Now the idea may get a second chance.

In a new paper (https://journals.aps.org/prd/abstract/10.1103/PhysRevD.95.063012), published in *Physical Review D*, scientists from the Kavli Institute for Particle Astrophysics and Cosmology (KIPAC), a joint institute of Stanford University and the Department of Energy’s SLAC National Accelerator Laboratory, suggest that their novel search method could work just as well with the future NASA-funded Micro-X rocket experiment (http://space.mit.edu/micro-x/index.html)—an X-ray space telescope attached to a research rocket.

The search method looks for a difference in the Doppler shifts produced by movements of dark matter and regular matter, says Devon Powell, a graduate student at KIPAC and lead author on the paper with co-authors Ranjan Laha, Kenny Ng and Tom Abel.

The Doppler effect is a shift in the frequency of sound or light as its source moves toward or away from an observer. The rising and falling pitch of a passing train whistle is a familiar example, and the radar guns that cops use to catch speeders also work on this principle.

The dark matter search technique, called Dark Matter Velocity Spectroscopy, is like setting up a speed trap to “catch” dark matter.

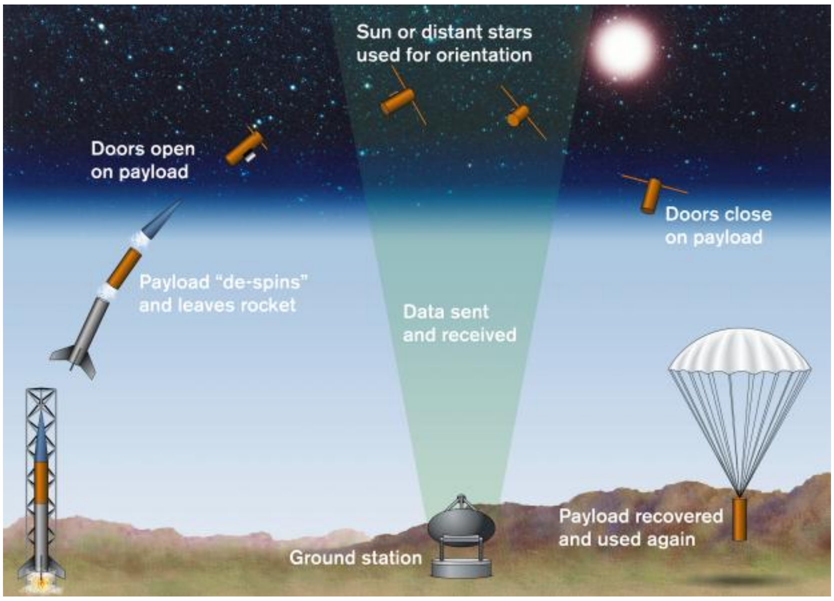
“We think that dark matter has zero averaged velocity, while our solar system is moving,” says Laha, who is a postdoc at KIPAC. “Due to this relative motion, the dark matter signal would experience a Doppler shift. However, it would be completely different than the Doppler shifts from signals coming from astrophysical objects because those objects typically co-rotate around the center of the galaxy with the sun, and dark matter doesn’t. This means we should be able to distinguish the Doppler signatures from dark and regular matter.”

Researchers would look for subtle frequency shifts in measurements of a mysterious X-ray emission. This 3500-electronvolt (3.5 keV) emission line, observed in data from the European XMM-Newton spacecraft and NASA’s Chandra X-ray Observatory, is hard to explain with known astrophysical processes. Some say it could be a sign of hypothetical dark matter particles called sterile neutrinos decaying in space.

“The challenge is to find out whether the X-ray line is due to dark matter or other astrophysical sources,” Powell says. “We’re looking for ways to tell the difference.”

The idea for this approach is not new: Laha and others described the method in a research paper (https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.116.031301) last year, in which they suggested using X-ray data from Hitomi to do the Doppler shift comparison. Although the spacecraft sent some data home before it disintegrated, it did not see any sign of the 3.5-keV signal, casting doubt on the interpretation that it might be produced by the decay of dark matter particles. The Dark Matter Velocity Spectroscopy method was never applied, and the issue was never settled.

In the future Micro-X experiment, a rocket will catapult a small telescope above Earth's atmosphere for about five minutes to collect X-ray signals from a specific direction in the sky. The experiment will then parachute back to the ground to be recovered. The researchers hope that Micro-X will do several flights to set up a speed trap for dark matter.



(http://www.symmetrymagazine.org/sites/default/files/images/standard/sounding-rocket-flight-path.jpeg)

Jeremy Stoller, NASA

"We expect the energy shifts of dark matter signals to be very small because our solar system moves relatively slowly," Laha says. "That's why we need cutting-edge instruments with superb energy resolution. Our study shows that Dark Matter Velocity Spectroscopy could be successfully done with Micro-X, and we propose six different pointing directions away from the center of the Milky Way."

Esra Bulbul from the MIT Kavli Institute for Astrophysics and Space Research, who wasn't involved in the study, says, "In the absence of Hitomi observations, the technique outlined for Micro-X provides a promising alternative for testing the dark matter origin of the 3.5-keV line." But Bulbul, who was the lead author of the paper that first reported the mystery X-ray signal in superimposed data of 73 galaxy clusters, also points out that the Micro-X analysis would be limited to our own galaxy.

The feasibility study for Micro-X is more detailed than the prior analysis for Hitomi. "The earlier paper used certain approximations—for instance, that the dark matter halos of galaxies are spherical, which we know isn't true," Powell says. "This time we ran computer simulations without this approximation and predicted very precisely what Micro-X would actually see."

The authors say their method is not restricted to the 3.5-keV line and can be applied to any sharp signal potentially associated with dark matter. They hope that Micro-X will do the first practice test. Their wish might soon come true.

"We really like the idea presented in the paper," says Enectali Figueroa-Feliciano, the principal investigator for Micro-X at Northwestern University, who was not involved in the study. "We would look at the center of the Milky Way first, where dark matter is most concentrated. If we saw an unidentified line and it were strong enough, looking for Doppler shifts away from the center would be the next step."

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From the cornfield to the cosmos (http://www.symmetrymagazine.org/article/from-the-cornfield-to-the-cosmos?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Jun 15, 2017

Fermilab celebrates 50 years of discovery.

Imagine how it must have felt to be Robert Wilson in the spring of 1967. The Atomic Energy Commission had hired him as the founding director of the planned National Accelerator Laboratory. Before him was the opportunity to build the most powerful particle accelerator in the world—and to create a great new American laboratory dedicated to giving scientists extraordinary new capabilities to explore the universe.

Fifty years later, we marvel at the boldness and scope of the project, and at the freedom, the leadership, the confidence and the vision that it took to conceive and build it. If anyone was up for the challenge, it was Wilson.

By the early 1960s, the science of particle physics had outgrown its birthplace in university laboratories. The accelerators and detectors for advancing research had grown too big, complex and costly for any university to build and operate alone. Particle physics required a new model: national laboratories where the resources of the federal government would bring together the intellectual, scientific, engineering, technical and management capabilities to give collaborations of scientists the ability to explore scientific questions that could no longer be addressed at individual universities.

The NAL, later renamed Fermi National Accelerator Laboratory, would be a national facility where university physicists—"users"—would be "at home and loved," in the words of physicist Leon Lederman, who eventually succeeded Wilson as Fermilab director. The NAL would be a truly national laboratory rising from the cornfields west of Chicago, open to scientists from across the country and around the world.

The Manhattan Project in the 1940s had shown the young Wilson—had shown the entire nation—what teams of physicists and engineers could achieve when, with the federal government's support, they devoted their energy and capability to a common goal. Now, Wilson could use his skills as an accelerator designer and builder, along with his ability to lead and inspire others, to beat the sword of his Manhattan Project experience into the plowshare of a laboratory devoted to peacetime physics research.

When the Atomic Energy Commission chose Wilson as NAL's director, they may have been unaware that they had hired not only a gifted accelerator physicist but also a sculptor, an architect, an environmentalist, a penny-pincher (that they would have liked), an iconoclast, an advocate for human rights, a Wyoming cowboy and a visionary.

Over the dozen years of his tenure Wilson would not only oversee the construction of the world's most powerful particle accelerator, on time and under budget, and set the stage for the next generation of accelerators. He would also shape the laboratory with a vision that included erecting a high-rise building inspired by a French cathedral, painting other buildings to look like children's building blocks, restoring a tall-grass prairie, fostering a herd of bison, designing an 847-seat auditorium (a venue for culture in the outskirts of Chicago), and adorning the site with sculptures he created himself.

Fermilab physicist Roger Dixon tells of a student who worked for him in the lab's early days.

"One night," Dixon remembers, "I had Chris working overtime in a basement machine shop. He noticed someone across the way grinding and welding. When the guy tipped back his helmet to examine his work, Chris walked over and asked, 'What've they got you doin' in here tonight?' The man said that he was working on a sculpture to go into the reflecting pond in front of the high rise. 'Boy,' Chris said, 'they can think of more ways for you to waste your time around here, can't they?' To which Robert Wilson, welder, sculptor and laboratory director, responded with remarks Chris will never forget on the relationship of science, technology and art."

Wilson believed a great physics laboratory should look beautiful. "It seemed to me," he wrote, "that the conditions of its being a beautiful laboratory were the same conditions as its being a successful laboratory."

With the passage of years, Wilson's outsize personality and gift for eloquence have given his role in Fermilab's genesis a near-mythic stature. In reality, of course, he had help. He used his genius for bringing together the right people with the right skills and knowledge at the right time to recruit and inspire scientists, engineers, technicians, administrators (and an artist) not only to build the laboratory but also to stick around and operate it. Later, these Fermilab pioneers recalled the laboratory's early days as a golden age, when they worked all hours of the day and night and everyone felt like family.

By 1972, the Main Ring of the laboratory's accelerator complex was sending protons to the first university users, and experiments proliferated in the laboratory's particle beams. In July 1977, Experiment E-288, a collaboration Lederman led, discovered the bottom quark.

Physicist Patty McBride, who heads Fermilab's Particle Physics Division, came to Fermilab in 1979 as a Yale graduate student. McBride's most vivid memory of her early days at the laboratory is meeting people with a wide variety of life experiences.

"True, there were almost no women," she says. "But out in this lab on the prairie were people from far more diverse backgrounds than I had ever encountered before. Some, including many of the skilled technicians, had returned from serving in the Vietnam War. Most of the administrative staff were at least bilingual. We always had Russian colleagues; in fact the first Fermilab experiment, E-36, at the height of the Cold War, was a collaboration between Russian and American physicists. I worked with a couple of guest scientists who came to Fermilab from China. They were part of a group who were preparing to build a new accelerator at the Institute of High Energy Physics there."

The diversity McBride found was another manifestation of Wilson's concept of a great laboratory.

"Prejudice has no place in the pursuit of knowledge," he wrote. "In any conflict between technical expediency and human rights, we shall stand firmly on the side of human rights. Our support of the rights of the members of minority groups in our laboratory and its environs is inextricably intertwined with our goal of creating a new center of technical and scientific excellence."

Designing the future

Advances in particle physics depend on parallel advances in accelerator technology. Part of an accelerator laboratory's charge is to develop better accelerators—at least that's how Wilson saw it. With the Main Ring delivering beam, it was time to turn to the next challenge. This time, he had a working laboratory to help.

The designers of Fermilab's first accelerator had hoped to use superconducting magnets for the Main Ring, but they soon realized that in 1967 it was not yet technically feasible. Nevertheless, they left room in the Main Ring tunnel for a next-generation accelerator.

Wilson applied his teambuilding gifts to developing this new machine, christened the Energy Doubler (and later renamed the Tevatron).

In 1972, he brought together an informal working group of metallurgists, magnet builders, materials scientists, physicists and engineers to begin investigating superconductivity, with the goal of putting this exotic phenomenon to work in accelerator magnets.

No one had more to do with the success of the superconducting magnets than Fermilab physicist Alvin Tollestrup. Times were different then, he recalls.

"Bob had scraped up enough money from here and there to get started on pursuing the Doubler before it was officially approved," Tollestrup says. "We had to fight tooth and nail for approval. But in those days, Bob could point the whole machine shop to do what we needed. They could build a model magnet in a week."

It took a decade of strenuous effort to develop the superconducting wire, the cable configuration, the magnet design and the manufacturing processes to bring the world's first large-scale superconducting accelerator magnets into production, establishing Fermilab's leadership in accelerator technology. Those involved say they remember it as an exhilarating experience.

By March 1983, the Tevatron magnets were installed underneath the Main Ring, and in July the proton beam in the Tevatron reached a world-record energy of 512 billion electronvolts. In 1985, a new Antiproton Source enabled proton-antiproton collisions that further expanded the horizons of the subatomic world.

Two particle detectors—called the Collider Detector at Fermilab, or CDF, and DZero—gave hundreds of collaborating physicists the means to explore this new scientific territory. Design for CDF began in 1978, construction in 1982, and CDF physicists detected particle collisions in 1985. Fermilab's current director, Nigel Lockyer, first came to work at Fermilab on CDF in 1984.

"The sheer ambition of the CDF detector was enough to keep everyone excited," he says.

The DZero detector came online in 1992. A primary goal for both experiments was the discovery of the top quark, the heavier partner of the bottom quark and the last undiscovered quark of the six that theory predicted. Both collaborations worked feverishly to be the first to accumulate enough evidence for a discovery.

In March 1995, CDF and DZero jointly announced that they had found the top. To spread the news, Fermilab communicators tried out a fledgling new medium called the World Wide Web.

Five decades of particle physics

1967

First day NAL employees started work in Illinois

Reaching new frontiers

Meanwhile, in the 1980s, growing recognition of the links between subatomic interactions and cosmology—between the inner space of particle physics and the outer space of astrophysics—led to the formation of the Fermilab Theoretical Astrophysics Group, pioneered by cosmologists Rocky Kolb and Michael Turner. Cosmology's rapid evolution from theoretical endeavor to experimental science demanded large collaborations and instruments of increasing complexity and scale, beyond the resources of universities—a problem that particle physics knew how to solve.

In the mid-1990s, the Sloan Digital Sky Survey turned to Fermilab for help. Under the leadership of former Fermilab Director John Peoples, who became SDSS director in 1998, the Sky Survey carried out the largest astronomical survey ever conducted and transformed the science of astrophysics.

The discovery of cosmological evidence of dark matter and dark energy had profound implications for particle physics, revealing a mysterious new layer to the universe and raising critical scientific questions. What are the particles of dark matter? What is dark energy? In 2004, in recognition of Fermilab's role in particle astrophysics, the laboratory established the Center for Particle Astrophysics.

As the twentieth century ended and the twenty-first began, Fermilab's Tevatron experiments defined the frontier of high-energy physics research. Theory had long predicted the existence of a heavy particle associated with particle mass, the Higgs boson, but no one had yet seen it. In the quest for the Higgs, Fermilab scientists and experimenters made a relentless effort to wring every ounce of performance from accelerator and detectors.

The Tevatron had reached maximum energy, but in 1999 a new accelerator in the Fermilab complex, the Main Injector, began giving an additional boost to particles before they entered the Tevatron ring, significantly increasing the rate of particle collisions. The experiments continuously re-invented themselves using advances in detector and computing technology to squeeze out every last drop of data. They were under pressure, because the clock was ticking.

A new accelerator with seven times the Tevatron's energy was under construction at CERN, the European laboratory for particle physics in Geneva, Switzerland. When Large Hadron Collider operations began, its higher-energy collisions and state-of-the-art detectors would eclipse Fermilab's experiments and mark the end of the Tevatron's long run.

In the early 1990s, the Tevatron had survived what many viewed as a near-death experience with the cancellation of the Superconducting Super Collider, planned as a 26-mile ring that would surpass Fermilab's accelerator, generating beams with 20 times as much energy. Construction began on the SSC's Texas site in 1991, but in 1993 Congress canceled funding for the multibillion-dollar project. Its demise meant that, for the time being, the high-energy frontier would remain in Illinois.

While the SSC drama unfolded, in Geneva the construction of the LHC went steadily onward—helped and supported by US physicists and engineers and by US funding.

Among the more puzzling aspects of particle physics for those outside the field is the simultaneous competition and collaboration of scientists and laboratories. It makes perfect sense to physicists, however, because science is the goal. The pursuit of discovery drives the advancement of technology. Particle physicists have decades of experience in working collaboratively to develop the tools for the next generation of experiments, wherever in the world that takes them.

Thus, even as the Tevatron experiments threw everything they had into the search for the Higgs, scientists and engineers at Fermilab—literally across the street from the CDF detector—were building advanced components for the CERN accelerator that would ultimately shut the Tevatron down.

Going global

Just as in the 1960s particle accelerators had outgrown the resources of any university, by the end of the century they had outgrown the resources of any one country to build and operate. Detectors had long been international construction projects; now accelerators were, too, as attested by the superconducting magnets accumulating at Fermilab, ready for shipment to Switzerland.

As the US host for CERN's CMS experiment, Fermilab built an LHC Remote Operations Center so that the growing number of US collaborating physicists could work on the experiment remotely. In the early morning hours of September 10, 2008, a crowd of observers watched on screens in the ROC as the first particle beam circulated in the LHC. Four years later, the CMS and ATLAS experiments announced the discovery of the Higgs boson. One era had ended, and a new one had begun.

The future of twenty-first century particle physics, and Fermilab's future, will unfold in a completely global context. More than half of US particle physicists carry out their research at LHC experiments. Now, the same model of international collaboration will create another pathway to discovery, through the physics of neutrinos. Fermilab is hosting the international Deep Underground Neutrino Experiment, powered by the Long-Baseline Neutrino Facility that will send the world's most powerful beam of neutrinos through the earth to a detector more than a kilometer underground and 1300 kilometers away in the Sanford Underground Research Facility in South Dakota.

"We are following the CERN model," Lockyer says. "We have split the DUNE project into an accelerator facility and an experiment. Seventy-five percent of the facility will be built by the US, and 25 percent by international collaborators. For the experiment, the percentages will be reversed."

The DUNE collaboration now comprises more than 950 scientists from 162 institutions in 30 countries. "To design the project," Lockyer says, "we started with a clean piece of paper and all of our international collaborators and their funding agencies in the room. They have been involved since t=0."

In Lockyer's model for Fermilab, the laboratory will keep its historic academic focus, giving scientists the tools to address the most compelling scientific questions. He envisions a diverse science portfolio with a flagship neutrino program and layers of smaller programs, including particle astrophysics.

At the same time, he says, Fermilab feels mounting pressure to demonstrate value beyond creating knowledge. One potential additional pursuit involves using the laboratory's unequaled capability in accelerator design and construction to build accelerators for other laboratories. Lockyer says he also sees opportunities to contribute the computing capabilities developed from decades of processing massive amounts of particle physics data to groundbreaking next-generation computing projects. "We have to dig deeper and reach out in new ways."

In the five decades since Fermilab began, knowledge of the universe has flowered beyond anything we could have imagined in 1967. Particles and forces then unknown have become familiar, like old friends. Whole realms of inner space have opened up to us, and outer space has revealed a new dark universe to explore. Across the globe, collaborators have joined forces to extend our reach into the unknown beyond anything we can achieve separately.

Times have changed, but Wilson would still recognize his laboratory. As it did then, Fermilab holds the same deep commitment to the science of the universe that brought it into being 50 years ago.

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Jun 13, 2017

The particle physics laboratory makes a Spanish connection.

Marylu Reyes and her 12-year-old daughter live just a few miles north of Fermi National Accelerator Laboratory, in West Chicago, Illinois, a town of 27,000 residents with a significant Spanish-speaking population.

When her client, a Fermilab employee, told her the big lab down the street was hosting an event given entirely in Spanish, Reyes and her daughter excitedly marked the date.

What they saw at Fermilab's Pregúntale a un Científico—Ask a Scientist—blew them away.

"When I walked through the lab, it was just like the movies about NASA: big rooms, computers, all that equipment. You felt like you could be a part of it," says Reyes, who heard presentations on particle accelerators, dark matter and neutrinos. "It was a great opportunity to see it — in our language."

March's Pregúntale a un Científico was the first time Fermilab had offered its Ask-a-Scientist, one of the lab's mainstay public-outreach programs, in Spanish. In fact it was Reyes' client, Griselda Lopez, who spearheaded the effort. And through the civic engagement of Fermilab's Hispanic/Latino Forum, a resource group, the successful event, which drew nearly a hundred people, demonstrated the great interest from the surrounding Latino community in the laboratory's work.

Pregúntale a un Científico is just one part of Fermilab's ongoing effort to reach Spanish speakers.

Fermilab is currently developing Spanish-language science materials for the classroom. And it has twice hosted a bilingual conference for a local organization that encourages Latina middle school girls to pursue a STEM education.

“As I was doing these outreach activities, I figured out that it’s not just about science,” said Erika Catano Mur, an Iowa State University graduate student on Fermilab’s NOvA neutrino experiment who has led Spanish-language tours at the lab. “There’s a wall that Spanish-speaking people face that you’re not always aware of. They say, ‘You tell me to go to this website, to call this person to learn more. Do they speak Spanish?’ So we're looking at what’s already out there in Spanish and what more is needed.”

Catano Mur learned English in school in her home country of Colombia, and she speaks English daily at work. Minerba Betancourt, a Fermilab scientist on the MINERvA neutrino experiment who gave presentations at Pregúntale a un Científico, started speaking English regularly only after she came to the United States for graduate school from Venezuela. She continues to speak Spanish with her family.

“I’m proof that you can do science in your second language,” Betancourt says.

Catano Mur says she rarely does physics in Spanish, since her first language becomes her second language when it comes to physics.

“If I’m talking to another Spanish speaker at the lab, then it can come out in Spanglish, because the science terms come to me much faster in English,” she says.

When talking with nonscientists, Betancourt says, neither language is more difficult than the other. The real translation challenge is moving from jargon into plainspeak.

It wasn’t just scientists interacting with the attendees at Pregúntale a un Científico. Nontechnical staff were also there to mingle and answer questions.

“We have a rich Spanish-speaking community at the lab—employees, graduate students and postdocs from Latin American and US institutions,” Betancourt says. “Each volunteer contributes something to the wonderful science program at Fermilab.”

The attendees came from all over—not just the surrounding suburbs. Betancourt met one family from Chicago, 40 miles away, and another who lives in Argentina and just happened to be in the area.

When it comes to the lab serving as an educational resource, it is of course nearby residents who have the most to gain, being a stone’s throw away.

“We have a good community with a great potential for students who could be physicists and engineers,” Betancourt says. “That’s an opportunity I didn’t have — to go to a nearby lab to see what they do.”

It’s as much a chance for the parents as for the children to learn about science careers.

“The parents are very involved. They sometimes have the idea that if you go into physics, you can be only a high school teacher and have to live a lonely life,” Catano Mur says.”“Any information beyond that is surprising.”

Her goal is to make it less so.

“The Hispanic community here has a big opportunity to get involved in science. A lab like this doesn’t exist in many parts of the world,” Catano Mur says. “A couple of science talks can get the process started.”

Reyes is already well on her way. Even before attending Pregúntale a un Científico, she assumed the role of town crier, distributing flyers about the event at local supermarkets, her daughter’s middle school and her church. It seems to have worked: She saw several friends and acquaintances there.

“I’m so happy that they did this for us. My daughter said, ‘Mom, this was a great experience.’ Reyes says. “I had heard about Fermilab, but I didn’t really know what it was. Now, we feel so welcome.”

(Version en español (http://www.symmetrymagazine.org/article/fermilab-en-espanol-es))

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Jun 13, 2017

El laboratorio de física de partículas establece una conexión en español.

Marylu Reyes y su hija de 12 años viven a unas pocas millas al norte de Fermi National Accelerator Laboratory, en West Chicago, Illinois, una ciudad de 27,000 habitantes con una población significativa de hispanohablantes.

Cuando la cliente de Reyes, una empleada de Fermilab, le contó que el gran laboratorio del vecindario estaba organizando un evento totalmente en español, Reyes y su hija apuntaron la fecha con gran entusiasmo.

Lo que vieron en Pregúntale a un Científico—Ask a Scientist—de Fermilab las cautivó.

“A medida que recorría el laboratorio, era igual que en las películas sobre la NASA: habitaciones grandes, computadoras, todos esos equipos. Sentías como si pudieras formar parte de ello,” cuenta Reyes, quien escuchó exposiciones sobre aceleradores de partículas, materia oscura y neutrinos. “Fue una gran oportunidad poder presenciarlo… ¡en nuestro idioma!”

Pregúntale a un Científico de marzo fue la primera vez que Fermilab ofreció Ask-a-Scientist, uno de sus principales programas de difusión pública del laboratorio, en idioma español. De hecho, fue la cliente de Reyes, Griselda Lopez, quien encabezó el esfuerzo. Asimismo, a través del compromiso cívico del Foro hispano/latino de Fermilab, un grupo de recursos, el exitoso evento, que atrajo a casi un centenar de personas, demostró el gran interés en el trabajo del laboratorio por parte de la comunidad latina circundante.

Pregúntale a un Científico es solo una parte del esfuerzo continuo de Fermilab para llegar a los hispanohablantes.

En la actualidad, Fermilab se encuentra desarrollando materiales de ciencia en idioma español para el salón de clases. Asimismo, ha organizado en dos oportunidades una conferencia bilingüe para una organización local que alienta a estudiantes latinas de la escuela secundaria a cursar estudios relacionados con la ciencia, la tecnología, la ingeniería y las matemáticas (STEM).

“Mientras estaba realizando estas actividades de difusión, me di cuenta de que no se trata solo de ciencia,” dijo Erika Catano Mur, una estudiante de posgrado de la Universidad Estatal de Iowa (Iowa State University) participante en el experimento NOvA sobre neutrinos de Fermilab, y quien ha guiado recorridos en idioma español dentro del laboratorio. “Existe un muro que enfrentan los hispanohablantes del cual uno no siempre es consciente. Ellos afirman: ‘Me dicen que me dirija a este sitio web para llamar a tal persona a fin de obtener más información. Y esa persona, ¿habla español?’ De modo que estamos observando lo que ya hay disponible en español y qué más se necesita.”

Catano Mur aprendió inglés en la escuela en Colombia, su país natal, y habla dicho idioma a diario en el trabajo. Minerba Betancourt, una científica de Fermilab participante en el experimento MINERvA sobre neutrinos, y quien realizó exposiciones en Pregúntale a un Científico, comenzó a hablar inglés de forma regular solo después de venir a los Estados Unidos desde Venezuela para cursar estudios de posgrado. Ella continúa hablando español con su familia.

“Soy la prueba de que se puede hacer ciencia en tu segundo idioma,” afirmó Betancourt.

Catano Mur dice que rara vez hace física en español. Por lo tanto, su primer idioma se convierte en su segundo idioma cuando se trata de física.

“Si estoy conversando con otro hispanohablante en el laboratorio, entonces podemos hacerlo en Spanglish, porque los términos científicos me vienen a la cabeza mucho más rápido en inglés,” afirma.

Al conversar con no científicos, según Betancourt, ninguno de los idiomas es más difícil que el otro. El verdadero desafío de traducción consiste en pasar los términos técnicos específicos a un léxico sencillo.

No eran solo científicos los que interactuaban con los participantes en Pregúntale a un Científico. Personal no técnico también estaba presente allí para mezclarse y responder preguntas.

“Contamos con una vasta comunidad de hispanohablantes en el laboratorio: empleados, estudiantes de posgrado y posdoctorados de instituciones latinoamericanas y estadounidenses,” contó Betancourt. “Cada voluntario aporta algo al maravilloso programa científico en Fermilab.”

Los participantes acudieron de todas partes, no solo de los suburbios aledaños. Betancourt conoció a una familia de Chicago, que vive a 40 millas de distancia, y otra que vive en Argentina que, casualmente, estaba por la zona.

Cuando se trata del laboratorio como un recurso educativo, los habitantes de los alrededores son, por supuesto, los que tienen más ventajas, ya que se encuentran a pasos del lugar.

“Disponemos de una buena comunidad con un gran potencial de estudiantes que podrían ser físicos e ingenieros,” expresa Betancourt. “Esa es una oportunidad que yo no tuve: ir a un laboratorio cercano para observar lo que hacen.”

Es una oportunidad tanto para padres como para hijos de obtener información sobre carreras científicas.

“Los padres están muy involucrados. A veces tienen la idea de que si te adentras en la física, solo podrás ser profesor de secundaria y tendrás que llevar una vida solitaria,” sostiene Catano Mur. “Cualquier información más allá de eso es sorprendente.”

Su objetivo consiste en reducir eso.

“La comunidad hispana tiene aquí una gran oportunidad de involucrarse en la ciencia. Un laboratorio como este no existe en muchas partes del mundo,” afirma Catano Mur. “Un par de conversaciones científicas puede iniciar el proceso.”

Reyes ya va por buen camino. Incluso antes de asistir a Pregúntale a un Científico, ella asumió el papel de pregonera, distribuyendo volantes acerca del evento en supermercados locales, en la escuela secundaria de su hija y en su iglesia. Parece haber funcionado: Reyes vio a varios amigos y conocidos allí.

“Estoy tan feliz de que hayan hecho esto por nosotros. Mi hija dijo: ‘Mamá, esta fue una gran experiencia,’” contó Reyes. “Había oído acerca de Fermilab pero no sabía realmente qué era. Ahora, nos sentimos muy bien recibidos.”

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Jun 12, 2017

The beam pipes of the LHC need to be so clean, even air molecules count as dirt.

The Large Hadron Collider is the world’s most powerful accelerator. Inside, beams of particles sprint 17 miles around in opposite directions through a pair of evacuated beam pipes that intersect at collision points surrounded by giant particle detectors.

The inside of the beam pipes need to be spotless, which is why the LHC is thoroughly cleaned every year before it ramps up its summer operations program.

It’s not dirt or grime that clogs the LHC. Rather, it’s microscopic air molecules.

“The LHC is incredibly cold and under a strong vacuum, but it’s not a perfect vacuum,” says LHC accelerator physicist Giovanni Rumolo. “There’s a tiny number of simple atmospheric gas molecules and even more frozen to the beam pipes’ walls.”

Protons racing around the LHC crash into these floating air molecules, detaching their electrons. The liberated electrons jump after the positively charged protons but quickly crash into the beam pipe walls, depositing heat and liberating even more electrons from the frozen gas molecules there.

This process quickly turns into an avalanche, which weakens the vacuum, heats up the cryogenic system, disrupts the proton beam and dramatically lowers the efficiency and reliability of the LHC.

But the clouds of buzzing electrons inside the beam pipe possess an interesting self-healing feature, Rumolo says.

“When the chamber wall is under intense electron bombardment, the probability of it creating secondary electrons decreases and the avalanche is gradually mitigated,” he says. “Before ramping the LHC up to its full intensity, we run the machine for several days with as many low-energy protons as we can safely manage and intentionally produce electron clouds. The effect is that we have fewer loose electrons during the LHC’s physics runs.”

In other words, accelerator engineers clean the inside of the LHC a little like they would unclog a shower drain. They gradually pump the LHC full of more and more sluggish protons, which act like a scrub brush and knock off the microscopic grime clinging to the inside of the beam pipe. This loose debris is flushed out by the vacuum system. In addition, the bombardment of electrons transforms simple carbon molecules, which are still clinging to the beam pipe’s walls, into an inert and protective coating of graphite.

Cleaning the beam pipe is such an important job that there is a team of experts responsible for it (officially called the “Scrubbing Team”).

“Scrubbing is essential if we want to operate the LHC at its full potential,” Rumolo says. “It’s challenging, because there is a fine line between thoroughly cleaning the machine and accidentally dumping the beam. When we’re scrubbing, we work around the clock in the CERN Control Center to make sure the accelerator is safe and the scrubbing is working properly.”

Read More... (http://www.symmetrymagazine.org/article/how-to-clean-inside-the-lhc?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Another year wiser (http://www.symmetrymagazine.org/article/another-year-wiser?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Jun 8, 2017

In honor of Fermilab’s upcoming 50th birthday, *Symmetry* presents physics birthday cards.

Some say there are five fundamental interactions: gravitational, electromagnetic, strong, weak and the exchange of birthday greetings on Facebook. But even if you prefer paper to pixels, *Symmetry* is here to help you celebrate another year. Try these five physics birthday cards, available as both gifs and printable PDFs.

Like two beams of particles in the Large Hadron Collider, your lives intersected. Tell a friend you're grateful:

(http://www.symmetrymagazine.org/sites/default/files/images/standard/Twitter_Another_year_wiser_Physics_Birthday_Card_1.gif)

Download A Printable PDF Card (/Sites/Default/Files/Birthday-Cards/Another_year_wiser_Physics_Birthday_Card_1.Pdf)

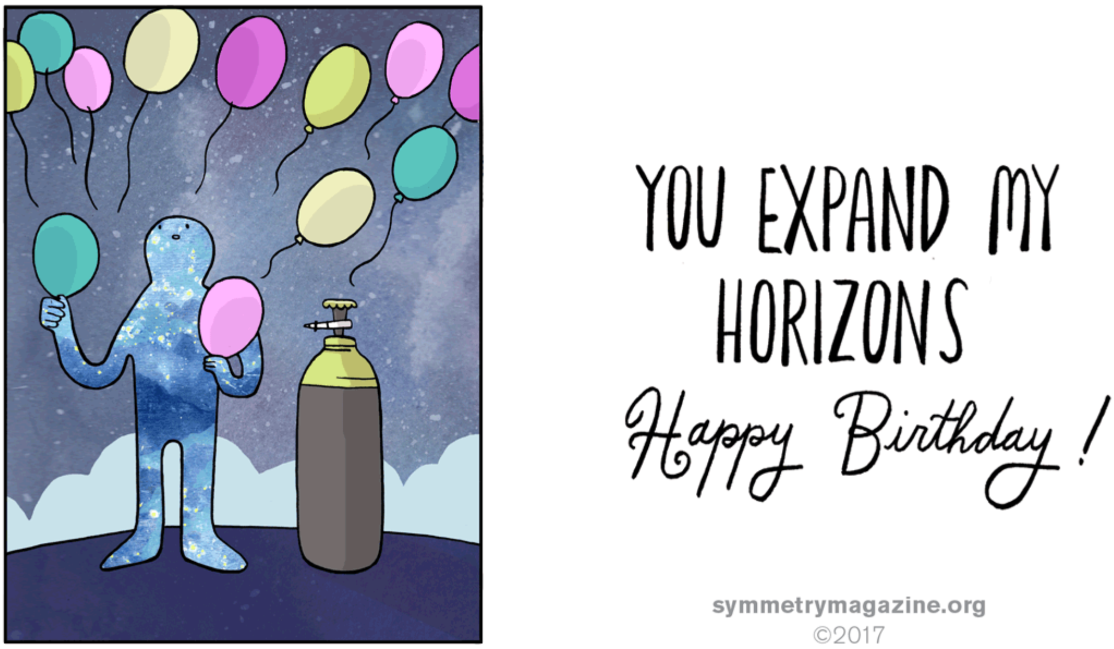
Artwork by Corinne Mucha

Like a neutrino, they may change over time, but you still appreciate their friendship:

(http://www.symmetrymagazine.org/sites/default/files/images/standard/Twitter_Another_year_wiser_Physics_Birthday_Card_2.gif)

Download A Printable PDF Card (/Sites/Default/Files/Birthday-Cards/Another_year_wiser_Physics_Birthday_Card_2.Pdf)
Artwork by Corinne Mucha

Whether it's dark energy or another force that pushes them forward, it’s an honor to see them grow: ?



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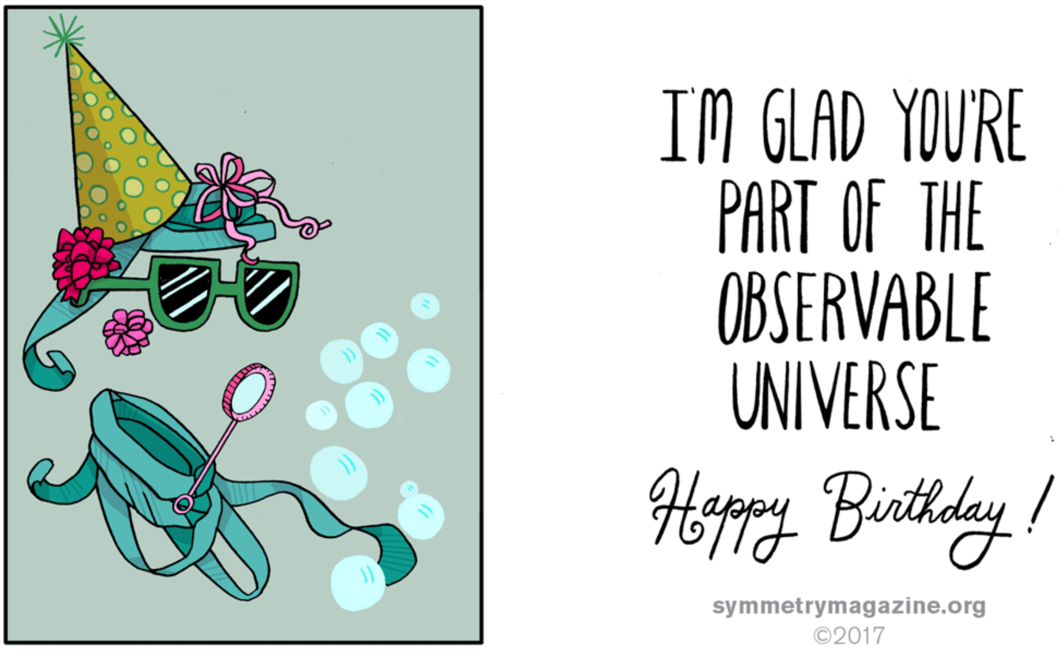
Artwork by Corinne Mucha

Let them know that, like dark matter, good friends can be hard to find:?



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Artwork by Corinne Mucha

And you're so glad that, like a long-sought gravitational wave or a Higgs boson, they finally appeared:?

(http://www.symmetrymagazine.org/sites/default/files/images/standard/Twitter_Another_year_wiser_Physics_Birthday_Card_5.gif)

Download A Printable PDF Card (/Sites/Default/Files/Birthday-Cards/Another_year_wiser_Physics_Birthday_Card_5.Pdf)
Artwork by Corinne Mucha

Can't wait to send your first card? We happen to know of a laboratory with a big day coming up on June 15.

Fermilab
PO Box 500, MS 206
Batavia, IL 60510-5011

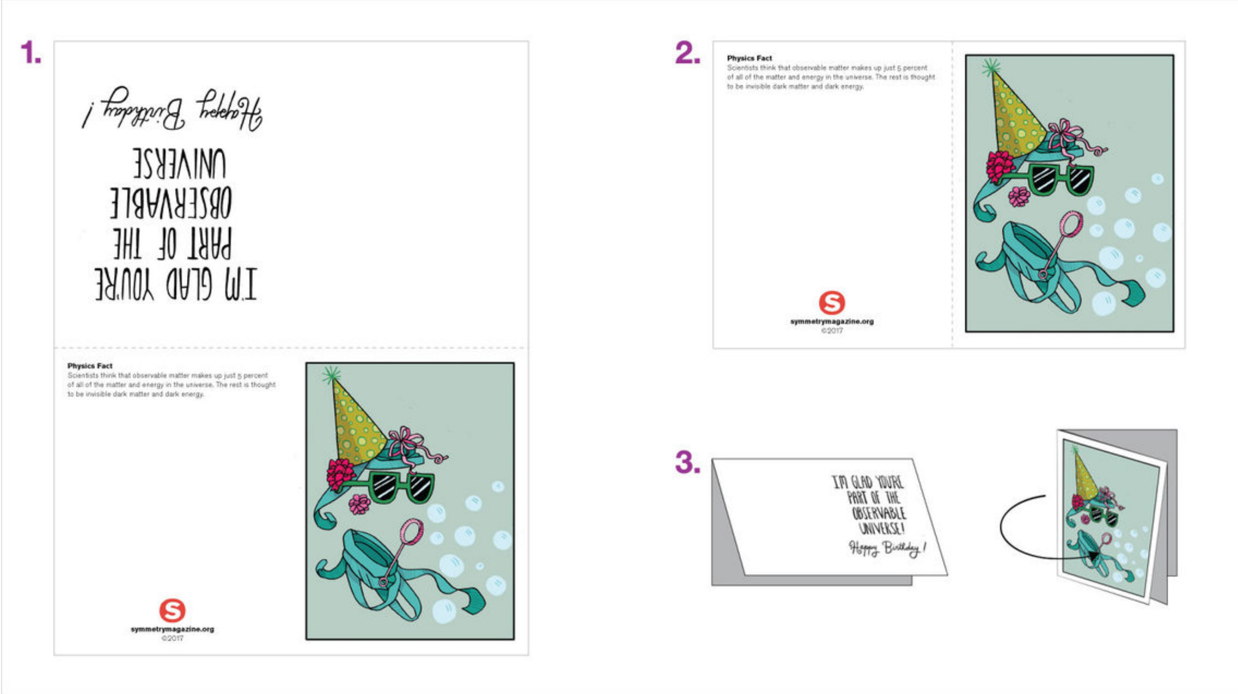
(Or reach them on Facebook (https://www.facebook.com/Fermilab/).)

Print setting recommendations:

Paper Size: Letter
Scale: 100 percent

How to fold your card:

Fold your 8.5 x 11 inch paper in half on the horizontal axis, then fold in half again on the vertical axis. Voilà!



(http://www.symmetrymagazine.org/sites/default/files/images/standard/Folding-Diagram_060817.jpg)
Artwork by Sandbox Studio, Chicago

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A tale of three cities (http://www.symmetrymagazine.org/article/a-tale-of-three-cities?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Jun 6, 2017

An enormous neutrino detector named ICARUS unites physics labs in Italy, Switzerland and the US.

Born in Italy, revitalized at CERN and bound for the US, the ICARUS detector is emblematic of modern particle physics experiments: international, collaborative and really, really big.

The ICARUS T600 (if you're inclined to use the full name) was a pioneer in particle physics technology and is still the largest detector of its kind. When operational, the detector is filled with 760 tons of liquid argon, the same element that, in gas form, makes up about 1 percent of our atmosphere. Since its creation, the ICARUS detector has become a model for modern experiments in the worldwide quest to better understand hard-to-catch particles called neutrinos.

Neutrinos are incredibly small, neutral and rarely interact with other particles, making them difficult to study. Even now, 60 years after their discovery, neutrinos continue to surprise and confound scientists. That's why this detector with a special talent for neutrino-hunting is undertaking a long journey across the Atlantic to a new home in the United States.

Breaking boundaries at INFN: L'Aquila, Italy

ICARUS got its start in Italy. A groundbreaking large-scale detector, it was the prototype of a sci-fi-sounding instrument called a liquid argon time projection chamber. It functions like four giant cameras, each taking separate 3D images of the signals from neutrinos interacting inside. The active section of the detector is about twice the height of a refrigerator, a couple of meters wider than that and about the length of a bowling lane.

The concept of a liquid argon time projection chamber was proposed in 1977 by physicist Carlo Rubbia, who would later win the Nobel Prize for the discovery of the massive, short-lived subatomic W and Z particles, the carriers of the so-called electroweak force. ICARUS came to life in 2010 at the Gran Sasso National Laboratory, run by Italy's National Institute for Nuclear Physics (INFN) after decades of development to advance technology and construct the experiment.

At the heart of Gran Sasso Mountain, shielded from cosmic rays raining down from space beneath 1400 meters of rock, it gathered thousands of neutrino interactions during its lifetime. The detector measured neutrinos that traveled 450 miles (730 kilometers) from CERN, but it also saw neutrinos born through natural processes in our sun and our atmosphere. Thus its name: Imaging Cosmic and Rare Underground Signals.

The ICARUS collaboration studied various properties of neutrinos, including a surprising phenomenon called neutrino oscillation. Neutrinos come in three varieties, or flavors, and have the uncommon ability to change from one type to another as they travel. But the proof of technology was just as important as the knowledge the experiment gained about neutrinos. ICARUS showed that liquid argon technology was an efficient, reliable and precise way to study the elusive particles.

"Following its initial conception, the experimental development from a table-top device to the huge ICARUS detector has required a number of successive steps in an experimental journey that has lasted almost 20 years," says Carlo Rubbia, spokesperson of the ICARUS collaboration. "The liquid argon, although initially coming from air, must reduce impurities to a few parts per trillion, a tiny amount in volume and free electron lifetimes of 20 milliseconds. Many truly remarkable collaborators have participated in Italy in the creation of such a novel technology."

CERN shut down its neutrino beam in 2012, but ICARUS had more to offer. Scientists decided to move the detector to the US Department of Energy's Fermi National Accelerator Laboratory, to make use of one of its intense neutrino beams.

To make the transition, ICARUS needed an upgrade. Workers maneuvered ICARUS out of the crowded Gran Sasso lab, packed it in two modules (drained of liquid argon) onto special transporters, and wound their way through the Alps to just the place to get an upgrade, the European particle physics laboratory CERN.

A rebirth at CERN: Geneva, Switzerland

After traversing the Mont Blanc tunnel and winding through small French villages toward Geneva, the two large ICARUS modules arrived at CERN in December 2014. After several years of operation at Gran Sasso, the detector was ready for a reboot. One of the main tasks was updating all the electronics and the read-out system.

"The detector itself is very modern and sophisticated, but the supporting technology has evolved over the last 20 years," says Andrea Zani, a CERN researcher working on the ICARUS experiment. "For example, the original cables are not produced anymore, and the new data read-out system will be higher-performing, exploiting newer components that are far more compact."

Zani and his colleagues started disassembling parts of the detector at Gran Sasso and then continued their work at CERN. They are replacing the old electronics with 50,000 new read-out channels, which streamline the data collection process and will improve the experiment's performance overall. Other upgrades involved realigning components to improve the detector's precision.

"The high-voltage cathode plates were slightly deformed in a few places, which was fine when the experiment first started operation," Zani says, "but we now we have the capability to make even more precise measurements. We had to heat and then press the plates until they were almost perfectly flat."

The team also replaced a few dozen outdated light sensors with 360 new photomultiplier tubes, which are now nested behind the wires lining the inner walls of their detectors.

When neutrinos strike atoms of argon in one of the detectors, they release a flash of light and a cascade of charged particles. As these charged particles pass through the detector they ionize other argon atoms releasing electrons. An electric field across the detector causes these electrons to drift toward a plane of roughly 13,000 wires (52,000 in total, counting all four sections of the detector), which measure the incoming particles and enable scientists to reconstruct finely detailed images.

"In addition to the cascade of ionized particles, neutrinos produce a tiny flash of ultraviolet light when they interact with argon atoms," Zani says. "We know the velocity of electrons as they travel through the liquid argon, and can calculate a particle's distance from the wire detectors based on the time it takes for the electrical signal to arrive after this flash.

These precise location measurements help scientists distinguish between interesting neutrino interactions and ordinary cosmic rays. Before their installation, all 360 new photomultiplier tubes had to be dusted with a fine powder that shifts the original UV light into a deep blue glow. Over the course of several months, a dedicated team of physicists and technicians completed the process of dusting, testing and finally installing the new light sensors.

In addition to refurbishing the detector, CERN's engineering team designed and built two huge coolers that will eventually hold the two large ICARUS modules. These containers work much like a thermos and use a vacuum between their inner and outer walls. A layer of solid foam between them will prevent heat from seeping into the experiment. An international collaboration of scientists and engineers are also developing the supporting infrastructure that will enable ICARUS to integrate into its new home at Fermilab.

The final step was stress-testing the containers and packaging the detector for its long journey across the Atlantic.

"It's been a lot of work," Zani says, "and putting this all together has been a close collaboration between many different institutions. But we all have the common goal of preparing this detector for its second life at Fermilab."

New horizons at Fermilab: Batavia, Illinois

While the ICARUS detector was getting an upgrade at CERN, teams of people at Fermilab were preparing for its arrival.

In July 2015, work began on the building that will house the detector 30 feet underground, precisely in the path of Fermilab's neutrino beam. To keep the cryogenic vessels cold, a team of workers from CERN and INFN visited Fermilab in May 2017 to help install a steel structure that will hold a hefty amount of insulation.

"We couldn't do this without our partners around the world, and it's been very rewarding to see it all come together," says Peter Wilson, the head of Fermilab's short-baseline neutrino program. "The steel vessel was designed by CERN and manufactured in Poland. The electronic systems were designed by INFN. We're working with CERN, INFN and other institutions on cosmic-ray taggers that will go above, around and below the detector."

When the ICARUS detector arrives, it will spend a couple of months undergoing tests and final preparations before being lowered by crane into the building. Once there, it will take its place as the largest in a suite of three detectors on site at Fermilab with a common purpose: to search for a theorized, but never seen, fourth type of neutrino.

Scientists have observed three types of neutrinos: the muon, the electron and the tau neutrino. But they have also seen hints that those three types might be changing into another type they can't detect. Two experiments in particular—the Liquid Scintillator Neutrino Detector (LSND) at Los Alamos National Lab and MiniBooNE at Fermilab—saw an unexplained excess of charged particles of unexplained origin. One theory is that they were produced by so-called "sterile" neutrinos, which would not interact in the same way as the other three neutrinos.

ICARUS will join the Short-Baseline Near Detector, currently under construction, and MiniBooNE's successor, MicroBooNE, which has been taking data for nearly two years, on the hunt for sterile neutrinos. All three detectors use the same liquid-argon technology pioneered for ICARUS.

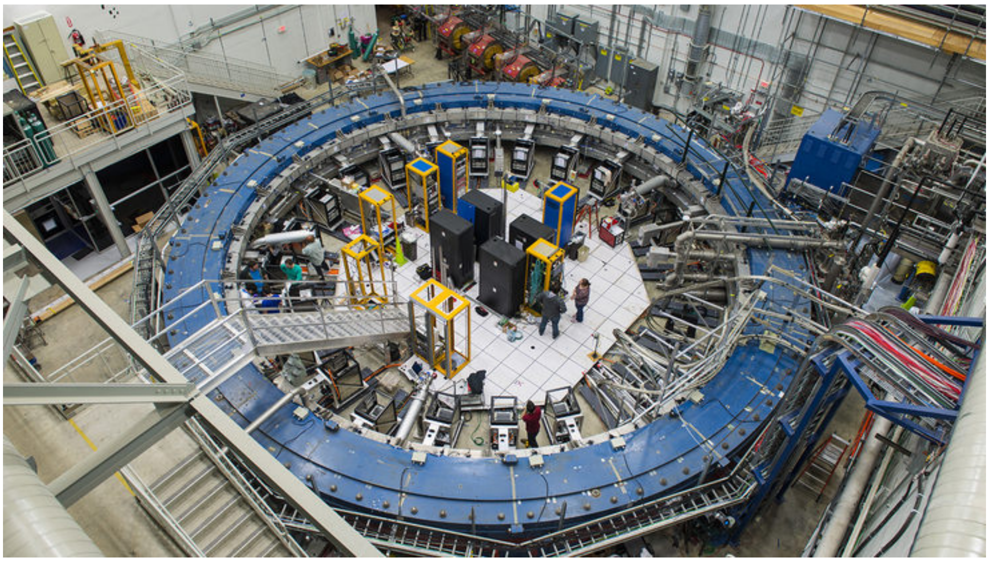
The journey of the ICARUS detector could have a destination beyond its new home at Fermilab. If evidence of a new kind of neutrino were discovered, it could travel all the way to a new understanding of the universe.

Read More... (http://www.symmetrymagazine.org/article/a-tale-of-three-cities?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Muon magnet's moment has arrived (http://www.symmetrymagazine.org/article/muon-magnets-moment-has-arrived?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Jun 1, 2017

The Muon g-2 experiment has begun its search for phantom particles with its well-traveled electromagnet.



What do you get when you revive a beautiful 20-year-old physics machine, carefully transport it 3200 miles over land and sea to its new home, and then use it to probe strange happenings in a magnetic field? Hopefully you get new insights into the elementary particles that make up everything.

The Muon g-2 experiment, located at the US Department of Energy's Fermi National Accelerator Laboratory, has begun its quest for those insights.

Take a 360-degree tour (http://vms.fnal.gov/w1/vr/mg2/index.html) of the Muon g-2 experimental hall.

On May 31, the 50-foot-wide superconducting electromagnet at the center of the experiment saw its first beam of muon particles from Fermilab's accelerators, kicking off a three-year effort to measure just what happens to those particles when placed in a stunningly precise magnetic field. The answer could rewrite scientists' picture of the universe and how it works.

"The Muon g-2 experiment's first beam truly signals the start of an important new research program at Fermilab, one that uses muon particles to look for rare and fascinating anomalies in nature," says Fermilab Director Nigel Lockyer. "After years of preparation, I'm excited to see this experiment begin its search in earnest."

Getting to this point was a long road for Muon g-2, both figuratively and literally. The first generation of this experiment took place at Brookhaven National Laboratory in New York State in the late 1990s and early 2000s. The goal of the experiment was to precisely measure one property of the muon—the particles' precession, or wobble, in a magnetic field. The final results were surprising, hinting at the presence of previously unknown phantom particles or forces affecting the muon's properties.

The new experiment at Fermilab will make use of the laboratory's intense beam of muons to definitively answer the questions the Brookhaven experiment raised. And since it would have cost 10 times more to build a completely new machine at Brookhaven rather than move the magnet to Fermilab, the Muon g-2 team transported that large, fragile superconducting magnet in one piece from Long Island to the suburbs of Chicago in the summer of 2013.

The magnet took a barge south around Florida, up the Tennessee-Tombigbee waterway and the Illinois River, and was then driven on a specially designed truck over three nights to Fermilab. And thanks to a GPS-powered map online, it collected thousands of fans over its journey, making it one of the most well-known electromagnets in the world.

"Getting the magnet here was only half the battle," says Chris Polly, project manager of the Muon g-2 experiment. "Since it arrived, the team here at Fermilab has been working around the clock installing detectors, building a control room and, for the past year, adjusting the uniformity of the magnetic field, which must be precisely known to an unprecedented level to obtain any new physics. It's been a lot of work, but we're ready now to really get started."

That work has included the creation of a new beamline to deliver a pure beam of muons to the ring, the installation of a host of instrumentation to measure both the magnetic field and the muons as they circulate within it, and a year-long process of "shimming" the magnet, inserting tiny pieces of metal by hand to shape the magnetic field. The field created by the magnet is now three times more uniform than the one it created at Brookhaven.

Over the next few weeks the Muon g-2 team will test the equipment installed around the magnet, which will be storing and measuring muons for the first time in 16 years. Later this year, they will start taking science-quality data, and if their results confirm the anomaly first seen at Brookhaven, it will mean that the elegant picture of the universe that scientists have been working on for decades is incomplete, and that new particles or forces may be out there, waiting to be discovered.

"It's an exciting time for the whole team, and for physics," says David Hertzog of the University of Washington, co-spokesperson of the Muon g-2 collaboration. "The magnet has been working, and working fantastically well. It won't be long until we have our first results, and a better view through the window that the Brookhaven experiment opened for us."

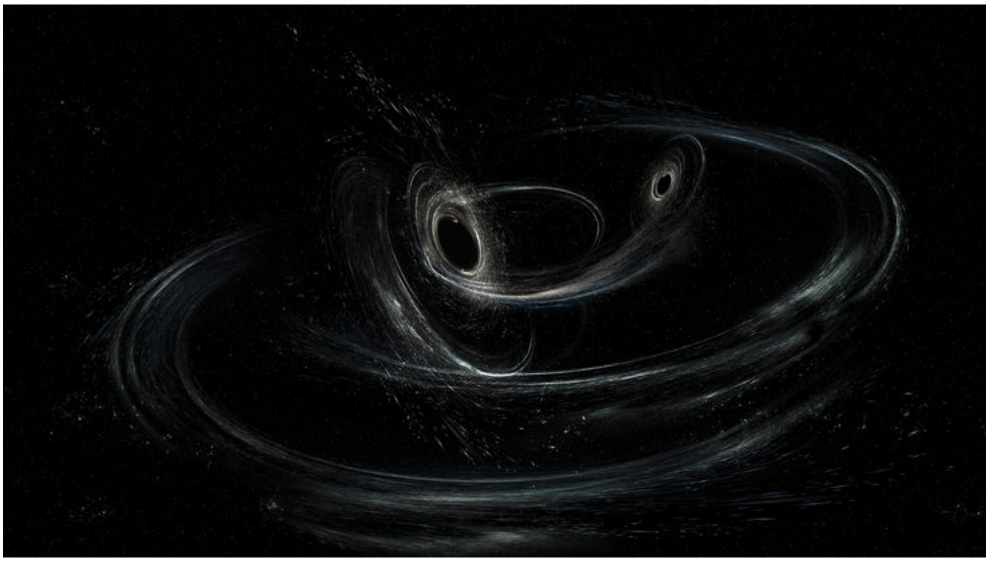
Editor's note: This article is based on a Fermilab press release (http://news.fnal.gov/2017/05/muon-magnets-moment-arrived/).

Read More... (http://www.symmetrymagazine.org/article/muon-magnets-moment-has-arrived?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

At LIGO, three's a trend (http://www.symmetrymagazine.org/article/at-ligo-threes-a-trend?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Jun 1, 2017

The third detection of gravitational waves from merging black holes provides a new test of the theory of general relativity.



For the third time, the LIGO and Virgo collaborations have announced directly detecting the merger of black holes many times the mass of our sun. In the process, they put general relativity to the test.

On January 4, the twin detectors of the Laser Interferometer Gravitational-Wave Observatory stretched and squeezed ever so slightly, breaking the symmetry between the motions of two sets of laser beams. This barely perceptible shiver, lasting a fraction of a second, was the consequence of a catastrophic event: About 3 billion light-years away, a pair of spinning black holes with a combined mass about 49 times that of our sun sank together into a single entity.

The merger produced more power than is radiated as light by the entire contents of the universe at any given time. “These are the most powerful astronomical events witnessed by human beings,” says Caltech scientist Mike Landry, head of the LIGO Hanford Observatory.

When the black holes merged, about two times the mass of the sun converted into energy and released in the form of ripples in the fabric of existence. These were gravitational waves, predicted by Albert Einstein’s theory of general relativity a century ago and first detected by LIGO in 2015.

“Gravitational waves are distortions in the medium that we live in,” Landry says. “Normally we don’t think of the nothing of space as having any properties of all. It’s counterintuitive to think it could expand or contract or vibrate.”

It was not a given that LIGO would be listening when the signal from the black holes arrived. “The machines don’t run 24-7,” says LIGO research engineer Brian Lantz of Stanford University. The list of distractions that can sabotage the stillness the detectors need includes earthquakes, wind, technical trouble, moving nitrogen tanks, mowing grass, harvesting trees and fires.

When the gravitational waves from the colliding black holes reached Earth in January, the LIGO detectors happened to be coming back online after a holiday break. The system that alerts scientists to possible detections wasn’t even fully back in service yet, but a scientist in Germany was poring over the data anyway.

“He woke us up in the middle of the night,” says MIT scientist David Shoemaker, newly elected spokesperson of the LIGO Scientific Collaboration, a body of more than 1000 scientists who perform LIGO research together with the European-based Virgo Collaboration.

The signal turned out to be worth getting out of bed for. “This clearly establishes a new population of black holes not known before LIGO discovered them,” says LIGO scientist Bangalore Sathyaprakash of Penn State and Cardiff University.

The merging black holes were more than twice as distant as the two pairs that LIGO previously detected, which were located 1.3 and 1.4 billion light-years away. This provided the best test yet of a second prediction of general relativity: gravitons without any mass.

Gravitons are hypothetical particles that would mediate the force of gravity, just as photons mediate the force of electromagnetism. Photons are quanta of light; gravitons would be quanta of gravitational waves.

General relativity predicts that, like photons, gravitons should have no mass, which means they should travel at the speed of light. However, if gravitons did have mass, they would travel at different speeds, depending on their energy.

As merging black holes spiral closer and closer together, they move at a faster and faster pace. If gravitons had no mass, this change would not faze them; they would uniformly obey the same speed limit as they traveled away from the event. But if gravitons did have mass, some of the gravitons produced would travel faster than others. The gravitational waves that arrived at the LIGO detectors would be distorted.

“That would mean general relativity is wrong,” says Stanford University Professor Emeritus Bob Wagoner. “Any one observation can kill a theory.”

LIGO scientists’ observations matched the first scenario, putting a new upper limit on the mass of the graviton—and letting general relativity live another day. “I wouldn’t bet against it, frankly,” Wagoner says.

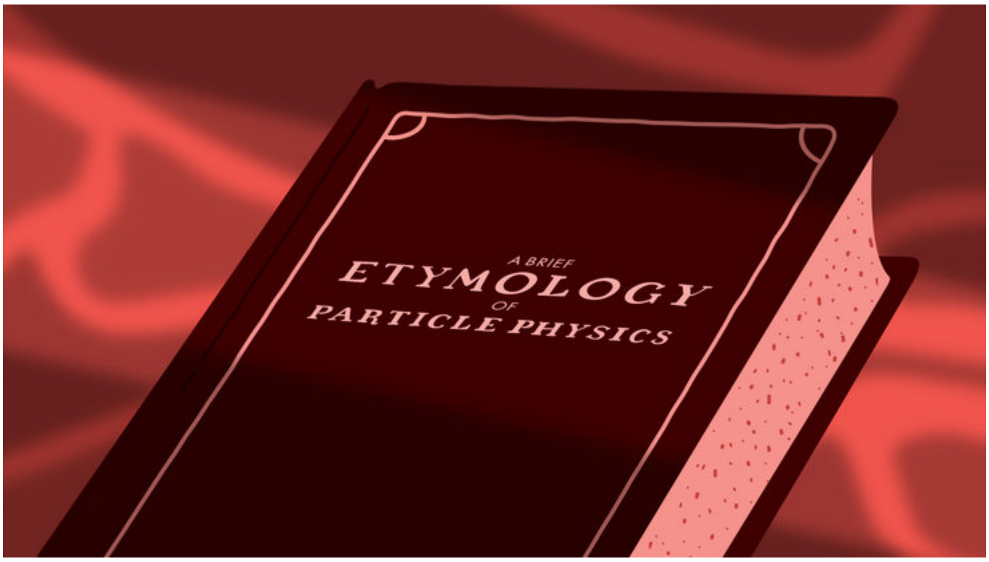
Like a pair of circling black holes, research at LIGO seems to be picking up speed. Collaboration members continue to make improvements to their detectors. Soon the complementary Virgo detector is expected to come online in Italy, and in 2024 another LIGO detector is scheduled to start up in India. Scientists hope to eventually see new events as often as once per day, accumulating a pool of data with which to make new discoveries about the goings-on of our universe.

Read More... (http://www.symmetrymagazine.org/article/at-ligo-threes-a-trend?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

A brief etymology of particle physics (http://www.symmetrymagazine.org/article/a-brief-etymology-of-particle-physics?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

May 30, 2017

How did the proton, photon and other particles get their names?



Over the years, physicists have given names to the smallest constituents of our universe.

This pantheon of particles has grown alongside progress in physics. Anointing a particle with a name is not just convenient; it marks a leap forward in our understanding of the world around us.

The etymology of particle physics contains a story that connects these sometimes outlandish names to a lineage of scientific thought and experiment.

So, without further ado, *Symmetry* presents a detailed guide to the etymology of particles—some we've found and others we have yet to discover.

Editor's note: PIE, referenced throughout, refers to proto-Indo-European, one of the earliest known languages.

Discovered particles

Expand all

ion	*ion*
fermion	*Fermi + on*
lepton	*leptos + on*
electron	*electric + on*
muon	*mu-meson (contraction)*
tau	*triton*
neutrino	*neutro (diminutive)*
quark	*quark*
boson	*Bose + on*
photon	*photo + on*
Higgs boson	*Higgs + boson*
W boson	*weak + boson*
Z boson	*zero + boson*
gluon	*glue + on*

hadron	*hadros + on*
baryon	*barys + on*
proton	*protos + on*
neutron	*neutral + on*
meson	*mesos + on*
antimatter	*anti + matter*

Hypothetical particles

Expand all

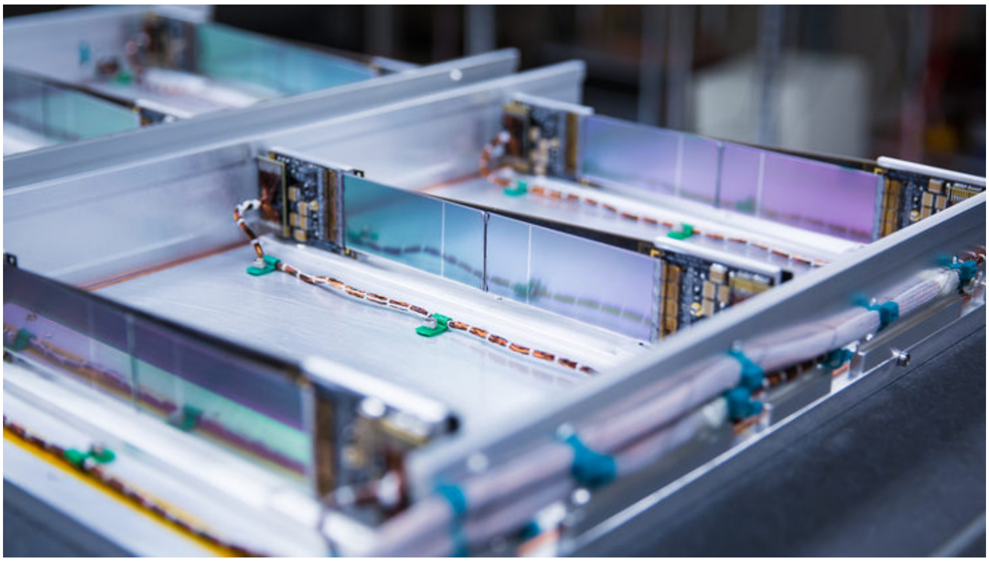
axion	*Axion*
chameleon	*chameleon*
graviton	*gravity + on*
majoron	*Majorana + on*
tachyon	*tachy + on*
supersymmetric particles	*super + symmetry*

Read More... (http://www.symmetrymagazine.org/article/a-brief-etymology-of-particle-physics?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

First results from search for a dark light (http://www.symmetrymagazine.org/article/first-results-from-search-for-a-dark-light?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

May 26, 2017

The Heavy Photon Search at Jefferson Lab is looking for a hypothetical particle from a hidden "dark sector."



In 2015, a group of researchers installed a particle detector just half of a millimeter away from an extremely powerful electron beam. The detector could either start them on a new search for a hidden world of particles and forces called the "dark sector"—or its sensitive parts could burn up in the beam.

Earlier this month, scientists presented the results (https://www.jlab.org/indico/event/214/contribution/33/material/slides/0.pdf) from that very first test run at the Heavy Photon Search collaboration meeting at the US Department of Energy's Thomas Jefferson National Accelerator Facility. To the scientists' delight, the experiment is working flawlessly.

Dark sector particles could be the long-sought components of dark matter, the mysterious form of matter thought to be five times more abundant in the universe than regular matter. To be specific, HPS is looking for a dark-sector version of the photon, the elementary "particle of light" that carries the fundamental electromagnetic force in the Standard Model of particle physics.

Analogously, the dark photon would be the carrier of a force between dark-sector particles. But unlike the regular photon, the dark photon would have mass. That's why it's also called the heavy photon.

To search for dark photons, the HPS experiment uses a very intense, nearly continuous beam of highly energetic electrons from Jefferson Lab's CEBAF accelerator. When slammed into a tungsten target, the electrons radiate energy that could potentially produce the mystery particles. Dark photons are believed to quickly decay into pairs of electrons and their antiparticles, positrons, which leave tracks in the HPS detector.

"Dark photons would show up as an anomaly in our data—a very narrow bump on a smooth background from other processes that produce electron-positron pairs," says Omar Moreno from SLAC National Accelerator Laboratory, who led the analysis of the first data and presented the results at the collaboration meeting.

The challenge is that, due to the large beam energy, the decay products are compressed very narrowly in beam direction. To catch them, the detector must be very close to the electron beam. But not too close—the smallest beam movements could make the beam swerve into the detector. Even if the beam doesn't directly hit the HPS apparatus, electrons interacting in the target can scatter into the detector and cause unwanted signals.

The HPS team implemented a number of precautions to make sure their detector could handle the potentially destructive beam conditions. They installed and carefully aligned a system to intercept any large beam motions, made the detector's support structure movable to bring the detector close to the beam and measure the exact beam position, and installed a feedback system that would shut the beam down if its motions were too large. They also placed their whole setup in vacuum because interactions of the beam with gas molecules would create too much background. Finally, they cooled the detector to negative 30 degrees Fahrenheit to reduce the effects of radiation damage. These measures allowed the team to operate their experiment so close to the beam.

"That's maybe as close as anyone has ever come to such a particle beam," says John Jaros, head of the HPS group at SLAC, which built the innermost part of the HPS detector, the Silicon Vertex Tracker. "So, it was fairly exciting when we gradually decreased the distance between the detector and the beam for the first time and saw that everything worked as planned. A large part of that success lies with the beautiful beams Jefferson Lab provided."

SLAC's Mathew Graham, who oversees the HPS analysis group, says, "In addition to figuring out if we can actually do the experiment, the first run also helped us understand the background signals in the experiment and develop the data analysis tools we need for our search for dark photons."

So far, the team has seen no signs of dark photons. But to be fair, the data they analyzed came from just 1.7 days of accumulated running time. HPS collects data in short spurts when the CLAS experiment, which studies protons and neutrons using the same beam line, is not in use.

A second part of the analysis is still ongoing: The researchers are also closely inspecting the exact location, or vertex, from which an electron-positron pair emerges.

"If a dark photon lives long enough, it might make it out of the tungsten target where it was produced and travel some distance through the detector before it decays into an electron-positron pair," Moreno says. The detector was specifically designed to observe such a signal.

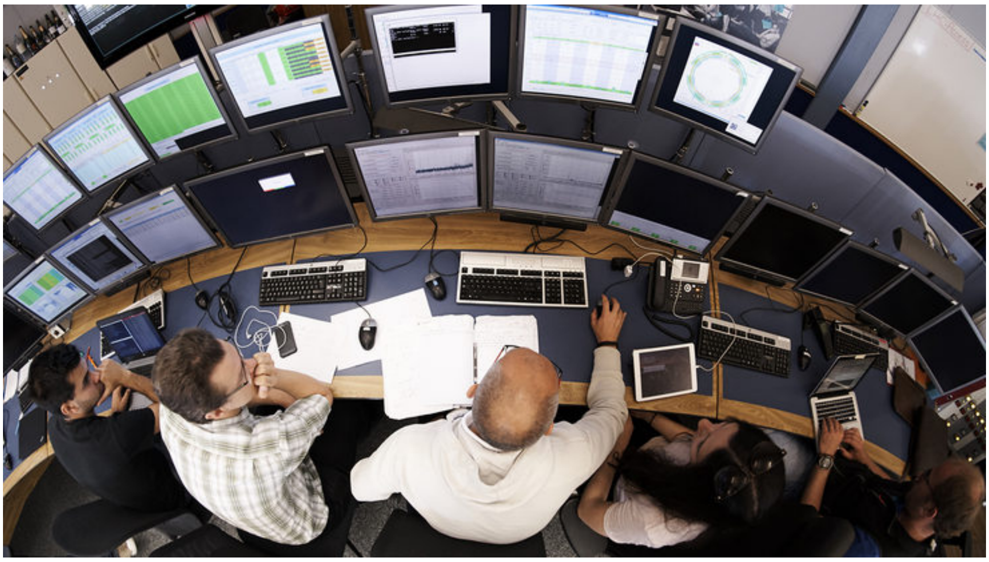
Jefferson Lab has approved the HPS project for a total of 180 days of experimental time. Slowly but surely, HPS scientists are finding chances to use it.

Read More... (http://www.symmetrymagazine.org/article/first-results-from-search-for-a-dark-light?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

LHC swings back into action (http://www.symmetrymagazine.org/article/lhc-swings-back-into-action?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

May 23, 2017

Protons are colliding once again in the Large Hadron Collider.



This morning at CERN, operators nudged two high-energy beams of protons into a collision course inside the world's largest and most energetic particle accelerator, the Large Hadron Collider. These first stable beams inside the LHC since the extended winter shutdown usher in another season of particle hunting.

The LHC's 2017 run is scheduled to last until December 10. The improvements made during the winter break will ensure that scientists can continue to search for new physics and study rare subatomic phenomena. The machine exploits Albert Einstein's principle that energy and matter are equivalent and enables physicists to transform ordinary protons into the rare massive particles that existed when our universe was still in its infancy.

"Every time the protons collide, it's like panning for gold," says Richard Ruiz, a theorist at Durham University. "That's why we need so much data. It's very rare that the LHC produces something interesting like a Higgs boson, the subatomic equivalent of a huge gold nugget. We need to find lots of these rare particles so that we can measure their properties and be confident in our results."

During the LHC's four-month winter shutdown, engineers replaced one of its main dipole magnets and carried out essential upgrades and maintenance work. Meanwhile, the LHC experiments installed new hardware and revamped their detectors. Over the last several weeks, scientists and engineers have been performing the final checks and preparations for the first "stable beams" collisions.

"There's no switch for the LHC that instantly turns it on," says Guy Crockford, an LHC operator. "It's a long process, and even if it's all working perfectly, we still need to check and calibrate everything. There's a lot of power stored in the beam and it can easily damage the machine if we're not careful."

In preparation for data-taking, the LHC operations team first did a cold checkout of the circuits and systems without beam and then performed a series of dress rehearsals with only a handful of protons racing around the machine.

"We set up the machine with low intensity beams that are safe enough that we could relax the safety interlocks and make all the necessary tweaks and adjustments," Crockford says. "We then deliberately made the proton beams unstable to check that all the loose particles were caught cleanly. It's a long and painstaking process, but we need complete confidence in our settings before ramping up the beam intensity to levels that could easily do damage to the machine."

The LHC started collisions for physics with only three proton bunches per beam. Over the course of the next month, the operations team will gradually increase the number of proton bunches until they have 2760 per beam. The higher proton intensity greatly increases the rate of collisions, enabling the experiments to collect valuable data at a much faster rate.

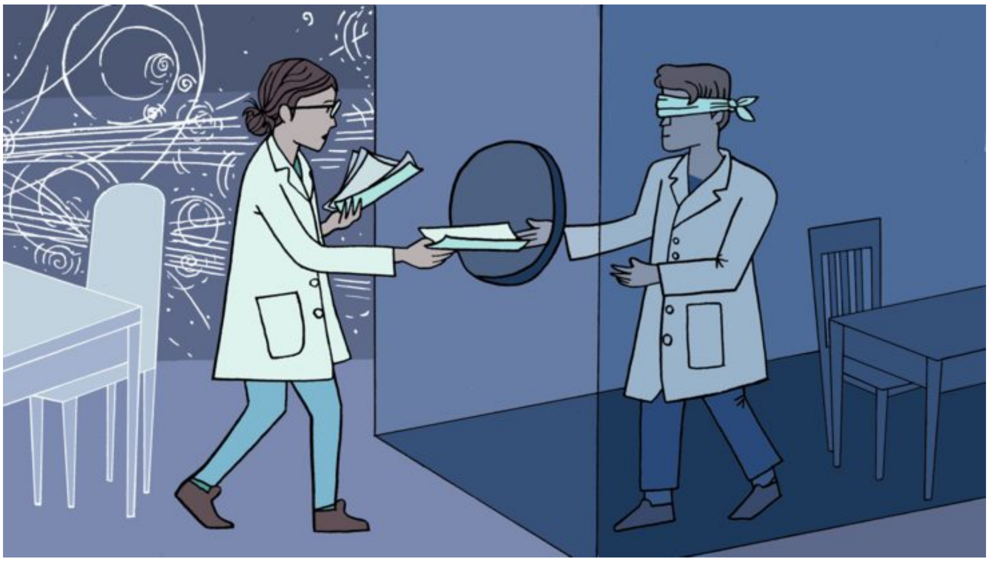
"We're always trying to improve the machine and increase the number of collisions we deliver to the experiments," Crockford says. "It's a personal challenge to do a little better every year."

Read More... (http://www.symmetrymagazine.org/article/lhc-swings-back-into-action?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

The facts and nothing but the facts (http://www.symmetrymagazine.org/article/the-facts-and-nothing-but-the-facts?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

May 16, 2017

At a recent workshop on blind analysis, researchers discussed how to keep their expectations out of their results.



Scientific experiments are designed to determine facts about our world. But in complicated analyses, there's a risk that researchers will unintentionally skew their results to match what they were expecting to find. To reduce or eliminate this potential bias, scientists apply a method known as "blind analysis."

Blind studies are probably best known from their use in clinical drug trials, in which patients are kept in the dark about—or blind to—whether they're receiving an actual drug or a placebo. This approach helps researchers judge whether their results stem from the treatment itself or from the patients' belief that they are receiving it.

Particle physicists and astrophysicists do blind studies, too. The approach is particularly valuable when scientists search for extremely small effects hidden among background noise that point to the existence of something new, not accounted for in the current model. Examples include the much-publicized discoveries of the Higgs boson by experiments at CERN's Large Hadron Collider and of gravitational waves by the Advanced LIGO detector.

"Scientific analyses are iterative processes, in which we make a series of small adjustments to theoretical models until the models accurately describe the experimental data," says Elisabeth Krause, a postdoc at the Kavli Institute for Particle Astrophysics and Cosmology, which is jointly operated by Stanford University and the Department of Energy's SLAC National Accelerator Laboratory. "At each step of an analysis, there is the danger that prior knowledge guides the way we make adjustments. Blind analyses help us make independent and better decisions."

Krause was the main organizer of a recent workshop (http://kipac-web.stanford.edu/they-blinded-it-science) at KIPAC that looked into how blind analyses could be incorporated into next-generation astronomical surveys that aim to determine more precisely than ever what the universe is made of and how its components have driven cosmic evolution.

Black boxes and salt

One outcome of the workshop was a finding that there is no one-size-fits-all approach, says KIPAC postdoc Kyle Story, one of the event organizers. "Blind analyses need to be designed individually for each experiment."

The way the blinding is done needs to leave researchers with enough information to allow a meaningful analysis, and it depends on the type of data coming out of a specific experiment.

A common approach is to base the analysis on only some of the data, excluding the part in which an anomaly is thought to be hiding. The excluded data is said to be in a “black box” or “hidden signal box.”

Take the search for the Higgs boson. Using data collected with the Large Hadron Collider until the end of 2011, researchers saw hints of a bump as a potential sign of a new particle with a mass of about 125 gigaelectronvolts. So when they looked at new data, they deliberately quarantined the mass range around this bump and focused on the remaining data instead.

They used that data to make sure they were working with a sufficiently accurate model. Then they “opened the box” and applied that same model to the untouched region. The bump turned out to be the long-sought Higgs particle.

That worked well for the Higgs researchers. However, as scientists involved with the Large Underground Xenon experiment reported at the workshop, the “black box” method of blind analysis can cause problems if the data you’re expressly not looking at contains rare events crucial to figuring out your model in the first place.

LUX has recently completed one of the world’s most sensitive searches for WIMPs—hypothetical particles of dark matter, an invisible form of matter that is five times more prevalent than regular matter. LUX scientists have done a lot of work to guard LUX against background particles—building the detector in a cleanroom, filling it with thoroughly purified liquid, surrounding it with shielding and installing it under a mile of rock. But a few stray particles make it through nonetheless, and the scientists need to look at all of their data to find and eliminate them.

For that reason, LUX researchers chose a different blinding approach for their analyses. Instead of using a “black box,” they use a process called “salting.”

LUX scientists not involved in the most recent LUX analysis added fake events to the data—simulated signals that just look like real ones. Just like the patients in a blind drug trial, the LUX scientists didn’t know whether they were analyzing real or placebo data. Once they completed their analysis, the scientists that did the “salting” revealed which events were false.

A similar technique was used by LIGO scientists, who eventually made the first detection of extremely tiny ripples in space-time called gravitational waves.

High-stakes astronomical surveys

The Blind Analysis workshop at KIPAC focused on future sky surveys that will make unprecedented measurements of dark energy and the Cosmic Microwave Background—observations that will help cosmologists better understand the evolution of our universe.

Dark energy is thought to be a force that is causing the universe to expand faster and faster as time goes by. The CMB is a faint microwave glow spread out over the entire sky. It is the oldest light in the universe, left over from the time the cosmos was only 380,000 years old.

To shed light on the mysterious properties of dark energy, the Dark Energy Science Collaboration is preparing to use data from the Large Synoptic Survey Telescope, which is under construction in Chile. With its unique 3.2-gigapixel camera, LSST will image billions of galaxies, the distribution of which is thought to be strongly influenced by dark energy.

“Blinding will help us look at the properties of galaxies picked for this analysis independent of the well-known cosmological implications of preceding studies,” DESC member Krause says. One way the collaboration plans on blinding its members to this prior knowledge is to distort the images of galaxies before they enter the analysis pipeline.

Not everyone in the scientific community is convinced that blinding is necessary. Blind analyses are more complicated to design than non-blind analyses and take more time to complete. Some scientists participating in blind analyses inevitably spend time looking at fake data, which can feel like a waste.

Yet others strongly advocate for going blind. KIPAC researcher Aaron Roodman, a particle-physicist-turned-astrophysicist, has been using blinding methods for the past 20 years.

“Blind analyses have already become pretty standard in the particle physics world,” he says. “They’ll be also crucial for taking bias out of next-generation cosmological surveys, particularly when the stakes are high. We’ll only build one LSST, for example, to provide us with unprecedented views of the sky.”

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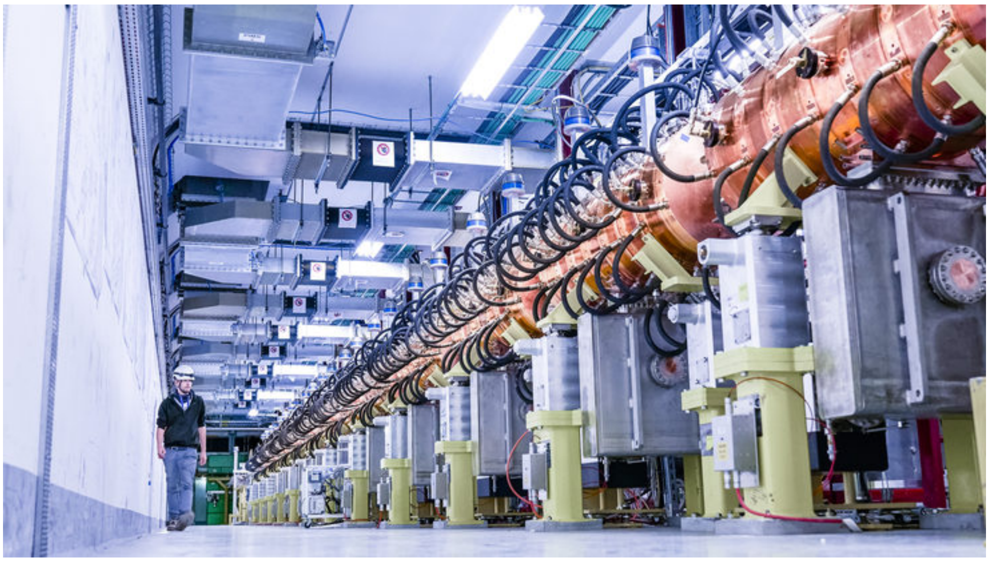
CERN unveils new linear accelerator (http://www.symmetrymagazine.org/article/cern-unveils-new-linear-accelerator?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

May 9, 2017

Linac 4 will replace an older accelerator as the first step in the complex that includes the LHC.



At a ceremony today, CERN European research center inaugurated its newest accelerator.

Linac 4 will eventually become the first step in CERN's accelerator chain, delivering proton beams to a wide range of experiments, including those at the Large Hadron Collider.

After an extensive testing period, Linac 4 will be connected to CERN's accelerator complex during a long technical shutdown in 2019-20. Linac 4 will replace Linac 2, which was put into service in 1978. Linac 4 will feed the CERN accelerator complex with particle beams of higher energy.

"We are delighted to celebrate this remarkable accomplishment," says CERN Director General Fabiola Gianotti. "Linac 4 is a modern injector and the first key element of our ambitious upgrade program, leading to the High-Luminosity LHC. This high-luminosity phase will considerably increase the potential of the LHC experiments for discovering new physics and measuring the properties of the Higgs particle in more detail."

"This is an achievement not only for CERN, but also for the partners from many countries who contributed in designing and building this new machine," says CERN Director for Accelerators and Technology Frédérick Bordry. "We also today celebrate and thank the wide international collaboration that led this project, demonstrating once again what can be accomplished by bringing together the efforts of many nations."

The linear accelerator is the first essential element of an accelerator chain. In the linear accelerator, the particles are produced and receive the initial acceleration. The density and intensity of the particle beams are also shaped in the linac. Linac 4 is an almost 90-meter-long machine sitting 12 meters below the ground. It took nearly 10 years to build it.

Linac 4 will send negative hydrogen ions, consisting of a hydrogen atom with two electrons, to CERN's Proton Synchrotron Booster, which further accelerates the negative ions and removes the electrons. Linac 4 will bring the beam up to an energy of 160 million electronvolts, more than 3 times the energy of its predecessor. The increase in energy, together with the use of hydrogen ions, will enable doubling the beam intensity delivered to the LHC, contributing to an increase in the luminosity of the LHC by 2021.

Luminosity is a parameter indicating the number of particles colliding within a defined amount of time. The peak luminosity of the LHC is planned to be increased by a factor of 5 by the year 2025. This will make it possible for the experiments to accumulate about 10 times more data over the period 2025 to 2035 than before.

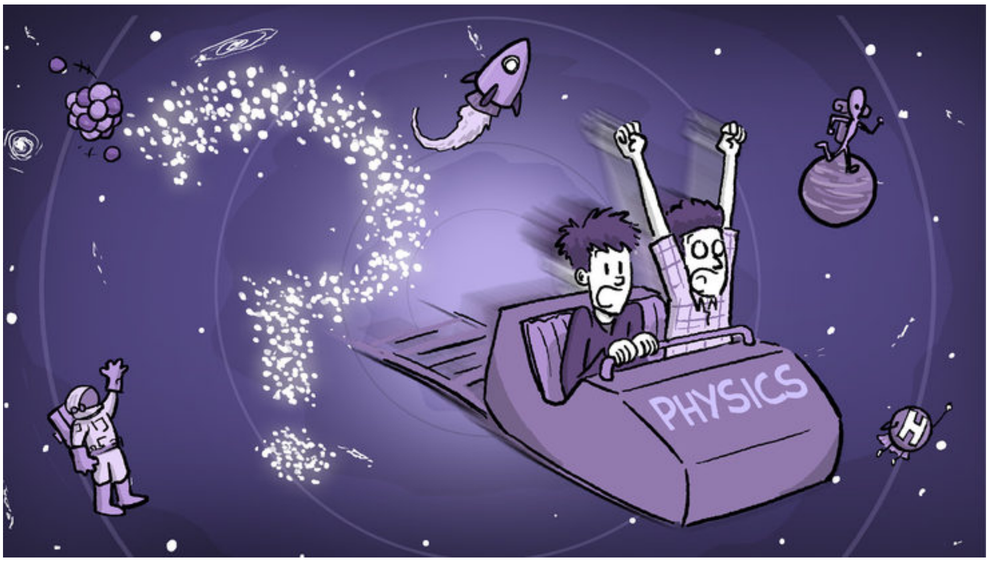
Editor's note: This article is based on a CERN press release (https://press.cern/press-releases/2017/05/cern-celebrates-completion-linac-4-its-brand-new-linear-particle-accelerator).

Read More... (http://www.symmetrymagazine.org/article/cern-unveils-new-linear-accelerator?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Understanding the unknown universe (http://www.symmetrymagazine.org/article/understanding-the-unknown-universe?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

May 9, 2017

The authors of *We Have No Idea* remind us that there are still many unsolved mysteries in science.



What is dark energy? Why aren't we made of antimatter? How many dimensions are there?

These are a few of the many unanswered questions that Jorge Cham, creator of the online comic Piled Higher and Deeper, and Daniel Whiteson, an experimental particle physicist at the University of California, Irvine, explain in their new book, We Have No Idea. In the process, they remind readers of one key point: When it comes to our universe, there's a lot we still don't know.

(http://www.symmetrymagazine.org/sites/default/files/images/standard/Jorge%20Cham%20%2528c%2529%20Michael%20Hall%255B3%255D_0.jpg)

Jorge Cham

The duo started working together in 2008 after Whiteson reached out to Cham, asking if he'd be willing to help create physics cartoons. "I always thought physics was well connected to the way comics work," Whiteson says. "Because, what's a Feynman diagram but a little cartoon of particles hitting each other?" (Feynman diagrams are pictures commonly used in particle physics papers that represent the interactions of subatomic particles.)

(http://www.symmetrymagazine.org/sites/default/files/images/standard/Daniel%20Whiteson%20%2528c%2529%20UC%20Irvine%20Department%20of%20Physic

Daniel Whiteson

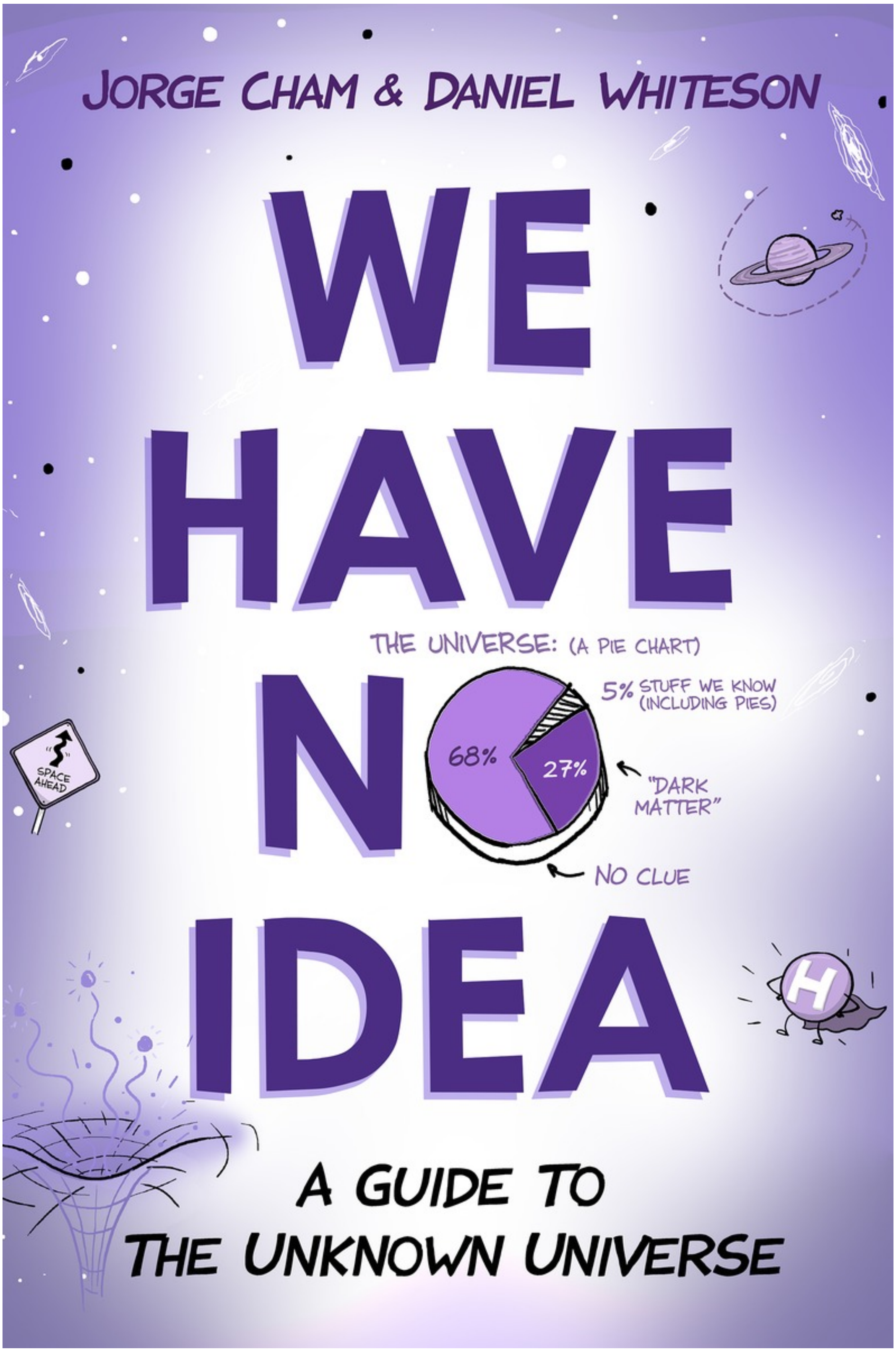
Before working on this book, the pair made a handful of popular YouTube videos on topics like dark matter, extra dimensions and the Higgs boson. Many of these subjects are also covered in We Have No Idea.

One of the main motivators of this latest project was to address a "certain apathy toward science," Cham says. "I think we both came into it having this feeling that the general public either thinks scientists have everything figured out, or they don't really understand what scientists are doing."

To get at this issue, the pair focused on topics that even someone without a science background could find compelling. "You don't need 10 years of physics background to know [that] questions about how the universe started or what it's made of are interesting," Whiteson says. "We tried to find questions that were gut-level approachable."

Another key theme of the book, the authors say, is the line between what science can and cannot tell us. While some of the possible solutions to the universe's mysteries have testable predictions, others (such as string theory) currently do not. "We wanted questions that were accessible yet answerable," says Whiteson. "We wanted to show people that there were deep, basic, simple questions that we all had, but that the answers were out there."

Many scientists are hard at work trying to fill the gaping holes in our knowledge about the universe. Particle physicists, for example, are exploring a number of these questions, such as those about the nature of antimatter and mass.



(http://www.symmetrymagazine.org/sites/default/files/images/standard/WE%20HAVE%20NO%20IDEA%20by%20Jorge%20Cham%20%20Daniel%20Whiteson%2

Artwork by Jorge Cham

Some lines of inquiry have brought different research communities together. Dark matter searches, for example, were primarily the realm of cosmologists, who probe large-scale structures of the universe. However, as the focus shifted to finding out what particle—or particles—dark matter was made of, this area of study started to attract astrophysicists as well.

Why are people trying to answer these questions? "I think science is an expression of humanity and our curiosity to know the answers to basic questions we ask ourselves: Who are we? Why are we here? How does the world work?" Whiteson says. "On the other hand, questions like these lead to understanding, and understanding leads to being able to have greater power over the environment to solve our problems.

In the very last chapter of the book, the authors explain the idea of a "testable universe," or the parts of the universe that fall within the bounds of science. In the Stone Ages, when humans had very few tools at their disposal, the testable universe was very small. But it increased as people built telescopes, satellites and particle colliders, and it continues to expand with ongoing advances in science and technology. "That's the exciting thing," Cham says. "Our ability to answer these questions is growing."

Some mysteries of the universe still live in the realm of philosophy. But tomorrow, next year or a thousand years from now, a scientist may come along and devise an experiment that will be able to find the answers.

"We're in a special place in history when most of the world seems explained," Whiteson says. Thousands of years ago, basic questions, such as why fire burns or where rain comes from, were still largely a mystery. "These days, all those mysteries seem answered, but the truth is, there's a lot of mysteries left. [If] you want to make a massive imprint on human intellectual history, there's plenty of room for that."

Read More... (http://www.symmetrymagazine.org/article/understanding-the-unknown-universe?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Sterile neutrino search hits roadblock at reactors (http://www.symmetrymagazine.org/article/sterile-neutrino-search-hits-roadblock-at-reactors?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

May 4, 2017

A new result from the Daya Bay collaboration reveals both limitations and strengths of experiments studying antineutrinos at nuclear reactors.

As nuclear reactors burn through fuel, they produce a steady flow of particles called neutrinos. Neutrinos interact so rarely with other matter that they can flow past the steel and concrete of a power plant's containment structures and keep on moving through anything else that gets in their way.

Physicists interested in studying these wandering particles have taken advantage of this fact by installing neutrino detectors nearby. A recent result using some of these detectors demonstrated both their limitations and strengths.

The reactor antineutrino anomaly

In 2011, a group of theorists noticed that several reactor-based neutrino experiments had been publishing the same, surprising result: They weren't detecting as many neutrinos as they thought they would.

Or rather, to be technically correct, they weren't seeing as many *anti*neutrinos as they thought they would; nuclear reactors actually produce the antimatter partners of the elusive particles. About 6 percent of the expected antineutrinos just weren't showing up. They called it "the reactor antineutrino anomaly."

The case of the missing neutrinos was a familiar one. In the 1960s, the Davis experiment located in Homestake Mine in South Dakota reported a shortage of neutrinos coming from processes in the sun. Other experiments confirmed the finding. In 2001, the Sudbury Neutrino Observatory in Ontario demonstrated that the missing neutrinos weren't missing at all; they had only undergone a bit of a costume change.

Neutrinos come in three types. Scientists discovered that neutrinos could transform from one type to another. The missing neutrinos had changed into a different type of neutrino that the Davis experiment couldn't detect.

Since 2011, scientists have wondered whether the reactor antineutrino anomaly was a sign of an undiscovered type of neutrino, one that was even harder to detect, called a sterile neutrino.

A new result (https://arxiv.org/abs/1704.01082) from the Daya Bay experiment in China not only casts doubt on that theory, it also casts doubt on the idea that scientists understand their model of reactor processes well enough at this time to use it to search for sterile neutrinos.

The word from Daya Bay

The Daya Bay experiment studies antineutrinos coming from six nuclear reactors on the southern coast of China, about 35 miles northeast of Hong Kong. The reactors are powered by the fission of uranium. Over time, the amount of uranium inside the reactor decreases while the amount of plutonium increases. The fuel is changed—or cycled—about every 18 months.

The main goal of the Daya Bay experiment was to look for the rarest of the known neutrino oscillations. It did that, making a groundbreaking discovery (http://www.symmetrymagazine.org/breaking/2012/03/08/daya-bay-experiment-makes-key-measurement-paves-way-for-future-discoveries) after just nine weeks of data-taking.

But that wasn't the only goal of the experiment. "We realized right from the beginning that it is important for Daya Bay to address as many interesting physics problems as possible," says Daya Bay co-spokesperson Kam-Biu Luk of the University of California, Berkeley and the US Department of Energy's Lawrence Berkeley National Laboratory.

For this result, Daya Bay scientists took advantage of their enormous collection of antineutrino data to expand their investigation to the reactor antineutrino anomaly.

Using data from more than 2 million antineutrino interactions and information about when the power plants refreshed the uranium in each reactor, Daya Bay physicists compared the measurements of antineutrinos coming from different parts of the fuel cycle: early ones dominated by uranium through later ones dominated by both uranium and plutonium.

In theory, the type of fuel producing the antineutrinos should not affect the rate at which they transform into sterile neutrinos. According to Bob Svoboda, chair of the Department of Physics at the University of California, Davis, “a neutrino wouldn’t care how it got made.” But Daya Bay scientists found that the shortage of antineutrinos existed only in processes dominated by uranium.

Their conclusion is that, once again, the missing neutrinos aren’t actually missing. This time, the problem of the missing antineutrinos seems to stem from our understanding of how uranium burns in nuclear power plants. The predictions for how many antineutrinos the scientists should detect may have been overestimated.

“Most of the problem appears to come from the uranium-235 model (uranium-235 is a fissile isotope of uranium), not from the neutrinos themselves,” Svoboda says. “We don’t fully understand uranium, so we have to take any anomaly we measured with a grain of salt.”

This knock against the reactor antineutrino anomaly does not disprove the existence of sterile neutrinos. Other, non-reactor experiments have seen different possible signs of their influence. But it does put a damper on the only evidence of sterile neutrinos to have come from reactor experiments so far.

Other reactor neutrino experiments, such as NEOS in South Korea and PROSPECT in the United States will fill in some missing details. NEOS scientists directly measured antineutrinos coming from reactors in the Hanbit nuclear power complex using a detector placed about 80 feet away, a distance some scientists believe is optimal for detecting sterile neutrinos should they exist. PROSPECT scientists will make the first precision measurement of antineutrinos coming from a highly enriched uranium core, one that does not produce plutonium as it burns.

A silver lining

The Daya Bay result offers the most detailed demonstration yet of scientists’ ability to use neutrino detectors to peer inside running nuclear reactors.

“As a study of reactors, this is a tour de force,” says theorist Alexander Friedland of SLAC National Accelerator Laboratory. “This is an explicit demonstration that the composition of the reactor fuel has an impact on the neutrinos.”

Some scientists are interested in monitoring nuclear power plants to find out if nuclear fuel is being diverted to build nuclear weapons.

“Suppose I declare my reactor produces 100 kilograms of plutonium per year,” says Adam Bernstein of Lawrence Livermore National Laboratory. “Then I operate it in a slightly different way, and at the end of the year I have 120 kilograms.” That 20-kilogram surplus, left unmeasured, could potentially be moved into a weapons program.

Current monitoring techniques involve checking what goes into a nuclear power plant before the fuel cycle begins and then checking what comes out after it ends. In the meantime, what happens inside is a mystery.

Neutrino detectors allow scientists to understand what’s going on in a nuclear reactor in real time.

Scientists have known for decades that neutrino detectors could be useful for nuclear nonproliferation purposes. Scientists studying neutrinos at the Rovno Nuclear Power Plant in Ukraine first demonstrated that neutrino detectors could differentiate between uranium and plutonium fuel.

Most of the experiments have done this by looking at changes in the aggregate number of antineutrinos coming from a detector. Daya Bay showed that neutrino detectors could track the plutonium inventory in nuclear fuel by studying the energy spectrum of antineutrinos produced.

“The most likely use of neutrino detectors in the near future is in so-called ‘cooperative agreements,’ where a $20-million-scale neutrino detector is installed in the vicinity of a reactor site as part of a treaty,” Svoboda says. “The site can be monitored very reliably without having to make intrusive inspections that bring up issues of national sovereignty.”

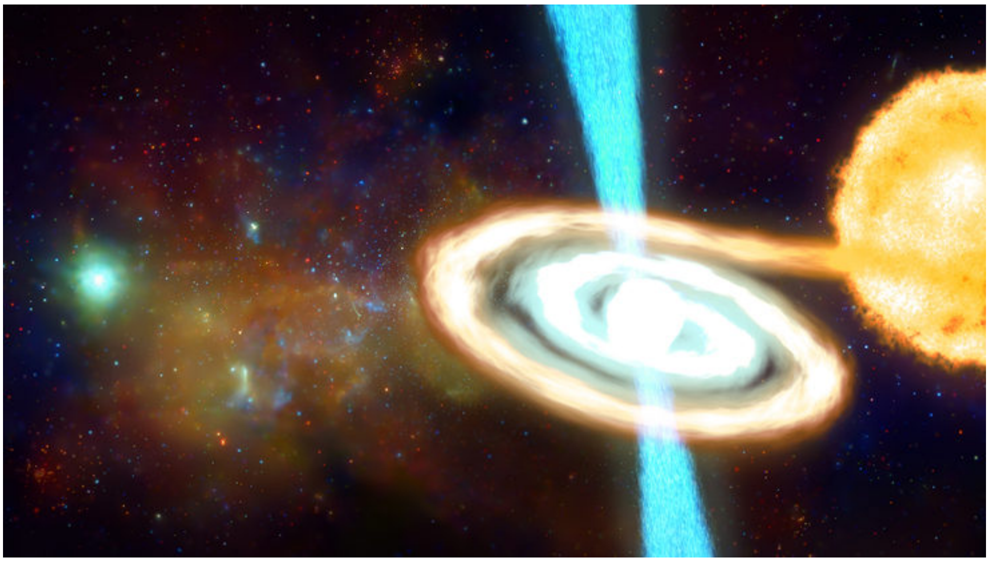
Luk says he is dubious that the idea will take off, but he agrees that Daya Bay has shown that neutrino detectors can give an incredibly precise report. “This result is the best demonstration so far of using a neutrino detector to probe the heartbeat of a nuclear reactor.”

Read More... (http://www.symmetrymagazine.org/article/sterile-neutrino-search-hits-roadblock-at-reactors?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Mystery glow of Milky Way likely not dark matter (http://www.symmetrymagazine.org/article/mystery-glow-of-milky-way-likely-not-dark-matter?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

May 2, 2017

According to the Fermi LAT collaboration, the galaxy’s excessive gamma-ray glow likely comes from pulsars, the remains of collapsed ancient stars.



A mysterious gamma-ray glow at the center of the Milky Way is most likely caused by pulsars, the incredibly dense, rapidly spinning cores of collapsed ancient stars that were up to 30 times more massive than the sun.

That's the conclusion of a new analysis by an international team of astrophysicists on the Fermi LAT collaboration. The findings cast doubt on previous interpretations of the signal as a potential sign of dark matter, a form of matter that accounts for 85 percent of all matter in the universe but that so far has evaded detection.

"Our study shows that we don't need dark matter to understand the gamma-ray emissions of our galaxy," says Mattia Di Mauro from the Kavli Institute for Particle Astrophysics and Cosmology, a joint institute of Stanford University and the US Department of Energy's SLAC National Accelerator Laboratory. "Instead, we have identified a population of pulsars in the region around the galactic center, which sheds new light on the formation history of the Milky Way."

Di Mauro led the analysis, which looked at the glow with the Large Area Telescope on NASA's Fermi Gamma-ray Space Telescope, which has been orbiting Earth since 2008. The LAT, a sensitive "eye" for gamma rays, the most energetic form of light, was conceived of and assembled at SLAC, which also hosts its operations center.

The collaboration's findings, submitted to *The Astrophysical Journal* for publication, are available as a preprint (https://arxiv.org/abs/1705.00009).

A mysterious glow

Dark matter is one of the biggest mysteries of modern physics. Researchers know that dark matter exists because it bends light from distant galaxies and affects how galaxies rotate. But they don't know what the substance is made of. Most scientists believe it's composed of yet-to-be-discovered particles that almost never interact with regular matter other than through gravity, making it very hard to detect them.

One way scientific instruments might catch a glimpse of dark matter particles is when the particles either decay or collide and destroy each other. "Widely studied theories predict that these processes would produce gamma rays," says Seth Digel, head of KIPAC's Fermi group. "We search for this radiation with the LAT in regions of the universe that are rich in dark matter, such as the center of our galaxy."

Previous studies have indeed shown that there are more gamma rays coming from the galactic center than expected, fueling some scientific papers and media reports that suggest the signal might hint at long-sought dark matter particles. However, gamma rays are produced in a number of other cosmic processes, which must be ruled out before any conclusion about dark matter can be drawn. This is particularly challenging because the galactic center is extremely complex, and astrophysicists don't know all the details of what's going on in that region.

Most of the Milky Way's gamma rays originate in gas between the stars that is lit up by cosmic rays, charged particles produced in powerful star explosions called supernovae. This creates a diffuse gamma-ray glow that extends throughout the galaxy. Gamma rays are also produced by supernova remnants, pulsars—collapsed stars that emit "beams" of gamma rays like cosmic lighthouses—and more exotic objects that appear as points of light.

"Two recent studies by teams in the US and the Netherlands have shown that the gamma-ray excess at the galactic center is speckled, not smooth as we would expect for a dark matter signal," says KIPAC's Eric Charles, who contributed to the new analysis. "Those results suggest the speckles may be due to point sources that we can't see as individual sources with the LAT because the density of gamma-ray sources is very high and the diffuse glow is brightest at the galactic center."

Remains of ancient stars

The new study takes the earlier analyses to the next level, demonstrating that the speckled gamma-ray signal is consistent with pulsars.

"Considering that about 70 percent of all point sources in the Milky Way are pulsars, they were the most likely candidates," Di Mauro says. "But we used one of their physical properties to come to our conclusion. Pulsars have very distinct spectra—that is, their emissions vary in a specific way with the energy of the gamma rays they emit. Using the shape of these spectra, we were able to model the glow of the galactic center correctly with a population of about 1,000 pulsars and without introducing processes that involve dark matter particles."

The team is now planning follow-up studies with radio telescopes to determine whether the identified sources are emitting their light as a series of brief light pulses—the trademark that gives pulsars their name.

Discoveries in the halo of stars around the center of the galaxy, the oldest part of the Milky Way, also reveal details about the evolution of our galactic home, just as ancient remains teach archaeologists about human history.

"Isolated pulsars have a typical lifetime of 10 million years, which is much shorter than the age of the oldest stars near the galactic center," Charles says. "The fact that we can still see gamma rays from the identified pulsar population today suggests that the pulsars are in binary systems with companion stars, from which they leach energy. This extends the life of the pulsars tremendously."

Dark matter remains elusive

The new results add to other data that are challenging the interpretation of the gamma-ray excess as a dark matter signal.

"If the signal were due to dark matter, we would expect to see it also at the centers of other galaxies," Digel says. "The signal should be particularly clear in dwarf galaxies orbiting the Milky Way. These galaxies have very few stars, typically don't have pulsars and are held together because they have a lot of dark matter. However, we don't see any significant gamma-ray emissions from them."

The researchers believe that a recently discovered strong gamma-ray glow at the center of the Andromeda galaxy, the major galaxy closest to the Milky Way, may also be caused by pulsars rather than dark matter.

But the last word may not have been spoken. Although the Fermi-LAT team studied a large area of 40 degrees by 40 degrees around the Milky Way's galactic center (the diameter of the full moon is about half a degree), the extremely high density of sources in the innermost four degrees makes it very difficult to see individual ones and rule out a smooth, dark matter-like gamma-ray distribution, leaving limited room for dark matter signals to hide.

This work was funded by NASA and the DOE Office of Science, as well as agencies and institutes in France, Italy, Japan and Sweden.

Editor's note: A version of this article was originally published by SLAC National Accelerator Laboratory (http://www6.slac.stanford.edu/news/2017-05-02-origin-milky-way-hypothetical-dark-matter-signal-may-not-be-so-dark.aspx).

Read More... (http://www.symmetrymagazine.org/article/mystery-glow-of-milky-way-likely-not-dark-matter?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

#AskSymmetry Twitter chat with Tulika Bose (http://www.symmetrymagazine.org/article/asksymmetry-twitter-chat-with-tulika-bose?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Apr 28, 2017

See Boston University physicist Tulika Bose's answers to readers' questions about research at the Large Hadron Collider.

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Did you see it? (http://www.symmetrymagazine.org/article/did-you-see-it?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Apr 27, 2017

Boston University physicist Tulika Bose explains why there's more than one large, general-purpose particle detector at the Large Hadron Collider.

Physicist Tulika Bose of the CMS experiment at CERN explains how the CMS and ATLAS experiments complement one another at the Large Hadron Collider.

Ask Symmetry - Why is there more than one detector at the Large Hadron Collider? (/file/ask-symmetry-why-is-there-more-than-one-detector-at-the-large-hadron-collider)

Have a burning question about research at the LHC? Tulika Bose will take over our Twitter handle, @symmetrymag (https://twitter.com/symmetrymag), on Friday, April 28, at noon Central. Tweet her your questions using the hashtag #AskSymmetry.

You can watch a playlist of the #AskSymmetry videos here (https://www.youtube.com/playlist?list=PLVuf4hejm7rVZMMwarDwTYknZXA120jyJ).

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Archaeology meets particle physics (http://www.symmetrymagazine.org/article/archaeology-meets-particle-physics?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Apr 25, 2017

Undergraduates search for hidden tombs in Turkey using cosmic-ray muons.

While the human eye is an amazing feat of evolution, it has its limitations. What we can see tells only a sliver of the whole story. Often, it is what is on the inside that counts.

To see a broken femur, we pass X-rays through a leg and create an image on a metal film. Archaeologists can use a similar technique to look for ancient cities buried in hillsides. Instead of using X-rays, they use muons, particles that are constantly raining down on us from the upper atmosphere.

Muons are heavy cousins of the electron and are produced when single-atom meteorites called cosmic rays collide with the Earth's atmosphere. Hold your hand up and a few muons will pass through it every second.

Physics undergraduates at Texas Tech University, led by Professors Nural Akchurin and Shuichi Kunori, are currently developing detectors that will act like an X-ray film and record the patterns left behind by muons as they pass through hillsides in Turkey. Archaeologists will use these detectors to map the internal structure of hills and look for promising places to dig for buried archaeological sites.

Like X-rays, muons are readily absorbed by thick, dense materials but can traverse through lighter materials. So they can be stopped by rock but move easily through the air in a buried cavern.

The detector under development at Texas Tech will measure the amount of cosmic-ray muons that make it through the hill. An unexpected excess could mean that there's a hollow subterranean structure facilitating the muon's passage.

"We're looking for a void, or a tomb, that the archaeologists can investigate to learn more about the history of the people that were buried there," says Hunter Cymes, one of the students working on the project.

The technique of using cosmic muons to probe for subterranean structures was developed almost half a century ago. Luis Alvarez, a Nobel Laureate in Physics, first used this technique to look inside the Second Pyramid of Chephren, one of the three great pyramids of Egypt. Since then, it has been used for many different applications, including searching for hidden cavities in other pyramids and estimating the lava content of volcanoes.

According to Jason Peirce, another undergraduate student working on this project, those previous applications had resolutions of about 10 meters. "We're trying to make that smaller, somewhere in the range of 2 to 5 meters, to find a smaller room than what's previously been done."

They hope to accomplish this by using an array of scintillators, a type of plastic that can be used to detect particles. "When a muon passes through it, it absorbs some of that energy and creates light," says student Hunter Cymes. That light can then be detected and measured and the data stored for later analysis.

Unfortunately, muons with enough energy to travel through a hill and reach the detector are relatively rare, meaning that the students will need to develop robust detectors which can collect data over a long period of time. Just like it's hard to see in dim light, it's difficult to reconstruct the internal structure of a hill with only a handful of muons.

Aashish Gupta, another undergraduate working on this project, is currently developing a simulation of cosmic-ray muons, the hill, and the detector prototype. The group hopes to use the simulation to guide their design process by predicting how well different designs will work and much data they will need to take.

As Peirce describes it, they are "getting some real, hands-on experience putting this together while also keeping in mind that we need to have some more of these results from the simulation to put together the final design."

They hope to finish building the prototype detector within the next few months and are optimistic about having a final design by next fall.

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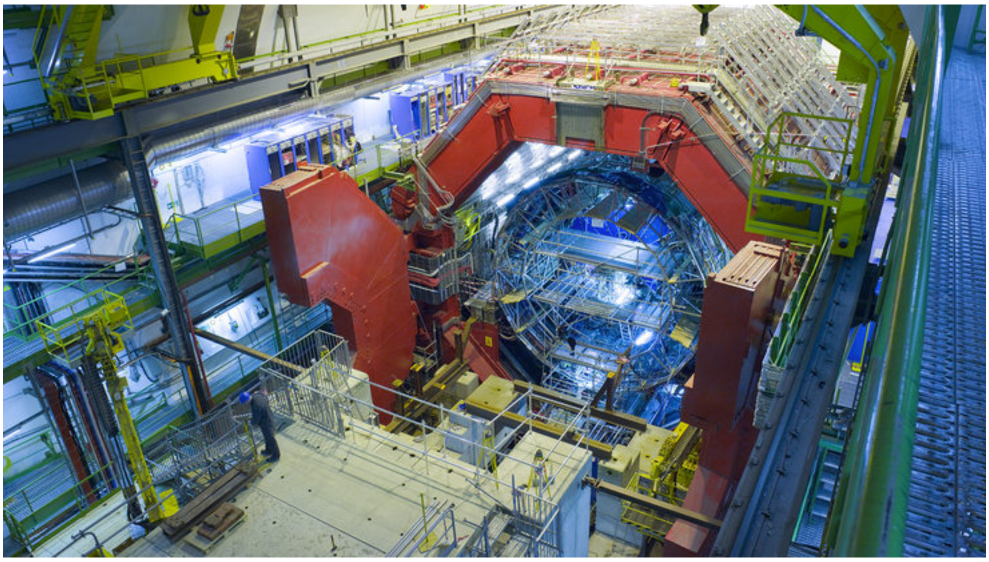
A tiny droplet of the early universe? (http://www.symmetrymagazine.org/article/a-tiny-droplet-of-the-early-universe?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Apr 24, 2017

Particles seen by the ALICE experiment hint at the formation of quark-gluon plasma during proton-proton collisions.



About 13.8 billion years ago, the universe was a hot, thick soup of quarks and gluons—the fundamental components that eventually combined into protons, neutrons and other hadrons.

Scientists can produce this primitive particle soup, called the quark-gluon plasma, in collisions between heavy ions. But for the first time physicists on an experiment at the Large Hadron Collider have observed particle evidence of its creation in collisions between protons as well.

The LHC collides protons during the majority of its run time. This new result, published in *Nature Physics* (https://www.nature.com/nphys/journal/vaop/ncurrent/full/nphys4111.html) by the ALICE collaboration, challenges long-held notions about the nature of those proton-proton collisions and about possible phenomena that were previously missed.

"Many people think that protons are too light to produce this extremely hot and dense plasma," says Livio Bianchi, a postdoc at the University of Houston who worked on this analysis. "But these new results are making us question this assumption."

Scientists at the LHC and at the US Department of Energy's Brookhaven National Laboratory's Relativistic Heavy Ion Collider, or RHIC, have previously created quark-gluon plasma in gold-gold and lead-lead collisions.

In the quark gluon plasma, mid-sized quarks—such as strange quarks—freely roam and eventually bond into bigger, composite particles (similar to the way quartz crystals grow within molten granite rocks as they slowly cool). These hadrons are ejected as the plasma fizzles out and serve as a telltale signature of their soupy origin. ALICE researchers noticed numerous proton-proton collisions emitting strange hadrons at an elevated rate.

"In proton collisions that produced many particles, we saw more hadrons containing strange quarks than predicted," says Rene Bellwied, a professor at the University of Houston. "And interestingly, we saw an even bigger gap between the predicted number and our experimental results when we examined particles containing two or three strange quarks."

From a theoretical perspective, a proliferation of strange hadrons is not enough to definitively confirm the existence of quark-gluon plasma. Rather, it could be the result of some other unknown processes occurring at the subatomic scale.

"This measurement is of great interest to quark-gluon-plasma researchers who wonder how a possible QGP signature can arise in proton-proton collisions," says Urs Wiedemann, a theorist at CERN. "But it is also of great interest for high energy physicists who have never encountered such a phenomenon in proton-proton collisions."

Earlier research at the LHC found that the spatial orientation of particles produced during some proton-proton collisions mirrored the patterns created during heavy-ion collisions, suggesting that maybe these two types of collisions have more in common than originally predicted. Scientists working on the ALICE experiment will need to explore multiple characteristics of these strange proton-proton collisions before they can confirm if they are really seeing a miniscule droplet of the early universe.

"Quark-gluon plasma is a liquid, so we also need to look at the hydrodynamic features," Bianchi says. "The composition of the escaping particles is not enough on its own."

This finding comes from data collected the first run of the LHC between 2009 and 2013. More research over the next few years will help scientists determine whether the LHC can really make quark-gluon plasma in proton-proton collisions.

"We are very excited about this discovery," says Federico Antinori, spokesperson of the ALICE collaboration. "We are again learning a lot about this extreme state of matter. Being able to isolate the quark-gluon-plasma-like phenomena in a smaller and simpler system, such as the collision between two protons, opens up an entirely new dimension for the study of the properties of the primordial state that our universe emerged from."

Other experiments, such as those using RHIC, will provide more information about the observable traits and experimental characteristics of quark-gluon plasmas at lower energies, enabling researchers to gain a more complete picture of the characteristics of this primordial particle soup.

"The field makes far more progress by sharing techniques and comparing results than we would be able to with one facility alone," says James Dunlop, a researcher at RHIC. "We look forward to seeing further discoveries from our colleagues in ALICE."

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A new search to watch from LHCb (http://www.symmetrymagazine.org/article/a-new-search-to-watch-from-lhcb?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Apr 18, 2017

A new result from the LHCb experiment could be an early indicator of an inconsistency in the Standard Model.

The subatomic universe is an intricate mosaic of particles and forces. The Standard Model of particle physics is a time-tested instruction manual that precisely predicts how particles and forces behave. But it's incomplete, ignoring phenomena such as gravity and dark matter.

Today the LHCb experiment at CERN European research center released a result (http://lhcb-public.web.cern.ch/lhcb-public/Welcome.html#RKstar) that could be an early indication of new, undiscovered physics beyond the Standard Model.

However, more data is needed before LHCb scientists can definitively claim they've found a crack in the world's most robust roadmap to the subatomic universe.

“In particle physics, you can't just snap your fingers and claim a discovery,” says Marie-Hélène Schune, a researcher on the LHCb experiment from Le Centre National de la Recherche Scientifique in Orsay, France. “It's not magic. It's long, hard work and you must be obstinate when facing problems. We always question everything and never take anything for granted.”

The LHCb experiment records and analyzes the decay patterns of rare hadrons—particles made of quarks—that are produced in the Large Hadron Collider's energetic proton-proton collisions. By comparing the experimental results to the Standard Model's predictions, scientists can search for discrepancies. Significant deviations between the theory and experimental results could be an early indication of an undiscovered particle or force at play.

This new result looks at hadrons containing a bottom quark as they transform into hadrons containing a strange quark. This rare decay pattern can generate either two electrons or two muons as byproducts. Electrons and muons are different types or “flavors” of particles called leptons. The Standard Model predicts that the production of electrons and muons should be equally favorable—essentially a subatomic coin toss every time this transformation occurs.

“As far as the Standard Model is concerned, electrons, muons and tau leptons are completely interchangeable,” Schune says. “It's completely blind to lepton flavors; only the large mass difference of the tau lepton plays a role in certain processes. This 50-50 prediction for muons and electrons is very precise.”

But instead of finding a 50-50 ratio between muons and electrons, the latest results from the LHCb experiment show that it's more like 40 muons generated for every 60 electrons.

“If this initial result becomes stronger with more data, it could mean that there are other, invisible particles involved in this process that see flavor,” Schune says. “We'll leave it up to the theorists' imaginations to figure out what's going on.”

However, just like any coin-toss, it's difficult to know if this discrepancy is the result of an unknown favoritism or the consequence of chance. To delineate between these two possibilities, scientists wait until they hit a certain statistical threshold before claiming a discovery, often 5 sigma.

“Five sigma is a measurement of statistical deviation and means there is only a 1-in-3.5-million chance that the Standard Model is correct and our result is just an unlucky statistical fluke,” Schune says. “That's a pretty good indication that it's not chance, but rather the first sightings of a new subatomic process.”

Currently, this new result is at approximately 2.5 standard deviations, which means there is about a 1-in-125 possibility that there's no new physics at play and the experimenters are just the unfortunate victims of statistical fluctuation.

This isn't the first time that the LHCb experiment has seen unexpected behavior in related processes. Hassan Jawahery from the University of Maryland also works on the LHCb experiment and is studying another particle decay involving bottom quarks transforming into charm quarks. He and his colleagues are measuring the ratio of muons to tau leptons generated during this decay.

“Correcting for the large mass differences between muons and tau leptons, we'd expect to see about 25 taus produced for every 100 muons,” Jawahery says. “We measured a ratio of 34 taus for every 100 muons.”

On its own, this measurement is below the line of statistical significance needed to raise an eyebrow. However, two other experiments—the BaBar experiment at SLAC and the Belle experiment in Japan—also measured this process and saw something similar.

“We might be seeing the first hints of a new particle or force throwing its weight around during two independent subatomic processes,” Jawahery says. “It's tantalizing, but as experimentalists we are still waiting for all these individual results to grow in significance before we get too excited.”

More data and improved experimental techniques will help the LHCb experiment and its counterparts narrow in on these processes and confirm if there really is something funny happening behind the scenes in the subatomic universe.

“Conceptually, these measurements are very simple,” Schune says. “But practically, they are very challenging to perform. These first results are all from data collected between 2011 and 2012 during Run 1 of the LHC. It will be intriguing to see if data from Run 2 shows the same thing.”

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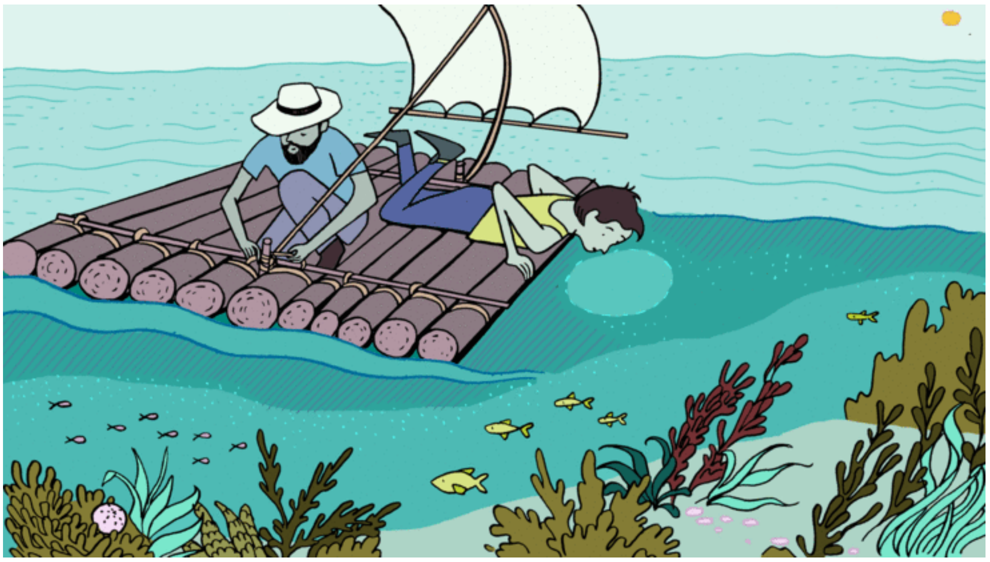
How blue-sky research shapes the future (http://www.symmetrymagazine.org/article/how-blue-sky-research-shapes-the-future?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Apr 18, 2017

While driven by the desire pursue curiosity, fundamental investigations are the crucial first step to innovation.



When scientists announced their discovery of gravitational waves in 2016, it made headlines all over the world. The existence of these invisible ripples in space-time had finally been confirmed.

It was a momentous feat in basic research, the curiosity-driven search for fundamental knowledge about the universe and the elements within it. Basic (or "blue-sky") research is distinct from applied research, which is targeted toward developing or advancing technologies to solve a specific problem or to create a new product.

But the two are deeply connected.

"Applied research is exploring the continents you know, whereas basic research is setting off in a ship and seeing where you get," says Frank Wilczek, a theoretical physicist at MIT. "You might just have to return, or sink at sea, or you might discover a whole new continent. So it's much more long-term, it's riskier and it doesn't always pay dividends."

When it does, he says, it opens up entirely new possibilities available only to those who set sail into uncharted waters.

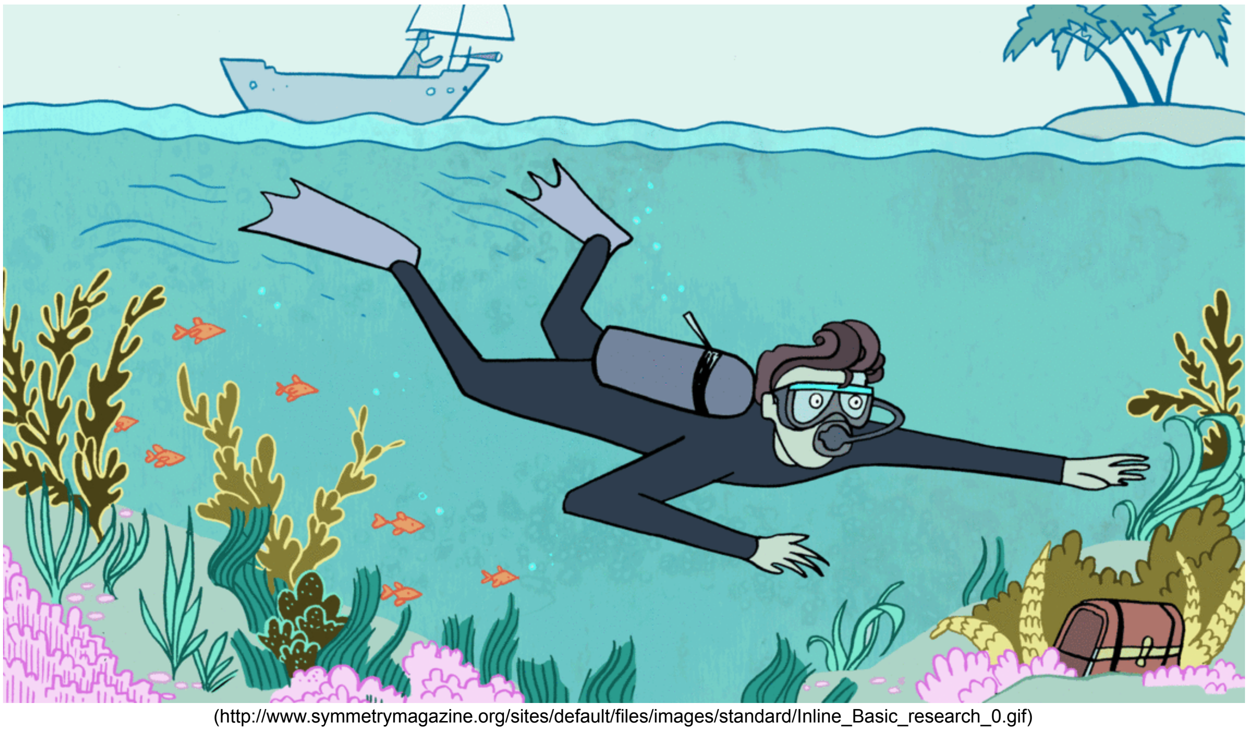
Most of physics—especially particle physics—falls under the umbrella of basic research. In particle physics "we're asking some of the deepest questions that are accessible by observations about the nature of matter and energy—and ultimately about space and time also, because all of these things are tied together," says Jim Gates, a theoretical physicist at the University of Maryland.

Physicists seek answers to questions about the early universe, the nature of dark energy, and theoretical phenomena, such as supersymmetry, string theory and extra dimensions.

Perhaps one of the most well-known basic researchers was the physicist who predicted the existence of gravitational waves: Albert Einstein.

Einstein devoted his life to elucidating elementary concepts such as the nature of gravity and the relationship between space and time. According to Wilczek, "it was clear that what drove what he did was not the desire to produce a product, or anything so worldly, but to resolve puzzles and perceived imperfections in our understanding."

In addition to advancing our understanding of the world, Einstein's work led to important technological developments. The Global Positioning System, for instance, would not have been possible without the theories of special and general relativity. A GPS receiver, like the one in your smart phone, determines its location based on timed signals it receives from the nearest four of a collection of GPS satellites orbiting Earth. Because the satellites are moving so quickly while also orbiting at a great distance from the gravitational pull of Earth, they experience time differently from the receiver on Earth's surface. Thanks to Einstein's theories, engineers can calculate and correct for this difference.



(http://www.symmetrymagazine.org/sites/default/files/images/standard/Inline_Basic_research_0.gif)

Illustration by Corinne Mucha

There's a long history of serendipitous output from basic research. For example, in 1989 at CERN European research center, computer scientist Tim Berners-Lee was looking for a way to facilitate information-sharing between researchers. He invented the World Wide Web.

While investigating the properties of nuclei within a magnetic field at Columbia University in the 1930s, physicist Isidor Isaac Rabi discovered the basic principles of nuclear magnetic resonance. These principles eventually formed the basis of Magnetic Resonance Imaging, MRI.

It would be another 50 years before MRI machines were widely used—again with the help of basic research. MRI machines require big, superconducting magnets to function. Luckily, around the same time that Rabi's discovery was being investigated for medical imaging, scientists and engineers at the US Department of Energy's Fermi National Accelerator Laboratory began building the Tevatron particle accelerator to enable research into the fundamental nature of particles, a task that called for huge amounts of superconducting wire.

"We were the first large, demanding customer for superconducting cable," says Chris Quigg, a theoretical physicist at Fermilab. "We were spending a lot of money to get the performance that we needed." The Tevatron created a commercial market for superconducting wire, making it practical for companies to build MRI machines on a large scale for places like hospitals.

Doctors now use MRI to produce detailed images of the insides of the human body, helpful tools in diagnosing and treating a variety of medical complications, including cancer, heart problems, and diseases in organs such as the liver, pancreas and bowels.

Another tool of particle physics, the particle detector, has also been adopted for uses in various industries. In the 1980s, for example, particle physicists developed technology precise enough to detect a single photon. Today doctors use this same technology to detect tumors, heart disease and central nervous system disorders. They do this by conducting positron emission tomography scans, or PET scans. Before undergoing a PET scan, the patient is given a dye containing radioactive tracers, either through an injection or by ingesting or inhaling. The tracers emit antimatter particles, which interact with matter particles and release photons, which are picked up by the PET scanner to create a picture detailed enough to reveal problems at the cellular level.

As Gates says, "a lot of the devices and concepts that you see in science fiction stories will never come into existence unless we pursue the concept of basic research. You're not going to be able to construct starships unless you do the research now in order to build these in the future."

It's unclear what applications could come of humanity's new knowledge of the existence of gravitational waves.

It could be enough that we have learned something new about how our universe works. But if history gives us any indication, continued exploration will also provide additional benefits along the way.

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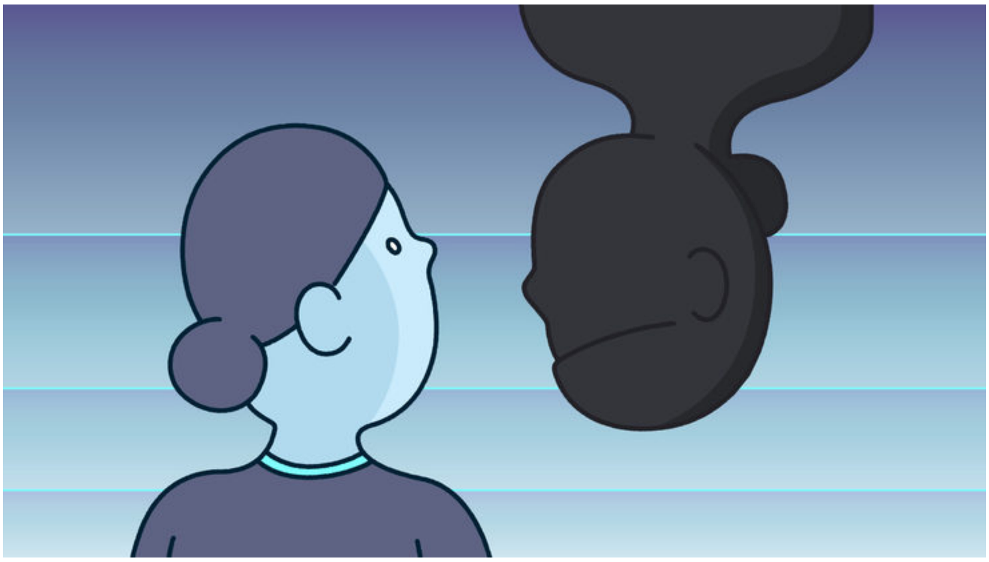
What's left to learn about antimatter? (http://www.symmetrymagazine.org/article/whats-left-to-learn-about-antimatter?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Apr 11, 2017

Experiments at CERN investigate antiparticles.



What do shrimp, tennis balls and pulsars all have in common? They are all made from matter.

Admittedly, that answer is a cop-out, but it highlights a big, persistent quandary for scientists: Why is everything made from matter when there is a perfectly good substitute—antimatter?

The European laboratory CERN hosts several experiments to ascertain the properties of antimatter particles, which almost never survive in our matter-dominated world.

Particles (such as the proton and electron) have oppositely charged antimatter doppelgangers (such as the antiproton and antielectron). Because they are opposite but equal, a matter particle and its antimatter partner annihilate when they meet.

Antimatter wasn't always rare. Theoretical and experimental research suggests that there was an equal amount of matter and antimatter right after the birth of our universe. But 13.8 billion years later, only matter-made structures remain in the visible universe.

Scientists have found small differences between the behavior of matter and antimatter particles, but not enough to explain the imbalance that led antimatter to disappear while matter perseveres. Experiments at CERN are working to solve that riddle using three different strategies.

(http://www.symmetrymagazine.org/sites/default/files/images/standard/antimatter_frozen_041117.jpg)
Illustration by Sandbox Studio, Chicago

Antimatter under the microscope

It's well known that CERN is home to Large Hadron Collider, the world's highest-energy particle accelerator. Less known is that CERN also hosts the world's most powerful particle decelerator—a machine that slows down antiparticles to a near standstill.

The antiproton decelerator is fed by CERN's accelerator complex. A beam of energetic protons is diverted from CERN's Proton Synchrotron and into a metal wall, spawning a multitude of new particles, including some antiprotons. The antiprotons are focused into a particle beam and slowed by electric fields inside the antiproton decelerator. From here they are fed into various antimatter experiments, which trap the antiprotons inside powerful magnetic fields.

"All these experiments are trying to find differences between matter and antimatter that are not predicted by theory," says Will Bertsche, a researcher at University of Manchester, who works in CERN's antimatter factory. "We're all trying to address the big question: Why is the universe made up of matter these days and not antimatter?"

By cooling and trapping antimatter, scientists can intimately examine its properties without worrying that their particles will spontaneously encounter a matter companion and disappear. Some of the traps can preserve antiprotons for more than a year. Scientists can also combine antiprotons with positrons (antielectrons) to make antihydrogen.

"Antihydrogen is fascinating because it lets us see how antimatter interacts with itself," Bertsche says. "We're getting a glimpse at how a mirror antimatter universe would behave."

Scientists in CERN's antimatter factory have measured the mass, charge, light spectrum, and magnetic properties of antiprotons and antihydrogen to high precision. They also look at how antihydrogen atoms are affected by gravity; that is, do the anti-atoms fall up or down? One experiment is even trying to make an assortment of matter-antimatter hybrids, such as a helium atom in which one of the electrons is replaced with an orbiting antiproton.

So far, all their measurements of trapped antimatter match the theory: Except for the opposite charge and spin, antimatter appears completely identical to matter. But these affirmative results don't deter Bertsche from looking for antimatter surprises. There must be unpredicted disparities between these particle twins that can explain why matter won its battle with antimatter in the early universe.

"There's something missing in this model," Bertsche says. "And nobody is sure what that is."

Antimatter in motion

The LHCb experiment wants to answer this same question, but they are looking at antimatter particles that are not trapped. Instead, LHCb scientists study how free-range antimatter particles behave as they travel and transform inside the detector.

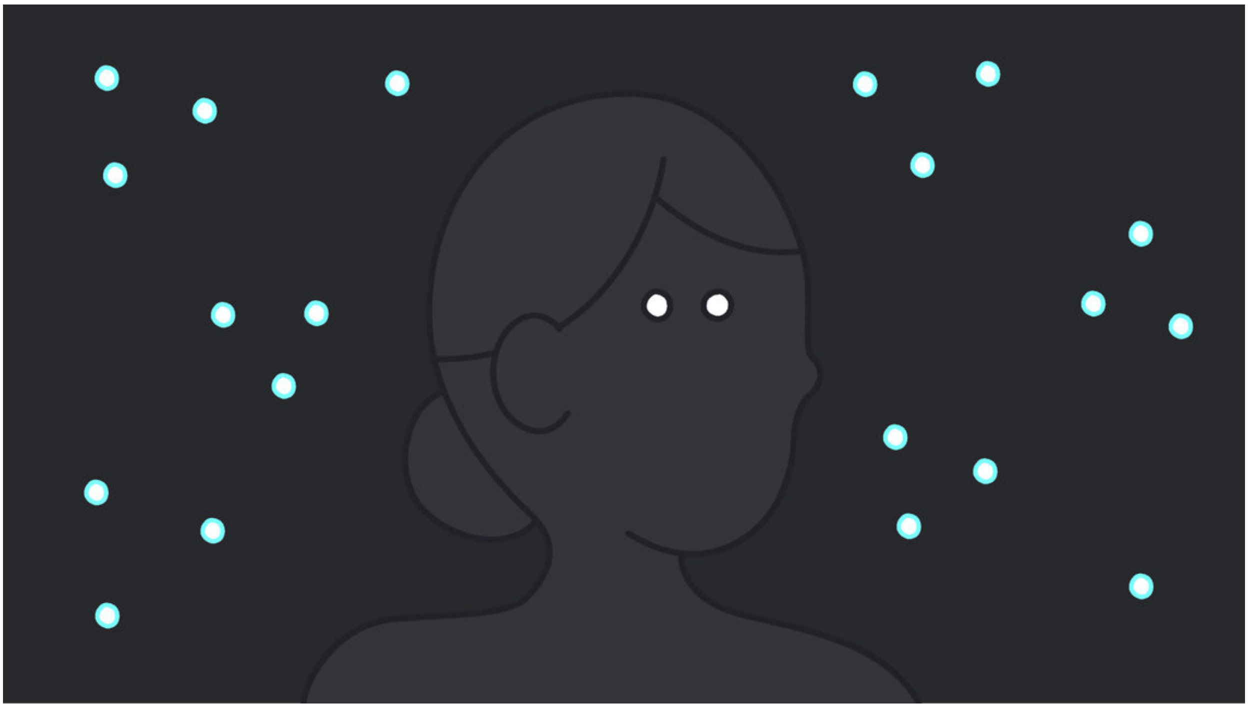
"We're recording how unstable matter and antimatter particles decay into showers of particles and the patterns they leave behind when they do," says Sheldon Stone, a professor at Syracuse University working on the LHCb Experiment. "We can't make these measurements if the particles aren't moving."

The particles-in-motion experiments have already observed some small differences between matter and antimatter particles. In 1964 scientists at Brookhaven National Laboratory noticed that neutral kaons (a particle containing a strange and down quark) decay into matter and antimatter particles at slightly different rates, an observation that won them the Nobel Prize in 1980.

The LHCb experiment continues this legacy, looking for even more discrepancies between the metamorphoses of matter and antimatter particles. They recently observed that the daughter particles of certain antimatter baryons (particles containing three quarks) have a slightly different spatial orientation than their matter contemporaries.

But even with the success of uncovering these discrepancies, scientists are still very far from understanding why antimatter all but disappeared.

"Theory tells us that we're still off by nine orders of magnitude," Stone says, "so we're left asking, where is it? What is antimatter's Achilles heel that precipitated its disappearance?"



(http://www.symmetrymagazine.org/sites/default/files/images/standard/antimatter_wild_041117.jpg)
Illustration by Sandbox Studio, Chicago

Antimatter in space

Most antimatter experiments based at CERN produce antiparticles by accelerating and colliding protons. But one experiment is looking for feral antimatter freely roaming through outer space.

The Alpha Magnetic Spectrometer is an international experiment supported by the US Department of Energy and NASA. This particle detector was assembled at CERN and is now installed on the International Space Station, where it orbits Earth 400 kilometers above the surface. It records the momentum and trajectory of roughly a billion vagabond particles every month, including a million antimatter particles.

Nomadic antimatter nuclei could be lonely relics from the Big Bang or the rambling residue of nuclear fusion in antimatter stars.

But AMS searches for phenomena not explained by our current models of the cosmos. One of its missions is to look for antimatter that is so complex and robust, there is no way it could have been produced through normal particle collisions in space.

“Most scientists accept that antimatter disappeared from our universe because it is somehow less resilient than matter,” says Mike Capell, a researcher at MIT and a deputy spokesperson of the AMS experiment. “But we’re asking, what if all the antimatter never disappeared? What if it’s still out there?”

If an antimatter kingdom exists, astronomers expect that they would observe mass particle-annihilation fizzing and shimmering at its boundary with our matter-dominated space—which they don’t. Not yet, at least. Because our universe is so immense (and still expanding), researchers on AMS hypothesize that maybe these intersections are too dim or distant for our telescopes.

“We already have trouble seeing deep into our universe,” Capell says. “Because we’ve never seen a domain where matter meets antimatter, we don’t know what it would look like.”

AMS has been collecting data for six years. From about 100 billion cosmic rays, they’ve identified a few strange events with characteristics of antihelium. Because the sample is so tiny, it’s impossible to say whether these anomalous events are the first messengers from an antimatter galaxy or simply part of the chaotic background.

“It’s an exciting result,” Capell says. “However, we remain skeptical. We need data from many more cosmic rays before we can determine the identities of these anomalous particles.”

Read More... (http://www.symmetrymagazine.org/article/whats-left-to-learn-about-antimatter?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Urban Sketchers visit Fermilab (http://www.symmetrymagazine.org/article/urban-sketchers-visit-fermilab?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Apr 10, 2017

The group brought their on-site drawing practice to the particle physics laboratory.

In March, about 30 participants in the Chicago chapter of the artist network Urban Sketchers visited Fermi National Accelerator Laboratory, located in west Chicagoland, and sketched their hearts out. They drew buildings, interiors and scenes of nature from the laboratory environment, capturing the laboratory's most iconic building, Wilson Hall, along with restored prairie land and the popular bison herd on site.

Urban Sketchers holds monthly “sketch crawls,” as they’re called. Their mission is to “show the world, one drawing at a time.”

Sketcher Harold Goldfus drew scenes of art and architecture.

“I regard myself as primarily a figurative artist. At the Urban Sketchers Chicago outing, I expected to sketch figures at Fermilab with hints of the environment in the background,” Goldfus said. “Instead, I found myself taken with the architecture and aesthetics of the interior of Wilson Hall, and decided on a more unconventional approach.”

The sketch crawl was organized by Peggy Condon and Wes Douglas from Urban Sketchers Chicago along with Fermilab Art Gallery curator Georgia Schwender.

“I was very inspired by Fermilab’s strong commitment to the arts. I didn’t expect this for a world-renowned scientific research institution,” said sketcher Lynne Fairchild. “I really appreciated that they found so many ways to honor the arts and culture: the art gallery, lecture series, the awe-inspiring sculptures on the campus, and the design of Wilson Hall, especially the beauty of the atrium.”

Editor's note: Fermilab previously posted a version (http://news.fnal.gov/2017/03/urban-sketchers-get-sketch-fermilab/) of this article.

Wilson Hall atrium, by Andrew Banks

Andrew Banks

Read More... (http://www.symmetrymagazine.org/article/urban-sketchers-visit-fermilab?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

WIMPs in the dark matter wind (http://www.symmetrymagazine.org/article/wimps-in-the-dark-matter-wind?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Apr 4, 2017

We know which way the dark matter wind should blow. Now we just have to find it.

Picture yourself in a car, your hand surfing the breeze through the open window. Hold your palm perpendicular to the wind and you can feel its force. Now picture the car slowing, rolling up to a stop sign, and feel the force of the wind lessen until it—and the car—stop.

This wind isn't due to the weather. It arises because of your motion relative to air molecules. Simple enough to understand and known to kids, dogs and road-trippers the world over.

This wind has an analogue in the rarefied world of particle astrophysics called the "dark matter wind," and scientists are hoping it will someday become a valuable tool in their investigations into that elusive stuff that apparently makes up about 85 percent of the mass in the universe.

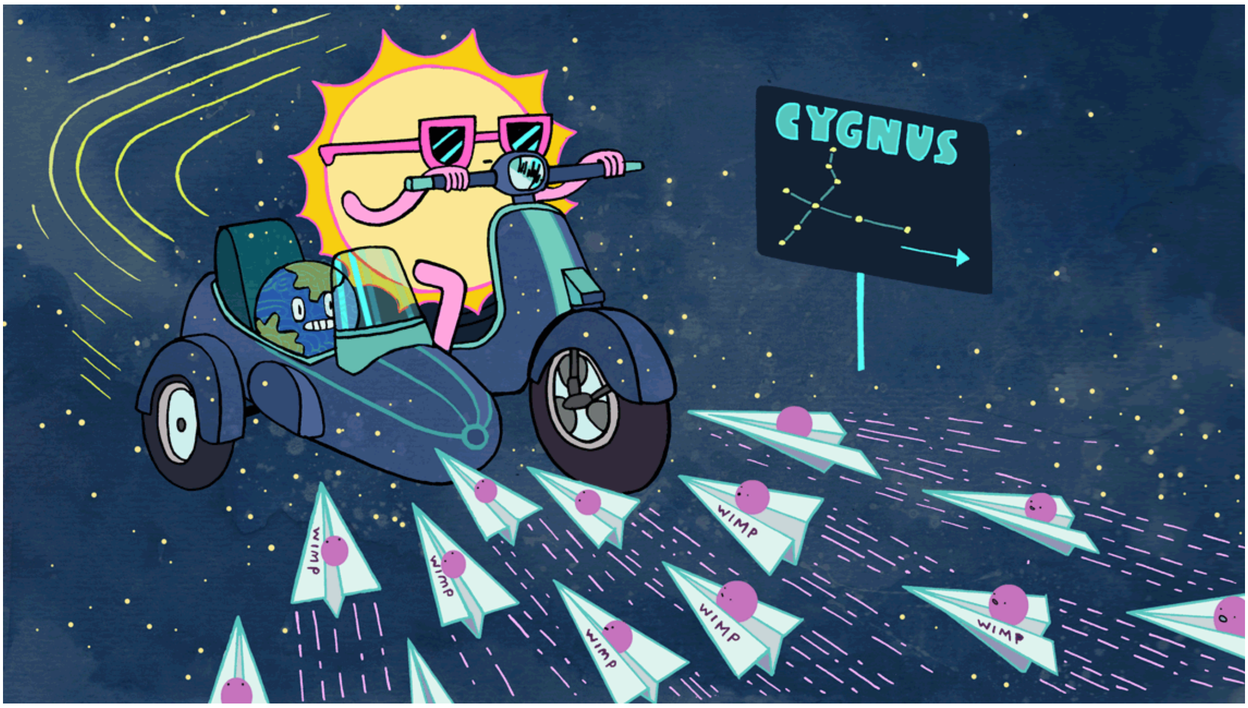
In the analogy above, the air molecules are dark matter particles called WIMPs, or weakly interacting massive particles. Our sun is the car, racing around the Milky Way at about 220 kilometers per second, with the Earth riding shotgun. Together, we move through a halo of dark matter that encompasses our galaxy. But our planet is a rowdy passenger; it moves from one side of the sun to the other in its orbit.

When you add the Earth's velocity of 30 kilometers per second to the sun's, as happens when both are traveling in the same direction (toward the constellation Cygnus), then the dark matter wind feels stronger. More WIMPs are moving through the planet than if it were at rest, resulting in greater number of detections by experiments. Subtract that velocity when the Earth is on the other side of its orbit, and the wind feels weaker, resulting in fewer detections.

Astrophysicists have been thinking about the dark matter wind for decades. Among the first, way back in 1986, were theorist David Spergel of Princeton University and colleagues Katherine Freese of the University of Michigan and Andrzej K. Drukier (now in private industry, but still looking for WIMPs).

"We looked at how the Earth's motion around the sun should cause the number of dark matter particles detected to vary on a regular basis by about 10 percent a year," Spergel says.

At least that's what should happen—if our galaxy really is embedded in a circular, basically homogeneous halo of dark matter, and if dark matter is really made up of WIMPs.



(http://www.symmetrymagazine.org/sites/default/files/images/standard/Inline_Dark_matter_wind.gif)

Illustration by Corinne Mucha

The Italian experiment DAMA/NaI and its upgrade DAMA/Libra claim to have been seeing this seasonal modulation for decades, a claim that has yet to be conclusively supported by any other experiments. CoGeNT, an experiment in the Soudan Underground Laboratory in South Dakota, seemed to back them up for a time, but now the signals are thought to be caused by other sources such as high-energy gamma rays hitting a layer of material just outside the germanium of the detector, resulting in a signal that looks much like a WIMP.

Actually confirming the existence of the dark matter wind is important for one simple reason: the pattern of modulation can't be explained by anything but the presence of dark matter. It's what's called a "model-independent" phenomenon. No natural backgrounds—no cosmic rays, no solar neutrinos, no radioactive decays—would show a similar modulation. The dark matter wind could provide a way to continue exploring dark matter, even if the particles are light enough that experiments cannot distinguish them from almost massless particles called neutrinos, which are constantly streaming from the sun and other sources.

"It's a big, big prize to go after," says Jocelyn Monroe, a physics professor at Royal Holloway University of London, who currently works on two dark matter detection experiments, DEAP-3600 at SNOLAB, in Canada, and DMTPC. "If you could correlate detections with the direction in which the planet is moving you would have unambiguous proof" of dark matter.

At the same time Spergel and his colleagues were exploring the wind's seasonal modulation, he also realized that this correlation could extend far beyond a twice-per-year variation in detection levels. The location of the Earth in its orbit would affect the direction in which nucleons, the particles that make up the nucleus of an atom, recoil when struck by WIMPs. A sensitive-enough detector should see not only the twice-yearly variations, but even daily variations, since the detector constantly changes its orientation to the dark matter wind as the Earth rotates.

"I had initially thought that it wasn't worth writing up the paper because no experiment had the sensitivity to detect the recoil direction," he says. "However, I realized that if I pointed out the effect, clever experimentalists would eventually figure out a way to detect it."

Monroe, as the leader of the DMTPC collaboration, is a member of the clever experimentalist set. The DMTPC, or Dark Matter Time-Projection Chamber, is one of a small number of direct detection experiments that are designed to track the actual movements of recoiling atoms.

Instead of semiconductor crystals or liquefied noble gases, these experiments use low-pressure gases as their target material. DMTPC, for example, uses carbon tetrafluoride. If a WIMP hits a molecule of carbon tetrafluoride, the low pressure in the chamber means that molecule has room to move —up to about 2 millimeters.

"Making the detector is super hard," Monroe says. "It has to map a 2-millimeter track in 3D." Not to mention reducing the number of molecules in a detector chamber reduces the chances for a dark matter particle to hit one. According to Monroe, DMTPC will deal with that issue by fabricating an array of 1-cubic-meter-sized modules. The first module has already been constructed and a worldwide collaboration of scientists from five different directional dark matter experiments (including DMTPC) are working on the next step together: a much larger directional dark matter array called the CYGNUS (for CosmoloGY with NUclear recoilS) experiment.

When and if such directional dark matter detectors raise their metaphorical fingers to test the direction of the dark matter wind, Monroe says they'll be able to see far more than just seasonal variations in detections. Scientists will be able to see variations in atomic recoils not on a seasonal basis, but on a daily basis. Monroe envisions a sort of dark matter telescope with which to study the structure of the halo in our little corner of the Milky Way.

Or not.

There's always a chance that this next generation of dark matter detectors, or the generation after, still won't see anything.

Even that, Monroe says, is progress.

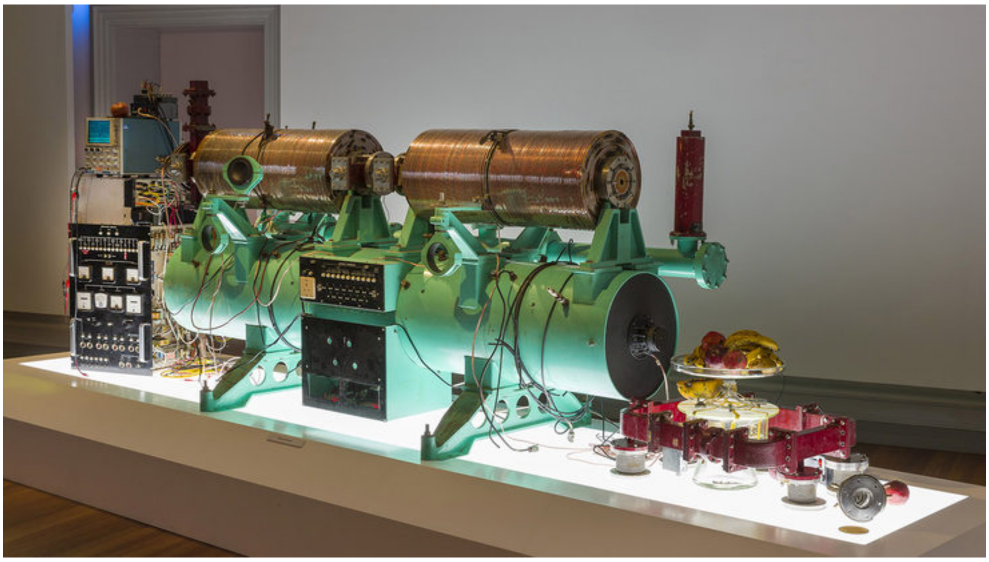
"If we're still looking in 10 years we might be able to say it's not WIMPs but something even more exotic As far as we can tell right now, dark matter has got to be something new out there."

Read More... (http://www.symmetrymagazine.org/article/wimps-in-the-dark-matter-wind?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Art intimates physics (http://www.symmetrymagazine.org/article/art-intimates-physics?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Apr 3, 2017

Artist Chris Henschke's latest piece inspired by particle physics mixes constancy with unpredictability, the natural with the synthetic.



Artist Chris Henschke has spent more than a decade exploring the intersection of art and physics. His pieces bring invisible properties and theoretical concepts to light through still images, sound and video.

His latest piece, called "Song of the Phenomena," gives new life to a retired piece of equipment once used by a long-time collaborator of Henschke, University of Melbourne and Australian Synchrotron physicist Mark Boland.

Crossing paths

The story of “Song of the Phenomena” begins in the 1990s. In 1991, Henschke enrolled in the University of Melbourne to study science, but he turned to sound design instead. Boland entered the same university to study physics.

Personal computers were just entering the market. Sound designers and animators began coding basic programs, and Henschke joined in. “I was always interested in making sounds and music, interested in light and art and physics and nature and how it all combines—either in our heads or the devices that mediate between us and nature,” he says.

Boland completed his thesis in physics at the Australian Radiation Laboratory (now called the Australian Radiation Protection and Nuclear Safety Agency). He was testing a new type of electron detector in a linear accelerator, or linac. The linac used radio waves to guide electrons through a series of accelerator cavities, which imparted more and more energy to the particles as they moved through.

That particular linac spent more than 20 years with the Australian Radiation Protection and Nuclear Safety Agency, where medical physics professionals used it to accelerate electrons to different energies to create calibration standards for radiation oncology treatments. Once they no longer needed it, Boland’s former advisor contacted him to ask if he’d like the accelerator or any of its still-working parts. He said yes, though he was unsure what he would do with it.

An artist’s view

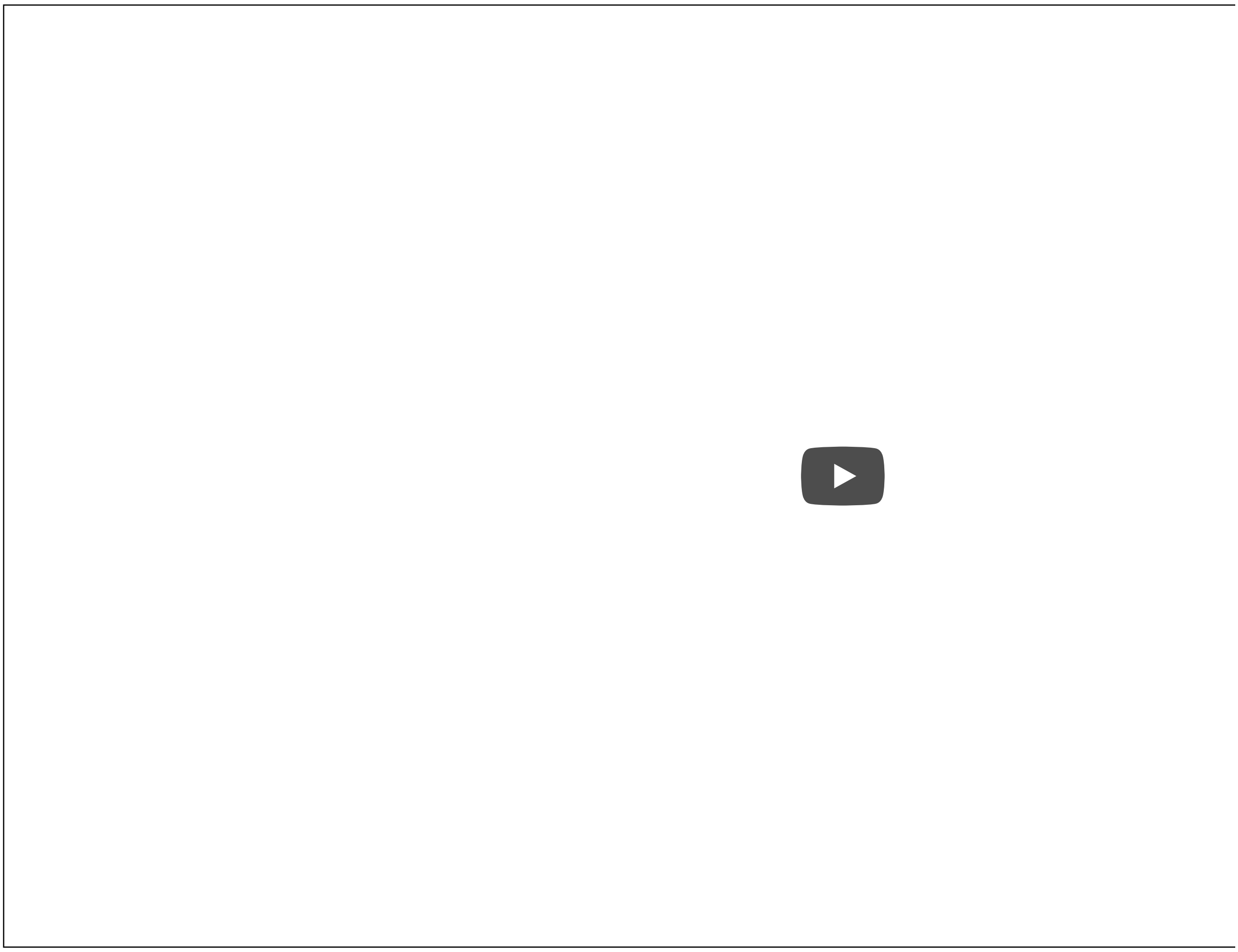
In 2007 Henschke came to the Australian Synchrotron as part of an artist-in-residence program. Boland was familiar with his artwork; he had seen Henschke’s first piece exploring particle physics in the pages of *Symmetry* (http://www.symmetrymagazine.org/article/may-2005/gallery-chris-henschke). Boland grew up with an appreciation for art; he says his parents made sure of that by “dragging” him through many galleries in his youth.

When Henschke and Boland met, they got into an hours-long conversation about physics. “We hit it off, we resonated,” Boland says, “and we’ve been working together ever since.”

Since that first residency program, Henschke has spent significant time at the Australian Synchrotron facility and at CERN European research center and has taken shorter trips to the DESY German national research center.

His process of creating artwork echoes the scientific process and the setup of an experiment, Boland says. Henschke thinks through the role that each piece of the artwork plays. Everything is where it is for a reason.

“He’s a perfectionist, he doesn't settle for second best,” Boland says. “He has the same level of professionalism and tenacity as an artist as a physicist does. It’s as if there’s a five-sigma quality test on his work as well.”



Once accelerator, now art

Boland mentioned the linac he had to Henschke during a conversation in early 2016. “Chris ran with it,” Boland says. “He took it and made it into his installation.”

Henschke discovered the machine hums at 220 hertz—the musical note of A—as it produces its resonant waves. “In a sense, particle accelerators are gigantic, high-energy synthesizers because they are creating high-energy waves at very specific frequencies and amplitudes,” Henschke says.

Henschke explored different aspects of the machine, still unsure how each part would come together as a final piece of art. “I have to let it speak to me, I have to let it speak for itself,” he says.

Finally it dawned on him; the art could be an echo of the accelerator’s past.

The accelerator no longer accelerates electrons. Instead Henschke feeds it a steady supply of electrons and their antimatter partners, positrons. He does this by placing it beside a pile of bananas, which release the particles as their potassium decays. (Using decaying fruit was a nod to Dutch still-life vanitas paintings, Henschke says.)

Observers cannot see the electrons and positrons in the piece, but they can hear them. Henschke ensured this by adding a Geiger counter, which emits a chirp each time it detects a particle.

Visitors can also hear the accelerator itself. Henschke attached speakers and pumped up the sound of the machine’s natural hum with a stereo amp (a bit too much at first; they blew up an oscilloscope they were using to measure the frequency). He used an AM radio coil to amplify the sound of the accelerator’s electromagnetic field.

“Song of the Phenomena” plays upon resonance, amplification and decay, Henschke says. “It creates this tension between the constant hum of the device versus the unpredictability of the subatomic emission.”

The idea of playing with the analogy between the linac’s resonance and sound resonance is one that Australian Synchrotron Director Andrew Peele appreciates. “A lot of science communication is about how you find analogies that people can engage with, and this is a great example,” Peele says.

Henschke displayed “Song of the Phenomena” at the Royal Melbourne Institute of Technology Gallery from November 17, 2016, to February 18, 2017. Since then, the apparatus has returned to the Australian Synchrotron, where it sits in a vast, open room where some of the facility’s synchrotron beamline stations used to stand. Scientists meet nearby for a weekly social coffee break.

Henschke is currently writing his thesis for his PhD in experimental art (with Boland as his advisor). In his next project, he hopes to tackle the subject of quantum entanglement.

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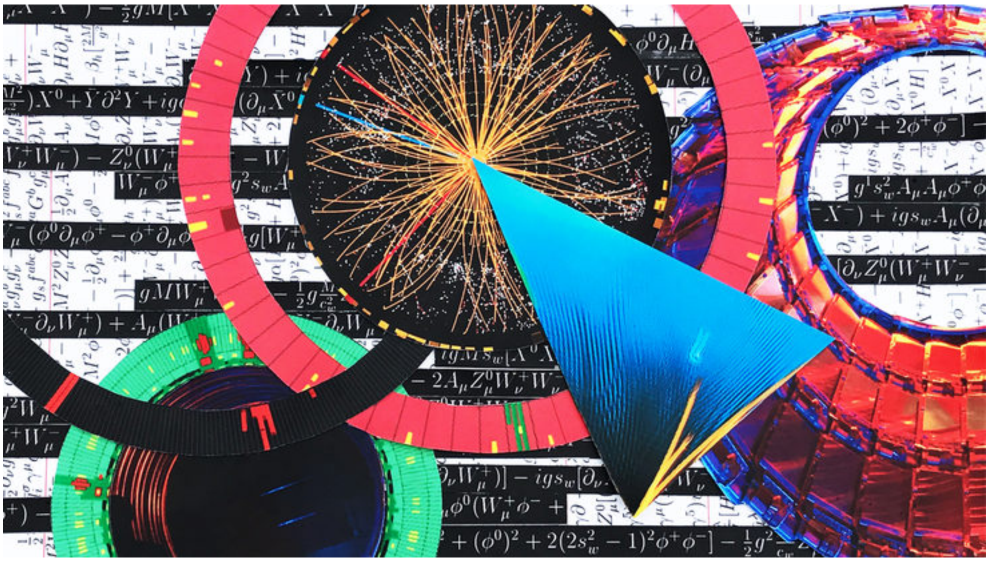
How to make a discovery (http://www.symmetrymagazine.org/article/how-to-make-a-discovery?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Mar 28, 2017

Particle physics is a dance between theory and experiment.



Meenakshi Narain, a professor of physics at Brown University, remembers working on the DZero experiment at Fermi National Accelerator Laboratory near Chicago in the winter of 1994. She would bring blankets up to her fifth-floor office to keep warm as she sat at her computer going through data in search of the then-undiscovered top quark.

For weeks, her group had been working on deciphering some extra background that originally had not been accounted for. Their conclusions contradicted the collaboration’s original assumptions.

Narain, who was a postdoctoral researcher at the time, talked to her advisor about sharing the group’s result. Her advisor told her that if she had followed the scientific method and was confident in her result, she should talk about it.

“I had a whole sequence of logic and explanation prepared,” Narain says. “When I presented it, I remember everybody was very supportive. I had expected some pushback or some criticism and nothing like that happened.”

This, she says, is the scientific process: A multitude of steps designed to help us explore the world we live in.

“In the end the process wins. It’s not about you or me, because we’re all going after the same thing. We want to discover that particle or phenomenon or whatever else is out there collaboratively. That’s the goal.”

Narain’s group’s analysis was essential to the collaboration’s understanding of a signal that turned out to be the elusive top quark.

(http://www.symmetrymagazine.org/sites/default/files/images/standard/Inline_1_Discovery.jpg)
Artwork by Sandbox Studio, Chicago

The modern hypothesis

“The scientific method was not invented overnight,” says Joseph Incandela, vice chancellor for research at the University of California, Santa Barbara. “People used to think completely differently. They thought if it was beautiful it had to be true. It took many centuries for people to realize that this is how you must approach the acquisition of true knowledge that you can verify.”

For particle physicists, says Robert Cahn, a senior scientist at Lawrence Berkeley National Laboratory, the scientific method isn’t so much going from hypothesis to conclusion, but rather “an exploration in which we measure with as much precision as possible a variety of quantities that we hope will reveal something new.

“We build a big accelerator and we might have some ideas of what we might discover, but it’s not as if we say, ‘Here’s the hypothesis and we’re going to prove or disprove it. If there’s a scientific method, it’s something much broader than that.”

Scientific inquiry is more of a continuing conversation between theorists and experimentalists, says Chris Quigg, a distinguished scientist emeritus at Fermilab.

“Theorists in particular spend a lot of time telling stories, making up ideas or elaborating ideas about how something might happen,” he says. “There’s an evolution of our ideas as we engage in dialogue with experiments.”

An important part of the process, he adds, is that the scientists are trained never to believe their own stories until they have experimental support.

“We are often reluctant to take our ideas too seriously because we’re schooled to think about ideas as tentative,” Quigg says. “It’s a very good thing to be tentative and to have doubt. Otherwise you think you know all the answers, and you should be doing something else.”

It’s also good to be tentative because “sometimes we see something that looks tantalizingly like a great discovery, and then it turns out not to be,” Cahn says.

At the end of 2015, hints appeared in the data of the two general-purpose experiments at the Large Hadron Collider that scientists had stumbled upon a particle 750 times as massive as a proton. The hints prompted more than 500 scientific papers, each trying to tell the story behind the bump in the data.

“It’s true that if you simply want to minimize wasting your time, you will ignore all such hints until they [reach the traditional uncertainty threshold of] 5 sigma,” Quigg said. “But it’s also true that as long as they’re not totally flaky, as long as it looks possibly true, then it can be a mind-expanding exercise.”

In the case of the 750-GeV bump, Quigg says, you could tell a story in which such a thing might exist and wouldn’t contradict other things that we knew.

“It helps to take it from just an unconnected observation to something that’s linked to everything else,” Quigg says. “That’s really one of the beauties of scientific theories, and specifically the current state of particle physics. Every new observation is linked to everything else we know, including all the old observations. It’s important that we have enough of a network of observation and interpretation that any new thing has to make sense in the context of other things.”

After collecting more data, physicists eventually ruled out the hints, and the theorists moved on to other ideas.

The importance of uncertainty

But sometimes an idea makes it further than that. Much of the work scientists put into publishing a scientific result involves figuring out how well they know it: What’s the uncertainty and how do we quantify it?

“If there’s any hallmark to the scientific method in particle physics and in closely related fields like cosmology, it’s that our results always come with an error bar,” Cahn says. “A result that doesn’t have an uncertainty attached to it has no value.”

In a particle physics experiment, some uncertainty comes from background, like the data Narain’s group found that mimicked the kind of signal they were looking for from the top quark.

This is called systematic uncertainty, which is typically introduced by aspects of the experiment that cannot be completely known.

“When you build a detector, you must make sure that for whatever signal you’re going to see, there is not much possibility to confuse it with the background,” says Helio Takai, a physicist at Brookhaven National Laboratory. “All the elements and sensors and electronics are designed having that in mind. You have to use your previous knowledge from all the experiments that came before.”

Careful study of your systematic uncertainties is the best way to eliminate bias and get reliable results.

“If you underestimate your systematic uncertainty, then you can overestimate the significance of the signal,” Narain says. “But if you overestimate the systematic uncertainty, then you can kill your signal. So, you really are walking this fine line in understanding where the issues may be. There are various ways the data can fool you. Trying to be aware of those ways is an art in itself and it really defines the thinking process.”

Physicists also must think about statistical uncertainty which, unlike systematic uncertainty, is simply the consequence having a limited amount of data.

“For every measurement we do, there’s a possibility that the measurement is a wrong measurement just because of all the events that happen at random while we are doing the experiment,” Takai says. “In particle physics, you’re producing many particles, so a lot of these particles may conspire and make it appear like the event you’re looking for.”

You can think of it as putting your hand inside a bag of M&Ms, Takai says. If the first few M&Ms you picked were brown and you didn’t know there were other colors, you would think the entire bag was brown. It wouldn’t be until you finally pulled out a blue M&M that you realized that the bag had more than one color.

Particle physicists generally want their results to have a statistical significance corresponding to at least 5 sigma, a measure that means that there is only a 0.00003 percent chance of a statistical fluctuation giving an excess as big or bigger than the one observed.

(http://www.symmetrymagazine.org/sites/default/files/images/standard/Inline_2_Discovery.jpg)
Artwork by Sandbox Studio, Chicago

The scientific method at work

One of the most stunning recent examples of the scientific method – careful consideration of statistical and systematic uncertainties coming together – was announced in 2012 at the moment the spokespersons for the ATLAS and CMS experiments at the LHC revealed the discovery of the Higgs boson.

More than half a century of theory and experimentation led up to that moment. Experiments from the 1950s on had accumulated a wealth of information on particle interactions, but the interactions were only partially understood and seemed to come from disconnected sources.

“But brilliant theoretical physicists found a way to make a single model that gave them a good description of all the known phenomena, says Incandela, who was spokesperson for the CMS experiment during the Higgs discovery. “It wasn’t guaranteed that the Higgs field existed. It was only guaranteed that this model works for everything we do and have already seen, and we needed to see if there really was a boson that we could find that could tell us in fact that that field is there.”

This led to a generation-long effort to build an accelerator that would reach the extremely high energies needed to produce the Higgs boson, a particle born of the Higgs field, and then two gigantic detectors that could detect the Higgs boson if it appeared.

Building two different detectors would allow scientists to double-check their work. If an identical signal appeared in two separate experiments run by two separate groups of physicists, chances were quite good that it was the real thing.

“So there you saw a really beautiful application of the scientific method where we confirmed something that was incredibly difficult to confirm, but we did it incredibly well with a lot of fail-safes and a lot of outstanding experimental approaches,” Incandela says. “The scientific method was already deeply engrained in everything we did to the greatest extreme. And so we knew when we saw these things that they were real, and we had to take them seriously.”

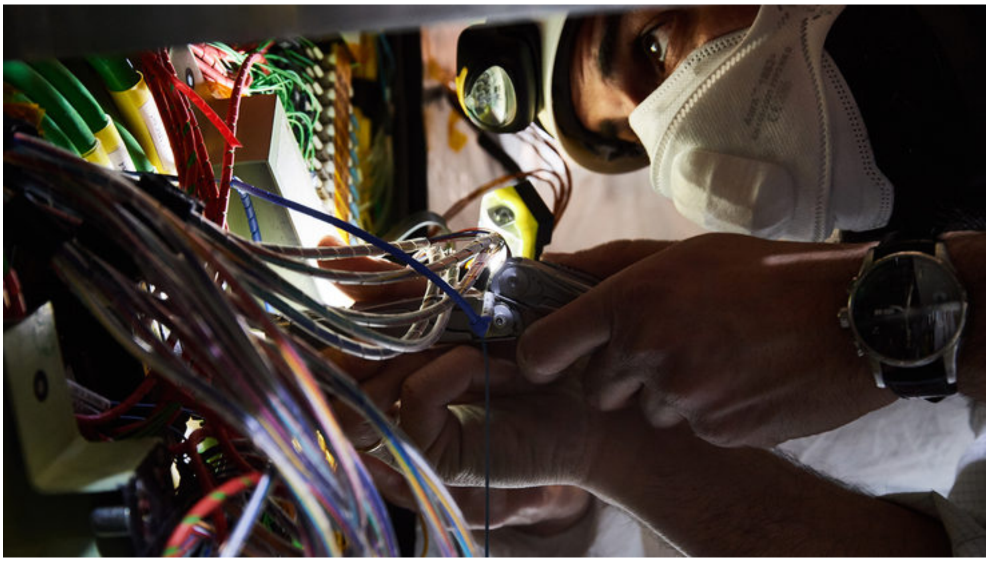
The scientific method is so engrained that scientists don’t often talk about it by name anymore, but implementing it “is what separates the great scientists from the average scientists from the poor scientists,” Incandela says. “It takes a lot of scrutiny and a deep understanding of what you’re doing.”

Read More... (http://www.symmetrymagazine.org/article/how-to-make-a-discovery?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

A new gem inside the CMS detector (http://www.symmetrymagazine.org/article/a-new-gem-inside-the-cms-detector?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Mar 24, 2017

This month scientists embedded sophisticated new instruments in the heart of a Large Hadron Collider experiment.



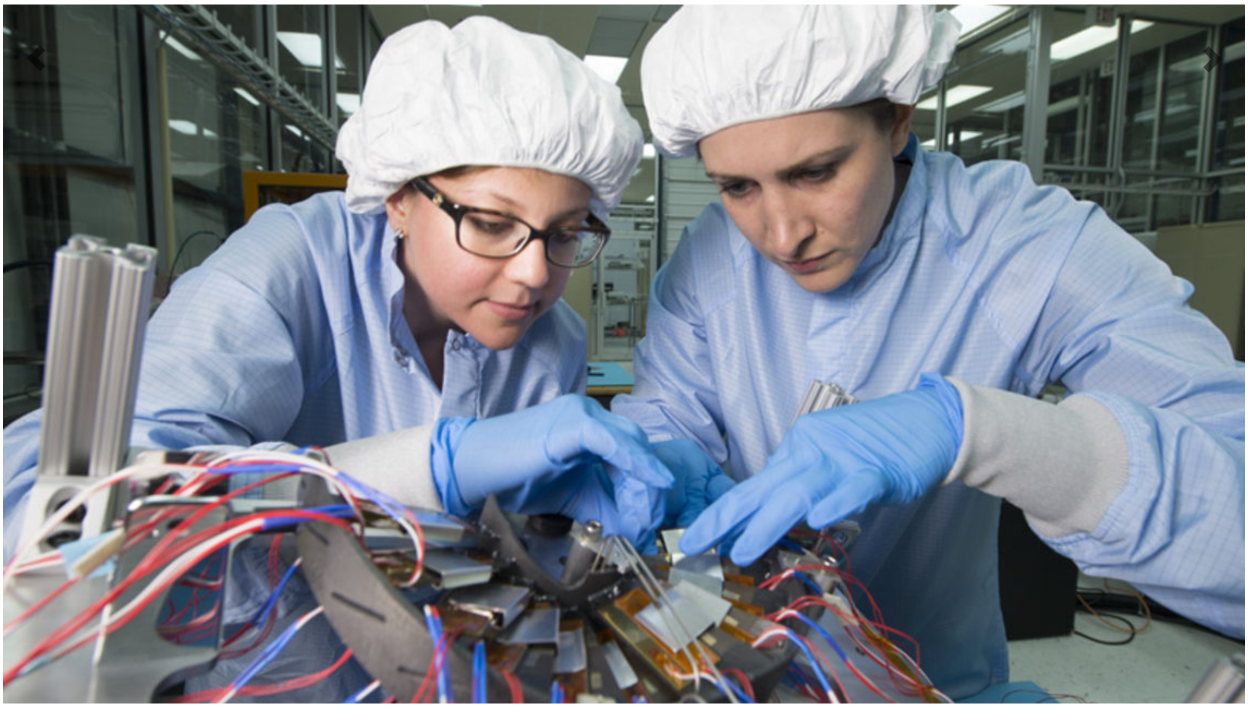
Sometimes big questions require big tools. That's why a global community of scientists designed and built gigantic detectors to monitor the high-energy particle collisions generated by CERN's Large Hadron Collider in Geneva, Switzerland. From these collisions, scientists can retrace the footsteps of the Big Bang and search for new properties of nature.

The CMS experiment is one such detector. In 2012, it co-discovered the elusive Higgs boson with its sister experiment, ATLAS. Now, scientists want CMS to push beyond the known laws of physics and search for new phenomena that could help answer fundamental questions about our universe. But to do this, the CMS detector needed an upgrade.

"Just like any other electronic device, over time parts of our detector wear down," says Steve Nahn, a researcher in the US Department of Energy's Fermi National Accelerator Laboratory and the US project manager for the CMS detector upgrades. "We've been planning and designing this upgrade since shortly after our experiment first started collecting data in 2010."

The CMS detector is built like a giant onion. It contains layers of instruments that track the trajectory, energy and momentum of particles produced in the LHC's collisions. The vast majority of the sensors in the massive detector are packed into its center, within what is called the pixel detector. The CMS pixel detector uses sensors like those inside digital cameras but with a lightning fast shutter speed: In three dimensions, they take 40 million pictures every second.

For the last several years, scientists and engineers at Fermilab and 21 US universities have been assembling and testing a new pixel detector to replace the current one as part of the CMS upgrade, with funding provided by the Department of Energy Office of Science and National Science Foundation.



Maral Alyari of SUNY Buffalo and Stephanie Timpone of Fermilab measure the thermal properties of a forward pixel detector disk at Fermilab. Almost all of the construction and testing of the forward pixel detectors occurred in the United States before the components were shipped to CERN for installation inside the CMS detector.

Photo by Reidar Hahn, Fermilab

The pixel detector consists of three sections: the innermost barrel section and two end caps called the forward pixel detectors. The tiered and can-like structure gives scientists a near-complete sphere of coverage around the collision point. Because the three pixel detectors fit on the beam pipe like three bulky bracelets, engineers designed each component as two half-moons, which latch together to form a ring around the beam pipe during the insertion process.

Over time, scientists have increased the rate of particle collisions at the LHC. In 2016 alone, the LHC produced about as many collisions as it had in the three years of its first run together. To be able to differentiate between dozens of simultaneous collisions, CMS needed a brand new pixel detector.

The upgrade packs even more sensors into the heart of the CMS detector. It's as if CMS graduated from a 66-megapixel camera to a 124-megapixel camera.

Each of the two forward pixel detectors is a mosaic of 672 silicon sensors, robust electronics and bundles of cables and optical fibers that feed electricity and instructions in and carry raw data out, according to Marco Verzocchi, a Fermilab researcher on the CMS experiment.

The multipart, 6.5-meter-long pixel detector is as delicate as raw spaghetti. Installing the new components into a gap the size of a manhole required more than just finesse. It required months of planning and extreme coordination.

"We practiced this installation on mock-ups of our detector many times," says Greg Derylo, an engineer at Fermilab. "By the time we got to the actual installation, we knew exactly how we needed to slide this new component into the heart of CMS."

The most difficult part was maneuvering the delicate components around the pre-existing structures inside the CMS experiment.

"In total, the full three-part pixel detector consists of six separate segments, which fit together like a three-dimensional cylindrical puzzle around the beam pipe," says Stephanie Timpone, a Fermilab engineer. "Inserting the pieces in the right positions and right order without touching any of the pre-existing supports and protections was a well-choreographed dance."

For engineers like Timpone and Derylo, installing the pixel detector was the last step of a six-year process. But for the scientists working on the CMS experiment, it was just the beginning.

"Now we have to make it work," says Stefanos Leontsinis, a postdoctoral researcher at the University of Colorado, Boulder. "We'll spend the next several weeks testing the components and preparing for the LHC restart."

Read More... (http://www.symmetrymagazine.org/article/a-new-gem-inside-the-cms-detector?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

High-energy visionary (http://www.symmetrymagazine.org/article/high-energy-visionary?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Mar 21, 2017

Meet Hernán Quintana Godoy, the scientist who made Chile central to international astronomy.

Professor Hernán Quintana Godoy has a way of taking the long view, peering back into the past through distant stars while looking ahead to the future of astronomy in his home, Chile.

For three decades, Quintana has helped shape the landscape of astronomy in Chile, host to some of the largest ground-based observatories in the world.

In January he became the first recipient of the Education Prize of the American Astronomical Society from a country other than the United States or Canada.

"Training the next generation of astronomers should not be limited to just a few countries," says Keely Finkelstein, former chair of the AAS Education Prize Committee. "[Quintana] has been a tireless advocate for establishing excellent education and research programs in Chile."

Quintana earned his doctorate from the University of Cambridge in the United Kingdom in 1973. The same year, a military junta headed by General Augusto Pinochet took power in a coup d'état.

Quintana came home and secured a teaching position at the University of Chile. At the time, Chilean researchers mainly focused on the fundamentals of astronomy—measuring the radiation from stars and calculating the coordinates of celestial objects. By contrast, Quintana's dissertation on high-energy phenomena seemed downright radical.

A year and a half after taking his new job, Quintana was granted a leave of absence to complete a post-doc abroad. Writing from the United States, Quintana published an article encouraging Chile to take better advantage of its existing international observatories. He urged the government to provide more funding and to create an environment that would encourage foreign-educated astronomers to return home to Chile after their postgraduate studies. The article did not go over well with the administration at his university.

"I wrote it for a magazine that was clearly against Pinochet," Quintana says. "The magazine cover was a black page with a big 'NO' in red" related to an upcoming referendum.

UCh dissolved Quintana's teaching position.

Quintana became a wandering postdoc and research associate in Europe, the US and Canada. It wasn't until 1981 that Quintana returned to teach at the Physics Institute at Pontifical Catholic University of Chile.

He continued to push the envelope at PUC. He created elective courses on general astronomy, extragalactic astrophysics and cluster dynamics. He revived and directed a small astronomy group. He encouraged students to expand their horizons by hiring both Chilean and foreign teachers and sending students to study abroad.

"Because of him I took advantage of most of the big observatories in Chile and had an international perspective of research from the very beginning of my career," says Amelia Ramirez, who studied with Quintana in 1983. A specialist in interacting elliptical galaxies, she is now head of Research and Development in University of La Serena.

In mid-1980s Quintana became the scriptwriter for a set of distance learning astronomy classes produced by the educational division of his university's public TV channel, TELEDUC. He challenged his viewers to take on advanced topics—and they responded.

(http://www.symmetrymagazine.org/sites/default/files/images/standard/Inline_1_Quintana_1.gif)
Illustration by Corinne Mucha

"I even introduced two episodes on relativity theory," Quintana says. "This shocked them. The reception was so good that I wrote a whole book on the subject."

The station partnered with universities and institutions across Chile to provide viewers the opportunity to earn a diploma by taking a written test based on the televised material. More than 5000 people enrolled during the four-year broadcasting period.

"What stands out [about Quintana] is his strategic vision and his creativity to materialize projects," says Alejandro Clocchiatti, a professor at PUC who worked with Quintana for 20 years. "All he does is with dedication and enthusiasm, even if things don't go according to plan. He's got an unbeatable optimism."

Over the years, Quintana has had a hand in planning the locations of multiple new telescopes in Chile. In 1994 he guided an expedition to identify the location of the Atacama Large Millimeter Array, a collection of 66 high-precision antennae.

In 1998, PUC finally responded to decades of advocating by Quintana and his colleagues and opened a new major in astronomy. Gradually more universities followed suit.

Quintana retired three years ago. He is optimistic about the future of Chilean astronomy. It has grown from a collection of 25 professors and their students in the late '90s to a community of more than 800 hundred students, teachers and researchers.

He says he is looking out for new discoveries forthcoming instruments will bring. The European Extremely Large Telescope, under construction on Cerro Armazones in the Atacama Desert of northern Chile, is expected to produce images 16 times sharper than Hubble's. The southern facilities of the Cherenkov Telescope Array, a planned collection of 99 telescopes in Chile, will complement a northern array to complete the world's most sensitive high-energy gamma-ray observatory. Both arrangements will peer into super-massive black holes, the atmospheres of extra-solar planets, and the origin of relativistic cosmic particles.

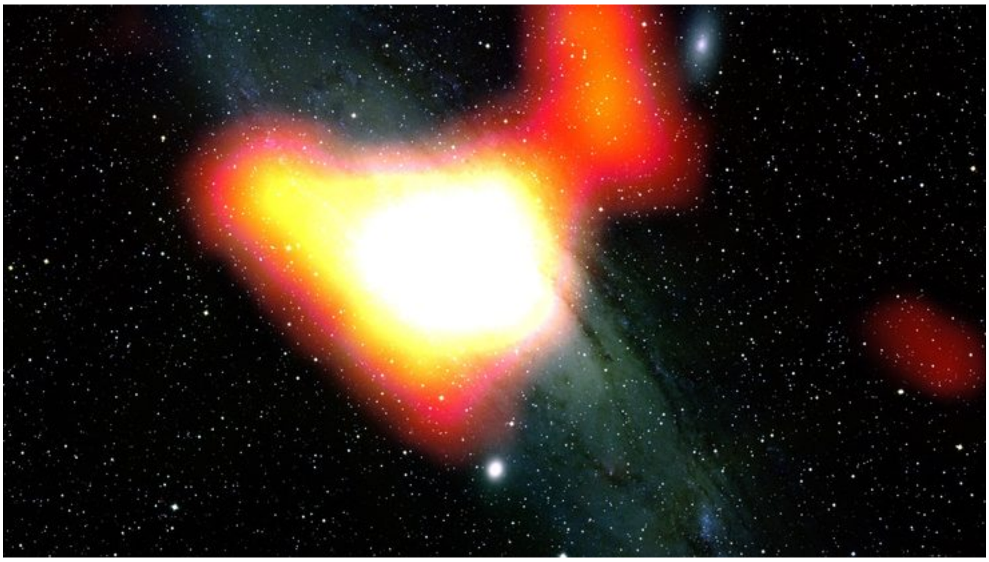
"Everything in our universe is constantly changing," Quintana says. "We are all heirs of that structural evolution."

Read More... (http://www.symmetrymagazine.org/article/high-energy-visionary?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Q&A: Dark matter next door? (http://www.symmetrymagazine.org/article/qa-dark-matter-next-door?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Mar 17, 2017

Astrophysicists Eric Charles and Mattia Di Mauro discuss the surprising glow of our neighbor galaxy.



Astronomers recently discovered (https://arxiv.org/abs/1702.08602) a stronger-than-expected glow of gamma rays at the center of the Andromeda galaxy, the nearest major galaxy to the Milky Way. The signal has fueled hopes that scientists are zeroing in on a sign of dark matter, which is five times more prevalent than normal matter but has never been detected directly.

Researchers believe that gamma rays—a very energetic form of light—could be produced when hypothetical dark matter particles decay or collide and destroy each other. However, dark matter isn't the only possible source of the gamma rays. A number of other cosmic processes are known to produce them.

So what do Andromeda's gamma rays really tell us about dark matter? To find out, Symmetry's Manuel Gnida talked with Eric Charles and Mattia Di Mauro, two members of the Fermi-LAT collaboration—an international team of researchers that found the Andromeda gamma-ray signal using the Large Area Telescope, a sensitive "eye" for dark matter on NASA's Fermi Gamma-ray Space Telescope.

Both researchers are based at the Kavli Institute for Particle Astrophysics and Cosmology, a joint institute of Stanford University and the Department of Energy's SLAC National Accelerator Laboratory. The LAT was conceived of and assembled at SLAC, which also hosts its operations center.

(http://www.symmetrymagazine.org/sites/default/files/images/standard/2017_0310_Eric_Charles_Mattia_DiMauro-24-Edit.jpg)

KIPAC researchers Eric Charles and Mattia Di Mauro

Dawn Harmer, SLAC National Accelerator Laboratory

Have you discovered dark matter?

MD:

No, we haven't. In the study, the LAT team looked at the gamma-ray emissions of the Andromeda galaxy and found something unexpected, something we don't fully understand yet. But there are other potential astrophysical explanations than dark matter.

It's also not the first time that the LAT collaboration has studied Andromeda with Fermi, but in the old data the galaxy only looked like a big blob. With more data and improved data processing, we have now obtained a much clearer picture of the galaxy's gamma-ray glow and how it's distributed.

What's so unusual about the results?

EC:
As a spiral galaxy, Andromeda is similar to the Milky Way. Therefore, we expected the emissions of both galaxies to look similar. What we discovered is that they are, in fact, quite different.

In our galaxy, gamma rays come from all kinds of locations—from the center and the spiral arms in the outer regions. For Andromeda, on the other hand, the signal is concentrated at the center.

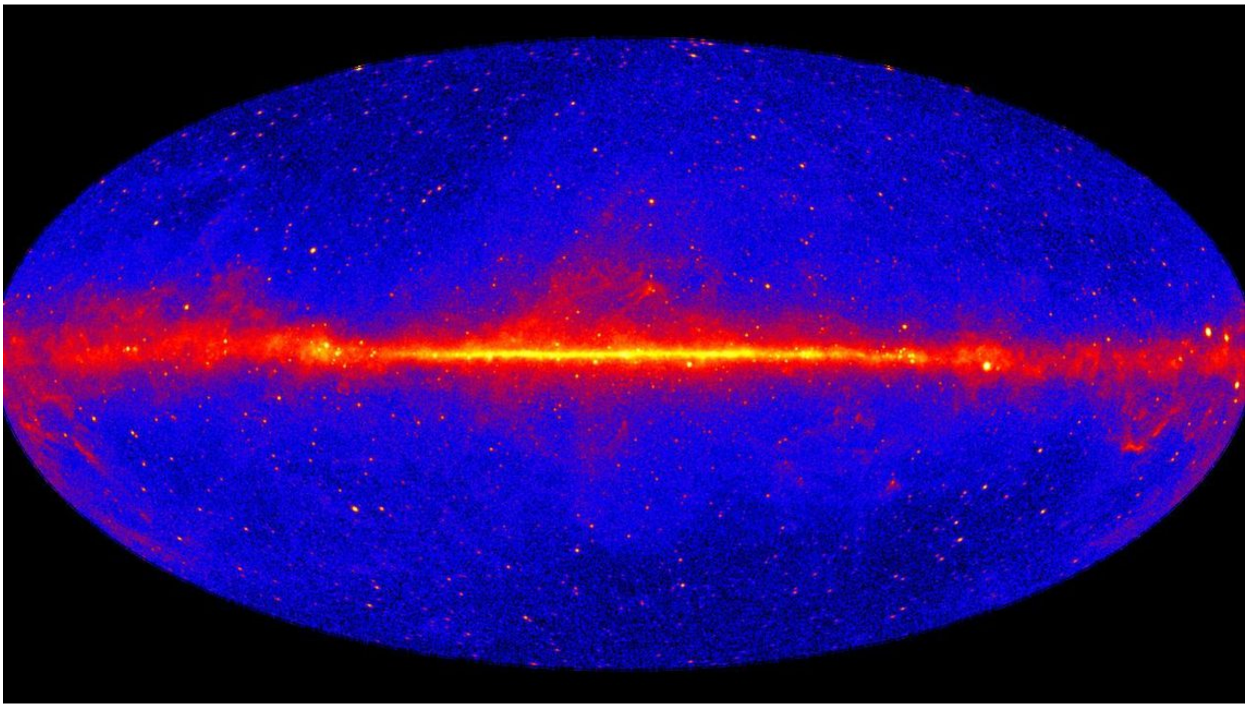
Why do galaxies glow in gamma rays?

EC:
The answer depends on the type of galaxy. There are active galaxies called blazars. They emit gamma rays when matter in close orbit around supermassive black holes generates jets of plasma. And then there are "normal" galaxies like Andromeda and the Milky Way that produce gamma rays in other ways.

When we look at the emissions of the Milky Way, the galaxy appears like a bright disk, with the somewhat brighter galactic center at the center of the disk. Most of this glow is diffuse and comes from the gas between the stars that lights up when it's hit by cosmic rays—energetic particles spit out by star explosions or supernovae.

Other gamma-ray sources are the remnants of such supernovae and pulsars—extremely dense, magnetized, rapidly rotating neutron stars. These sources show up as bright dots in the gamma-ray map of the Milky Way, except at the center where the density of gamma-ray sources is high and the diffuse glow of the Milky Way is brightest, which prevents the LAT from detecting individual sources.

Andromeda is too far away to see individual gamma-ray sources, so it only has a diffuse glow in our images. But we expected to see most of the emissions to come from the disk as well. Its absence suggests that there is less interaction between gas and cosmic rays in our neighbor galaxy. Since this interaction is tied to the formation of stars, this also suggests that Andromeda had a different history of star formation than the Milky Way.



(http://www.symmetrymagazine.org/sites/default/files/images/standard/Fermi_8_year.jpg)

The sky in gamma rays with energies greater than 1 gigaelectronvolts, based on eight years of data from the LAT on NASA's Fermi Gamma-ray Space Telescope.

NASA/DOE/Fermi LAT Collaboration

What does all this have to do with dark matter?

MD:
When we carefully analyze the gamma-ray emissions of the Milky Way and model all the gas and point-like sources to the best of our knowledge, then we're left with an excess of gamma rays at the galactic center. Some people have argued this excess could be a telltale sign of dark matter particles.

We know that the concentration of dark matter is largest at the galactic center, so if there were a dark matter signal, we would expect it to come from there. The localization of gamma-ray emissions at Andromeda's center seems to have renewed the interest in the dark matter interpretation in the media.

Is dark matter the most likely interpretation?

EC:
No, there are other explanations. There are so many gamma-ray sources at the galactic center that we can't really see them individually. This means that their light merges into an extended, diffuse glow.

In fact, two recent studies from the US (https://arxiv.org/pdf/1506.05124.pdf) and the Netherlands (https://arxiv.org/pdf/1506.05104.pdf) have suggested that this glow in the Milky Way could be due to unresolved point sources such as pulsars. The same interpretation could also be true for Andromeda's signal.

What would it take to know for certain?

MD:
To identify a dark matter signal, we would need to exclude all other possibilities. This is very difficult for a complex region like the galactic center, for which we don't even know all the astrophysical processes. Of course, this also means that, for the same reason, we can't completely rule out the dark matter interpretation.

But what's really important is that we would want to see the same signal in a few different places. However, we haven't detected any gamma-ray excesses in other galaxies that are consistent with the ones in the Milky Way and Andromeda.

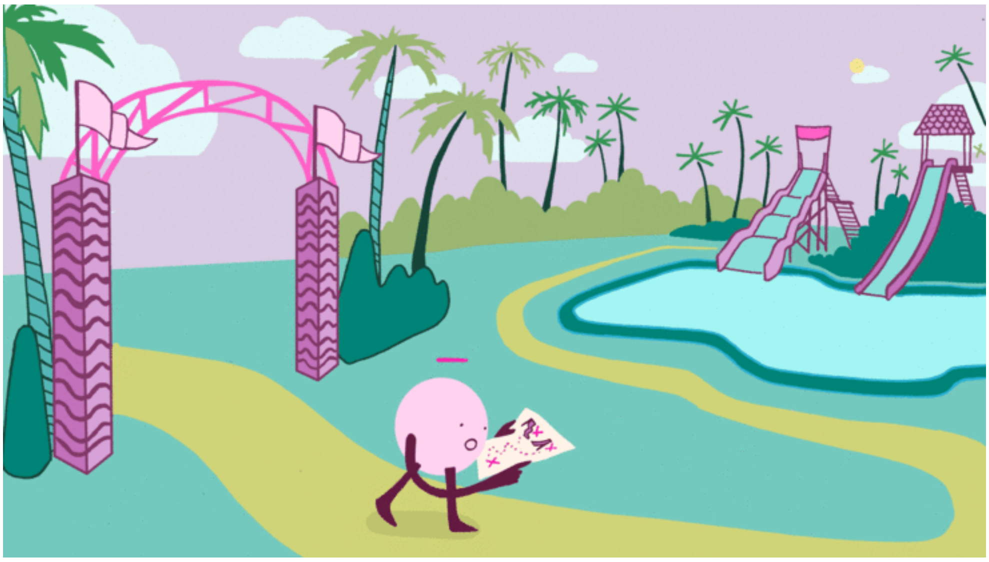
This is particularly striking for dwarf galaxies, small companion galaxies of the Milky Way that only have few stars. These objects are only held together because they are dominated by dark matter. If the gamma-ray excess at the galactic center were due to dark matter, then we should have already seen similar signatures in the dwarf galaxies. But we don't.

Read More... (http://www.symmetrymagazine.org/article/qa-dark-matter-next-door?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

The life of an accelerator (http://www.symmetrymagazine.org/article/the-life-of-an-accelerator?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Mar 14, 2017

As it evolves, the SLAC linear accelerator illustrates some important technologies from the history of accelerator science.

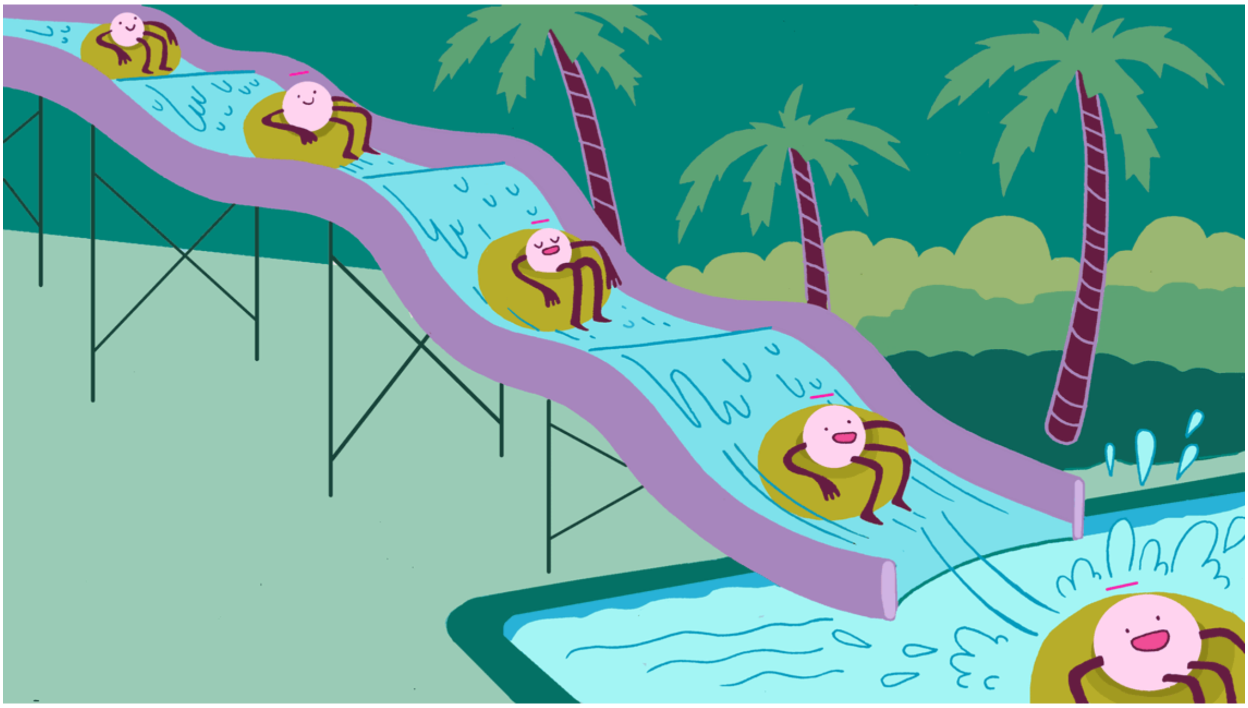


Tens of thousands of accelerators exist around the world, producing powerful particle beams for the benefit of medical diagnostics, cancer therapy, industrial manufacturing, material analysis, national security, and nuclear as well as fundamental particle physics. Particle beams can also be used to produce powerful beams of X-rays.

Many of these particle accelerators rely on artfully crafted components called cavities.

The world's longest linear accelerator (also known as a linac) sits at the Department of Energy's SLAC National Accelerator Laboratory. It stretches two miles and accelerates bunches of electrons to very high energies.

The SLAC linac has undergone changes in its 50 years of operation that illustrate the evolution of the science of accelerator cavities. That evolution continues and will determine what the linac does next.



(http://www.symmetrymagazine.org/sites/default/files/images/standard/Inline_1_Cavities.gif)
Illustration by Corinne Mucha

Robust copper

An accelerator cavity is a mostly closed, hollow chamber with an opening on each side for particles to pass through. As a particle moves through the cavity, it picks up energy from an electromagnetic field stored inside. Many cavities can be lined up like beads on a string to generate higher and higher particle energies.

When SLAC's linac first started operations, each of its cavities was made exclusively from copper. Each tube-like cavity consisted of a 1-inch-long, 4-inch-wide cylinder with disks on either side. Technicians brazed together more than 80,000 cavities to form a straight particle racetrack.

Scientists generate radiofrequency waves in an apparatus called a klystron that distributes them to the cavities. Each SLAC klystron serves a 10-foot section of the beam line. The arrival of the electron bunch inside the cavity is timed to match the peak in the accelerating electric field. When a particle arrives inside the cavity at the same time as the peak in the electric field, then that bunch is optimally accelerated.

"Particles only gain energy if the variable electric field precisely matches the particle motion along the length of the accelerator," says Sami Tantawi, an accelerator physicist at Stanford University and SLAC. "The copper must be very clean and the shape and size of each cavity must be machined very carefully for this to happen."

In its original form, SLAC's linac boosted electrons and their antimatter siblings, positrons, to an energy of 50 billion electronvolts. Researchers used these beams of accelerated particles to study the inner structure of the proton, which led to the discovery of fundamental particles known as quarks.

Today almost all accelerators in the world—including smaller systems for medical and industrial applications—are made of copper. Copper is a good electric conductor, which is important because the radiofrequency waves build up an accelerating field by creating electric currents in the cavity walls. Copper can be machined very smoothly and is cheaper than other options, such as silver.

"Copper accelerators are very robust systems that produce high acceleration gradients of tens of millions of electronvolts per meter, which makes them very attractive for many applications," says SLAC accelerator scientist Chris Adolphsen.

Today, one-third of SLAC's original copper linac is used to accelerate electrons for the Linac Coherent Light Source, a facility that turns energy from the electron beam into what is currently the world's brightest X-ray laser light.

Researchers continue to push the technology to higher and higher gradients—that is, larger and larger amounts of acceleration over a given distance.

"Using sophisticated computer programs on powerful supercomputers, we were able to develop new cavity geometries that support almost 10 times larger gradients," Tantawi says. "Mixing small amounts of silver into the copper further pushes the technology toward its natural limits." Cooling the copper to very low temperatures helps as well. Tests at 45 Kelvin—negative 384 degrees Fahrenheit—have shown to increase acceleration gradients 20-fold compared to SLAC's old linac.

Copper accelerators have their limitations, though. SLAC's historic linac produces 120 bunches of particles per second, and recent developments have led to copper structures capable of firing 80 times faster. But for applications that need much higher rates, Adolphsen says, "copper cavities don't work because they would melt."

(http://www.symmetrymagazine.org/sites/default/files/images/standard/Inline_2_Cavities.gif)
Illustration by Corinne Mucha

Chill niobium

For this reason, crews at SLAC are in the process of replacing one-third of the original copper linac with cavities made of niobium.

Niobium can support very large bunch rates, as long as it is cooled. At very low temperatures, it is what's known as a superconductor.

"Below the critical temperature of 9.2 Kelvin, the cavity walls conduct electricity without losses, and electromagnetic waves can travel up and down the cavity many, many times, like a pendulum that goes on swinging for a very long time," says Anna Grassellino, an accelerator scientist at Fermi National Accelerator Laboratory. "That's why niobium cavities can store electromagnetic energy very efficiently and can operate continuously."

You can find superconducting niobium cavities in modern particle accelerators such as the Large Hadron Collider at CERN and the CEBAF accelerator at Thomas Jefferson National Accelerator Facility. The European X-ray Free-Electron Laser in Germany, the European Spallation Source at CERN, and the Facility for Rare Isotope Beams at Michigan State University are all being built using niobium technology. Niobium cavities also appear in designs for the next-generation International Linear Collider.

At SLAC, the niobium cavities will support LCLS-II, an X-ray laser that will produce up to a million ultrabright light flashes per second. The accelerator will have 280 cavities, each about three feet long with a 3-inch opening for the electron beam to fly through. Sets of eight cavities will be strung together into cryomodules that keep the cavities at a chilly 2 Kelvin, which is colder than interstellar space.

Each niobium cavity is made by fusing together two halves stamped from a sheet of pure metal. The cavities are then cleaned very thoroughly because even the tiniest impurities would degrade their performance.

The shape of the cavities is reminiscent of a stack of shiny donuts. This is to maximize the cavity volume for energy storage and to minimize its surface area to cut down on energy dissipation. The exact size and shape also depends on the type of accelerated particle.

"We've come a long way since the first development of superconducting cavities decades ago," Grassellino says. "Today's niobium cavities produce acceleration gradients of up to about 50 million electronvolts per meter, and R&D work at Fermilab and elsewhere is further pushing the limits."

(http://www.symmetrymagazine.org/sites/default/files/images/standard/Inline_3_Cavities.gif)
Illustration by Corinne Mucha

Hot plasma

Over the past few years, SLAC accelerator scientists have been working on a way to push the limits of particle acceleration even further: accelerating particles using bubbles of ionized gas called plasma.

Plasma wakefield acceleration is capable of creating acceleration gradients that are up to 1000 times larger than those of copper and niobium cavities, promising to drastically shrink the size of particle accelerators and make them much more powerful.

“These plasma bubbles have certain properties that are very similar to conventional metal cavities,” says SLAC accelerator physicist Mark Hogan. “But because they don’t have a solid surface, they can support extremely high acceleration gradients without breaking down.”

Hogan’s team at SLAC and collaborators from the University of California, Los Angeles, have been developing their plasma acceleration method at the Facility for Advanced Accelerator Experimental Tests, using an oven of hot lithium gas for the plasma and an electron beam from SLAC’s copper linac.

Researchers create bubbles by sending either intense laser light or a high-energy beam of charged particles through plasma. They then send beams of particles through the bubbles to be accelerated.

When, for example, an electron bunch enters a plasma, its negative charge expels plasma electrons from its flight path, creating a football-shaped cavity filled with positively charged lithium ions. The expelled electrons form a negatively charged sheath around the cavity.

This plasma bubble, which is only a few hundred microns in size, travels at nearly the speed of light and is very short-lived. On the inside, it has an extremely strong electric field. A second electron bunch enters that field and experiences a tremendous energy gain. Recent data show possible energy boosts of billions of electronvolts in a plasma column of just a little over a meter.

“In addition to much higher acceleration gradients, the plasma technique has another advantage,” says UCLA researcher Chris Clayton. “Copper and niobium cavities don’t keep particle beams tightly bundled and require the use of focusing magnets along the accelerator. Plasma cavities, on the other hand, also focus the beam.”

Much more R&D work is needed before plasma wakefield accelerator technology can be turned into real applications. But it could represent the future of particle acceleration at SLAC and of accelerator science as a whole.

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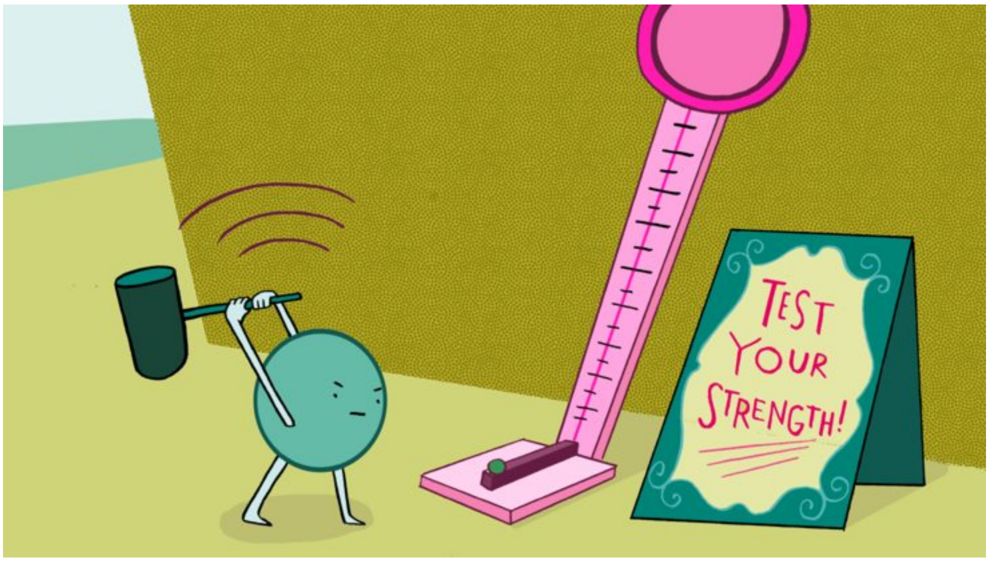
A strength test for the strong force (http://www.symmetrymagazine.org/article/a-strength-test-for-the-strong-force?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Mar 10, 2017

New research could tell us about particle interactions in the early universe and even hint at new physics.



Much of the matter in the universe is made up of tiny particles called quarks. Normally it’s impossible to see a quark on its own because they are always bound tightly together in groups. Quarks only separate in extreme conditions, such as immediately after the Big Bang or in the center of stars or during high-energy particle collisions generated in particle colliders.

Scientists at Louisiana Tech University are working on a study of quarks and the force that binds them by analyzing data from the ATLAS experiment at the LHC. Their measurements could tell us more about the conditions of the early universe and could even hint at new, undiscovered principles of physics.

The particles that stick quarks together are aptly named “gluons.” Gluons carry the strong force, one of four fundamental forces in the universe that govern how particles interact and behave. The strong force binds quarks into particles such as protons, neutrons and atomic nuclei.

As its name suggests, the strong force is the strongest—it’s 100 times stronger than the electromagnetic force (which binds electrons into atoms), 10,000 times stronger than the weak force (which governs radioactive decay), and a hundred million million million million million million (10^{39}) times stronger than gravity (which attracts you to the Earth and the Earth to the sun).

But this ratio shifts when the particles are pumped full of energy. Just as real glue loses its stickiness when overheated, the strong force carried by gluons becomes weaker at higher energies.

“Particles play by an evolving set of rules,” says Markus Wobisch from Louisiana Tech University. “The strength of the forces and their influence within the subatomic world changes as the particles’ energies increase. This is a fundamental parameter in our understanding of matter, yet has not been fully investigated by scientists at high energies.”

Characterizing the cohesiveness of the strong force is one of the key ingredients to understanding the formation of particles after the Big Bang and could even provide hints of new physics, such as hidden extra dimensions.

“Extra dimensions could help explain why the fundamental forces vary dramatically in strength,” says Lee Sawyer, a professor at Louisiana Tech University. “For instance, some of the fundamental forces could only appear weak because they live in hidden extra dimensions and we can’t measure their full strength. If the strong force is weaker or stronger than expected at high energies, this tells us that there’s something missing from our basic model of the universe.”

By studying the high-energy collisions produced by the LHC, the research team at Louisiana Tech University is characterizing how the strong force pulls energetic quarks into encumbered particles. The challenge they face is that quarks are rambunctious and caper around inside the particle detectors. This subatomic soirée involves hundreds of particles, often arising from about 20 proton-proton collisions happening simultaneously. It leaves a messy signal, which scientists must then reconstruct and categorize.

Wobisch and his colleagues innovated a new method to study these rowdy groups of quarks called jets. By measuring the angles and orientations of the jets, he and his colleagues are learning important new information about what transpired during the collisions—more than what they can deduce by simple counting the jets.

The average number of jets produced by proton-proton collisions directly corresponds to the strength of the strong force in the LHC’s energetic environment.

“If the strong force is stronger than predicted, then we should see an increase in the number of proton-protons collisions that generate three jets. But if the strong force is actually weaker than predicted, then we’d expect to see relatively more collisions that produce only two jets. The ratio between these two possible outcomes is the key to understanding the strong force.”

After turning on the LHC, scientists doubled their energy reach and have now determined the strength of the strong force up to 1.5 trillion electronvolts, which is roughly the average energy of every particle in the universe just after the Big Bang. Wobisch and his team are hoping to double this number again with more data.

“So far, all our measurements confirm our predictions,” Wobisch says. “More data will help us look at the strong force at even higher energies, giving us a glimpse as to how the first particles formed and the microscopic structure of space-time.”

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Researchers face engineering puzzle (http://www.symmetrymagazine.org/article/researchers-face-engineering-puzzle?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Mar 7, 2017

How do you transport 70,000 tons of liquid argon nearly a mile underground?

Nearly a mile below the surface of Lead, South Dakota, scientists are preparing for a physics experiment that will probe one of the deepest questions of the universe: Why is there more matter than antimatter?

To search for that answer, the Deep Underground Neutrino Experiment, or DUNE, will look at minuscule particles called neutrinos. A beam of neutrinos will travel 800 miles through the Earth from Fermi National Accelerator Laboratory to the Sanford Underground Research Facility, headed for massive underground detectors that can record traces of the elusive particles.

Because neutrinos interact with matter so rarely and so weakly, DUNE scientists need a lot of material to create a big enough target for the particles to run into. The most widely available (and cost effective) inert substance that can do the job is argon, a colorless, odorless element that makes up about 1 percent of the atmosphere.

The researchers also need to place the detector full of argon far below Earth's surface, where it will be protected from cosmic rays and other interference.

"We have to transfer almost 70,000 tons of liquid argon underground," says David Montanari, a Fermilab engineer in charge of the experiment's cryogenics. "And at this point we have two options: We can either transfer it as a liquid or we can transfer it as a gas."

Either way, this move will be easier said than done.

Liquid or gas?

The argon will arrive at the lab in liquid form, carried inside of 20-ton tanker trucks. Montanari says the collaboration initially assumed that it would be easier to transport the argon down in its liquid form—until they ran into several speed bumps.

Transporting liquid vertically is very different from transporting it horizontally for one important reason: pressure. The bottom of a mile-tall pipe full of liquid argon would have a pressure of about 3000 pounds per square inch—equivalent to 200 times the pressure at sea level. According to Montanari, to keep these dangerous pressures from occurring, multiple de-pressurizing stations would have to be installed throughout the pipe.

Even with these depressurizing stations, safety would still be a concern. While argon is non-toxic, if released into the air it can reduce access to oxygen, much like carbon monoxide does in a fire. In the event of a leak, pressurized liquid argon would spill out and could potentially break its vacuum-sealed pipe, expanding rapidly to fill the mine as a gas. One liter of liquid argon would become about 800 liters of argon gas, or four bathtubs' worth.

Even without a leak, perhaps the most important challenge in transporting liquid argon is preventing it from evaporating into a gas along the way, according to Montanari.

To remain a liquid, argon is kept below a brisk temperature of minus 180 degrees Celsius (minus 300 degrees Fahrenheit).

"You need a vacuum-insulated pipe that is a mile long inside a mine shaft," Montanari says. "Not exactly the most comfortable place to install a vacuum-insulated pipe."

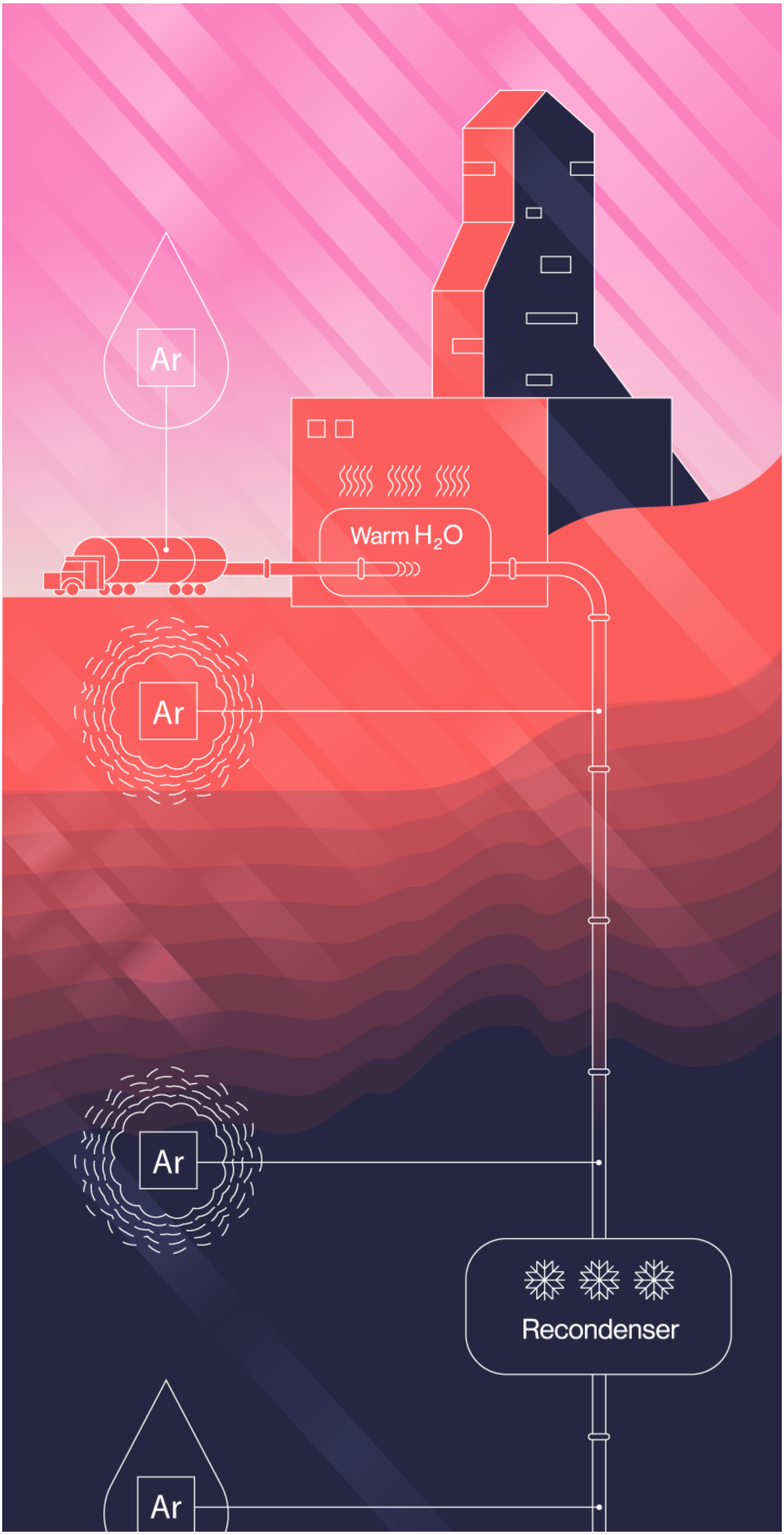
To avoid these problems, the cryogenics team made the decision to send the argon down as gas instead.

Routing the pipes containing liquid argon through a large bath of water will warm it up enough to turn it into gas, which will be able to travel down through a standard pipe. Re-condensers located underground act as massive air conditioners will then cool the gas until becomes a liquid again.

"The big advantage is we no longer have vacuum insulated pipe," Montanari says. "It is just straight piece of pipe."

Argon gas poses much less of a safety hazard because it is about 1000 times less dense than liquid argon. High pressures would be unlikely to build up and necessitate depressurizing stations, and if a leak occurred, it would not expand as much and cause the same kind of oxygen deficiency.

The process of filling the detectors with argon will take place in four stages that will take almost two years, Montanari says. This is due to the amount of available cooling power for re-condensing the argon underground. There is also a limit to the amount of argon produced in the US every year, of which only so much can be acquired by the collaboration and transported to the site at a time.


Ar
Warm H_2O
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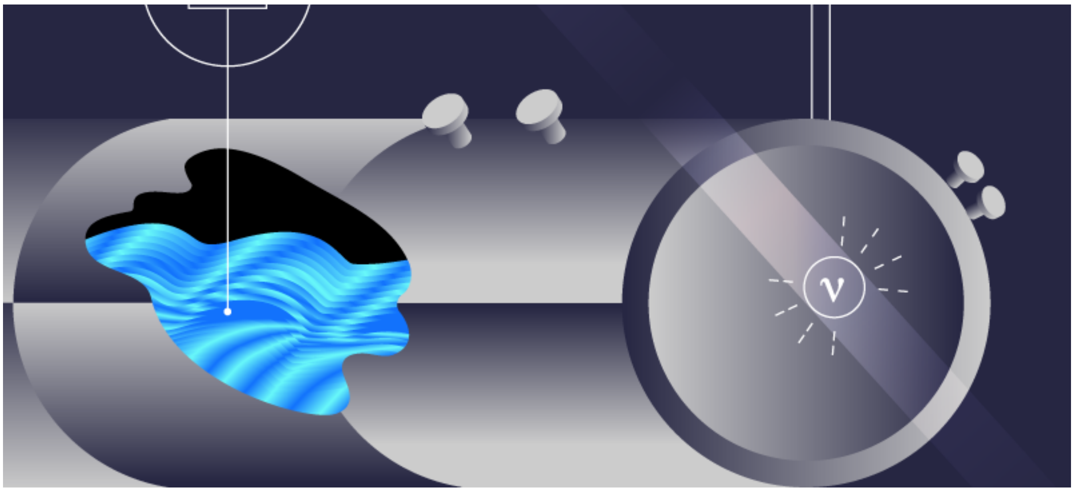

(http://www.symmetrymagazine.org/sites/default/files/images/standard/Inline_Liquid_argon.png)

Illustration by Ana Kova

Argon for answers

Once filled, the liquid argon detectors will pick up light and electrons produced by neutrino interactions.

Part of what makes neutrinos so fascinating to physicists is their habit of oscillating from one flavor—electron, muon or tau—to another. The parameters that govern this “flavor change” are tied directly to some of the most fundamental questions in physics, including why there is more matter than antimatter. With careful observation of neutrino oscillations, scientists in the DUNE collaboration hope to unravel these mysteries in the coming years.

“At the time of the Big Bang, in theory, there should have been equal amounts of matter and antimatter in the universe,” says Eric James, DUNE’s technical coordinator. That matter and antimatter should have annihilated, leaving behind an empty universe. “But we became a matter-dominated universe.”

James and other DUNE scientists will be looking to neutrinos for the mechanism behind this matter favoritism. Although the fruits of this labor won’t appear for several years, scientists are looking forward to being able to make use of the massive detectors, which are hundreds of times larger than current detectors that hold only a few hundred tons of liquid argon.

Currently, DUNE scientists and engineers are working at CERN to construct Proto-DUNE, a miniature replica of the DUNE detector filled with only 300 tons of liquid argon that can be used to test the design and components.

“Size is really important here,” James says. “A lot of what we’re doing now is figuring out how to take those original technologies which have already being developed... and taking it to this next level with bigger and bigger detectors.”

Read More... (http://www.symmetrymagazine.org/article/researchers-face-engineering-puzzle?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Hey Fermilab, it’s a Monkee (http://www.symmetrymagazine.org/article/hey-fermilab-its-a-monkee?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Mar 2, 2017

Micky Dolenz, best known as a vocalist and drummer in 1960s pop band The Monkees, turns out to be one of Fermi National Accelerator Laboratory’s original fans.

“Dear Ms. Higgins,” began the email to an employee of Fermi National Accelerator Laboratory. “My name is Micky Dolenz. I am in the entertainment business and probably best known for starring in a ’60s TV show called *The Monkees*. I have also been a big fan of particle physics for many decades.”

The message, which laboratory archivist Valerie Higgins received in November 2016, was legit. And it turns out Dolenz wasn't kidding about his love of physics. Dolenz visited Fermilab on February 10 and impressed and amazed the scientists he met with his knowledge of (and genuine affection for) the science of quarks, leptons and bosons. Dolenz was, by all accounts, just as excited to meet with Fermilab scientists as they were to meet with him.

"He was so enthusiastic about the lab," Higgins says. "It was such a treat to see someone of his stature and popularity be so interested and knowledgeable about our kind of physics."

Previously unbeknownst to most of the lab's employees, Dolenz's association with Fermilab actually stretches back more than 40 years. The last time Dolenz visited Fermilab, the year was 1970. *The Monkees* TV show had wound down, and Dolenz, then 25, was starring in a play called *Remains to Be Seen* at the Pheasant Run Playhouse in nearby St. Charles, Illinois. Fermilab wasn't even called Fermilab yet—it still went by the name National Accelerator Laboratory.

Dolenz says he remembers his first visit well. At the time, the lab consisted of a few trailers and bungalows—Fermilab's now-iconic high-rise building, Wilson Hall, would not be completed until 1973. Dolenz had lunch with several of the scientists then toured the construction site for the Main Ring, the future home of Fermilab's first superconducting accelerator, the Tevatron.

Dolenz captured some of his visit on 16mm film, footage he says he still has in storage. Dolenz called his previous tour of Fermilab "wonderful" and "a dream come true."

Dolenz credits a junior high science teacher with sparking his interest in physics. He spent much of his childhood in Los Angeles building oscilloscopes and transceivers for ham radios and other gadgets. "I was always curious, always building stuff," he says. "While the other kids were reading Superman comics, I was reading *Science News*. I loved it all, particularly particle physics and quantum physics."

Dolenz was in training to be an architect, but at age 20, the *Monkees* audition offered him the opportunity to catapult to worldwide fame as a TV star and musician instead. ("I'm not an idiot," he says of accepting the role.) Still, he maintained his interest in science—his first email address, created in the 1990s, was "Higgs137," referencing both the then-undiscovered Higgs boson and the measure of the fine structure constant.

(http://www.symmetrymagazine.org/sites/default/files/images/standard/Micky_Dolenz3-s.jpg)

Fermilab Director Nigel Lockyer, left, and Deputy Director Joe Lykken, right, talk with Monkee Micky Dolenz during his tour.

Photo by Reidar Hahn, Fermilab

That interest in science has remained strong, Fermilab physicists noted during the February tour. Dolenz toured the underground cavern that houses detectors for the MINOS, NOvA and MINERvA neutrino experiments, the Muon g-2 experiment hall (where scientists played the theme from *The Monkees* when he walked in), and the DZero detector in the long-since completed Main Ring. He also spent time in three control rooms.

In every location, he impressed the scientists he met with his understanding of physics and his full-on joy at seeing science in action.

"Who knew he is a life-long physics aficionado?" says scientist Adam Lyon, who gave Dolenz his Tevatron tour. "I had a great time talking with him."

Dolenz says he sees plenty of connection between his twin interests of physics and music, noting that Einstein played the violin; Richard Feynman played bongos; and Queen guitarist Brian May is an astrophysicist on several experimental collaborations.

"According to theory the universe is constantly vibrating, down to even the smallest particles," Dolenz says. "We talked a lot about vibrations in the '60s, and Eastern philosophy has been talking about the vibration of the universe for thousands of years. Music is vibration and meter and frequency. There's a lot of overlap."

Dolenz enjoyed his time at Fermilab so much that he hung out at the lab's on-site pub until late in the evening, chatting with scientists. And according to Higgins, who spent the most time with him, he's hoping to return very soon.

"He's still looking for the footage he shot in 1970, and plans to donate that to the archive," she says. "But I told him he's welcome here anytime."

(http://www.symmetrymagazine.org/sites/default/files/images/standard/Micky_Dolenz-s.jpg)

Monkee Micky Dolenz stands by a model particle accelerator with Fermilab physicist Herman White and Fermilab Director of Communication Katie Yurkewicz.

Photo by Reidar Hahn, Fermilab

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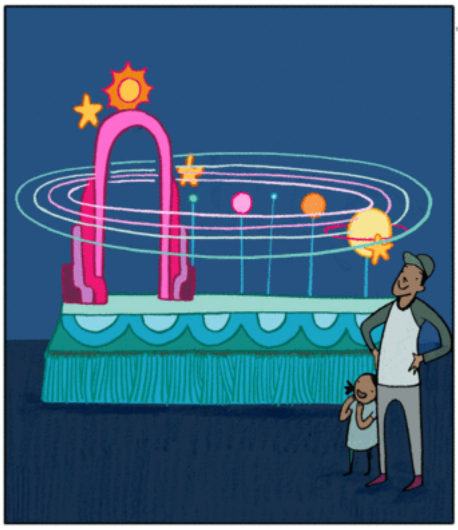
How to build a universe (http://www.symmetrymagazine.org/article/how-to-build-a-universe?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Feb 28, 2017

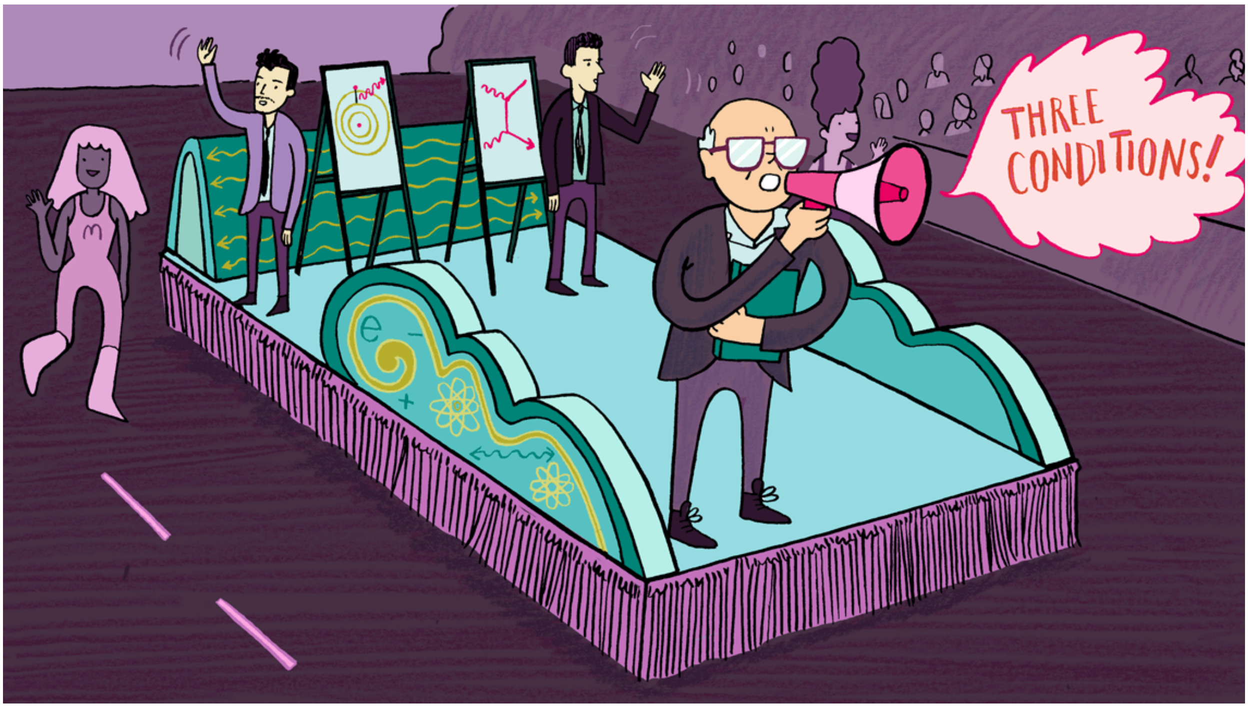
Our universe should be a formless fog of energy. Why isn't it?



According to the known laws of physics, the universe we see today should be dark, empty and quiet. There should be no stars, no planets, no galaxies and no life—just energy and simple particles diffusing further and further into an expanding universe.

And yet, here we are.

Cosmologists calculate that roughly 13.8 billion years ago, our universe was a hunk of thick, hot energy with no boundaries and its own rules. But then, in less than a microsecond, it matured, and the fundamental laws and properties of matter arose from the pandemonium. How did our elegant and intricate universe emerge?



(http://www.symmetrymagazine.org/sites/default/files/images/standard/Inline_1_How_to_build_a_universe.gif)

Illustration by Corinne Mucha

The three conditions

The question *"How is it here?"* alludes to a conundrum that arose during the development of quantum mechanics.

In 1928 Paul Dirac combined quantum theory and special relativity to predict the energy of an electron moving near the speed of light. But his equations produced two equally favorable answers: one positive and one negative. Because energy itself cannot be negative, Dirac mused that perhaps the two answers represented the particle's two possible electric charges. The idea of oppositely charged matter-antimatter pairs was born.

Meanwhile, about six minutes away from Dirac's office in Cambridge, physicist Patrick Blackett was studying the patterns etched in cloud chambers by cosmic rays. In 1933 he detected 14 tracks that showed a single particle of light colliding with an air molecule and bursting into two new particles. The spiral tracks of these new particles were mirror images of each other, indicating that they were oppositely charged. This was one of the first observations of what Dirac had predicted five years earlier—the birth of an electron-positron pair.

Today it's well known that matter and antimatter are the ultimate wonder twins. They're spontaneously born from raw energy as a team of two and vanish in a silent poof of energy when they merge and annihilate. This appearing-disappearing act spawned one of the most fundamental mysteries in the universe: What is engraved in the laws of nature that saved us from the broth of appearing and annihilating particles of matter and antimatter?

"We know this cosmic asymmetry must exist because here we are," says Jessie Shelton, a theorist at the University of Illinois. "It's a puzzling imbalance because theory requires three conditions—which all have to be true at once—to create this cosmic preference for matter."

In the 1960s physicist Andrei Sakharov proposed this set of three conditions that could explain the appearance of our matter-dominated universe. Scientists continue to look for evidence of these conditions today.

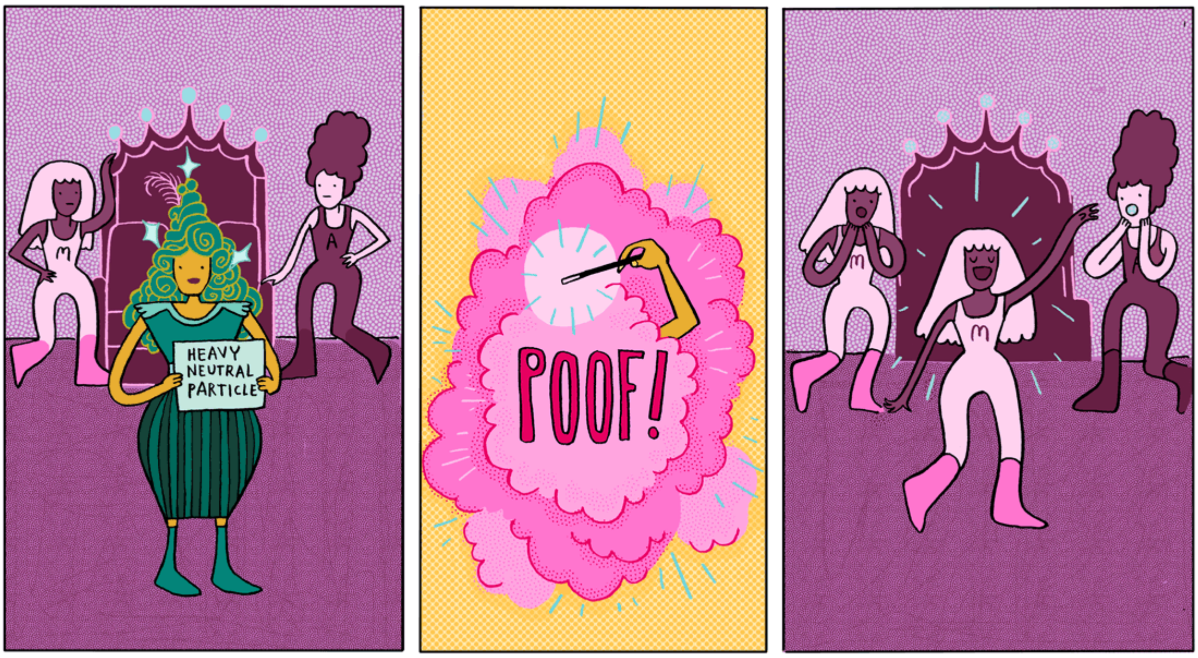


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Illustration by Corinne Mucha

1. Breaking the tether

The first problem is that matter and antimatter always seem to be born together. Just as Blackett observed in the cloud chambers, uncharged energy transforms into evenly balanced matter-antimatter pairs. Charge is always conserved through any transition. For there to be an imbalance in the amounts of matter and antimatter, there needs to be a process that creates more of one than the other.

"Sakharov's first criterion essentially says that there must be some new process that converts antimatter into matter, or vice versa," says Andrew Long, a postdoctoral researcher in cosmology at the University of Chicago. "This is one of the things experimentalists are looking for in the lab."

In the 1980s, scientists searched for evidence of Sakharov's first condition by looking for signs of a proton decaying into a positron and two photons. They have yet to find evidence of this modern alchemy, but they continue to search.

"We think that the early universe could have contained a heavy neutral particle that sometimes decayed into matter and sometimes decayed into antimatter, but not necessarily into both at the same time," Long says.

(http://www.symmetrymagazine.org/sites/default/files/images/standard/Inline_3_How_to_build_a_universe.gif)

Illustration by Corinne Mucha

2. Picking a favorite

Matter and antimatter cannot co-habitate; they always annihilate when they come into contact. But the creation of just a little more matter than antimatter after the Big Bang—about one part in 10 billion—would leave behind the ingredients needed to build the entire visible universe.

How could this come about? Sakharov's second criterion dictates that the matter-only process outlined in his first criterion must be more efficient than the opposing antimatter process. And specifically, "we need to see a favoritism for the right kinds of matter to agree with astronomical observations," Shelton says.

Observations of light left over from the early universe and measurements of the first lightweight elements produced after the Big Bang show that the discrepancy must exist in a class of particles called baryons: protons, antiprotons and other particles constructed from quarks.

"These are snapshots of the early universe," Shelton says. "From these snapshots, we can derive the density and temperature of the early universe and calculate the slight difference between the number of baryons and antibaryons."

But this slight difference presents a problem. While there are some tiny discrepancies between the behavior of particles and their antiparticle counterparts, these idiosyncrasies are still consistent with the Standard Model and are not enough to explain the origin of the cosmic imbalance nor the universe's tenderness towards matter.

(http://www.symmetrymagazine.org/sites/default/files/images/standard/Inline_4_How_to_build_a_universe.gif)

Illustration by Corinne Mucha

3. Taking a one-way street

In particle physics, any process that runs forward can just as easily run in reverse. A pair of photons can merge and morph into a particle and antiparticle pair. And just as easily, the particle and antiparticle pair can recombine into a pair of photons. This process happens all around us, continually. But because it is cyclical, there is no net gain or loss for a type of matter.

If this were always true, our young universe could have been locked in an infinite loop of creation and destruction. Without something slamming the brakes on these cycles at least for a moment, matter could not have evolved into the complex structures we see today.

“For every stitch that’s knit, there a simultaneous tug on the thread,” Long says. “We need a way to force the reaction to move forward and not simultaneously run in reverse at the same rate.”

Many cosmologists suspect that the gradual expansion and cooling of the universe was enough to lock matter into being, like a supersaturated sweet tea whose sugar crystals drop to the bottom of the glass as it cools (or in the “freezing” interpretation, like a sweet tea that instantly freezes into ice, locking sugar crystals in place without giving them a chance to dissolve).

Other cosmologists think that the plasma of the early universe may have contained bubbles that helped separate matter and antimatter (and then served as incubators for particles to acquire mass).

Several experiments at CERN are looking for evidence that the universe meets Sakharov’s three conditions. For instance, several precision experiments at CERN’s Antimatter Factory are looking for minuscule differences between the intrinsic characteristics of protons and antiprotons. The LHCb experiment at the Large Hadron Collider is examining the decay patterns of unstable matter and antimatter particles.

Shelton and Long both hope that more research from experiments at the LHC will be the key to building a more complete picture of our early universe.

LHC experiments could discover that the Higgs field served as the lock that halted the early universe’s perpetually evolving and devolving particle soup—especially if the field contained bubbles that froze faster than others, providing cosmic petri dishes in which matter and antimatter could evolve differently, Long says. “More measurements of the Higgs boson and the fundamental properties of matter and antimatter will help us develop better theories and a better understanding of what and where we come from.”

What exactly transpired during the birth of our universe may always remain a bit of an enigma, but we continue to seek new pieces of this formidable puzzle.

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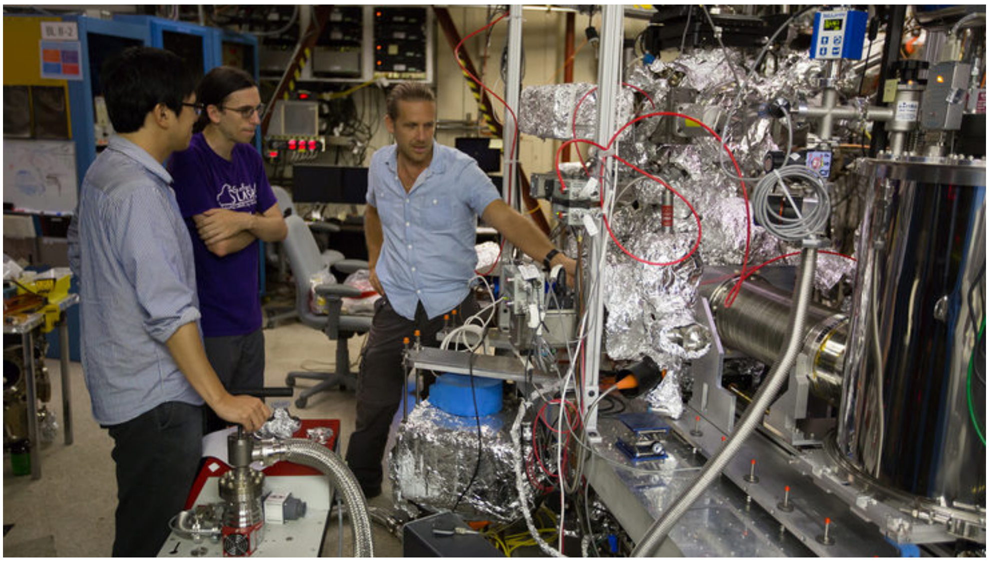
Instrument finds new earthly purpose (http://www.symmetrymagazine.org/article/instrument-finds-new-earthly-purpose?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Feb 23, 2017

Detectors long used to look at the cosmos are now part of X-ray experiments here on Earth.

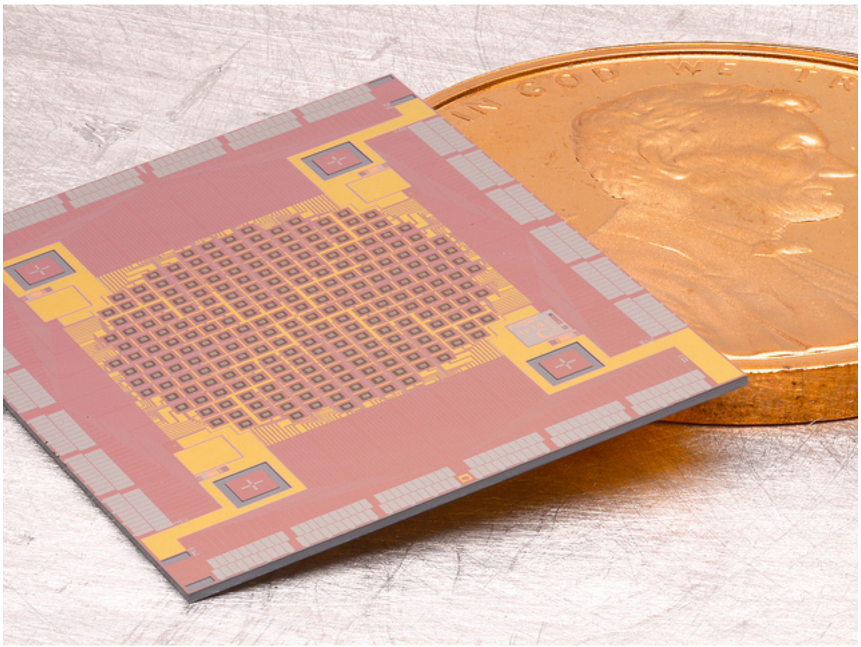


Modern cosmology experiments—such as the BICEP instruments and the Keck Array in Antarctica—rely on superconducting photon detectors to capture signals from the early universe.

These detectors, called transition edge sensors, are kept at temperatures near absolute zero, at only tenths of a Kelvin. At this temperature, the "transition" between superconducting and normal states, the sensors function like an extremely sensitive thermometer. They are able to detect heat from cosmic microwave background radiation, the glow emitted after the Big Bang, which is only slightly warmer at around 3 Kelvin.

Scientists also have been experimenting with these same detectors to catch a different form of light, says Dan Swetz, a scientist at the National Institute of Standards and Technology. These sensors also happen to work quite well as extremely sensitive X-ray detectors.

NIST scientists, including Swetz, design and build the thin, superconducting sensors and turn them into pixelated arrays smaller than a penny. They construct an entire X-ray spectrometer system around those arrays, including a cryocooler, a refrigerator that can keep the detectors near absolute zero temperatures.



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TES array and cover shown with penny coin for scale.

Dan Schmidt, NIST

Over the past several years, these X-ray spectrometers built at the NIST Boulder MicroFabrication Facility have been installed at three synchrotrons at US Department of Energy national laboratories: the National Synchrotron Light Source at Brookhaven National Laboratory, the Advanced Photon Source at Argonne National Laboratory and most recently at the Stanford Synchrotron Radiation Lightsource at SLAC National Accelerator Laboratory.

Organizing the transition edge sensors into arrays made a more powerful detector. The prototype sensor—built in 1995—consisted of only one pixel.

These early detectors had poor resolution, says physicist Kent Irwin of Stanford University and SLAC. He built the original single-pixel transition edge sensor as a postdoc. Like a camera, the detector can capture greater detail the more pixels it has.

"It's only now that we're hitting hundreds of pixels that it's really getting useful," Irwin says. "As you keep increasing the pixel count, the science you can do just keeps multiplying. And you start to do things you didn't even conceive of being possible before."

Each of the 240 pixels is designed to catch a single photon at a time. These detectors are efficient, says Irwin, collecting photons that may be missed with more conventional detectors.

Spectroscopy experiments at synchrotrons examine subtle features of matter using X-rays. In these types of experiments, an X-ray beam is directed at a sample. Energy from the X-rays temporarily excites the electrons in the sample, and when the electrons return to their lower energy state, they release photons. The photons' energy is distinctive for a given chemical element and contains detailed information about the electronic structure.

As the transition edge sensor captures these photons, every individual pixel on the detector functions as a high-energy-resolution spectrometer, able to determine the energy of each photon collected.

The researchers combine data from all the pixels and make note of the pattern of detected photons across the entire array and each of their energies. This energy spectrum reveals information about the molecule of interest.

These spectrometers are 100 times more sensitive than standard spectrometers, says Dennis Nordlund, SLAC scientist and leader of the transition edge sensor project at SSRL. This allows a look at biological and chemical details at extremely low concentrations using soft (low-energy) X-rays.

“These technology advances mean there are many things we can do now with spectroscopy that were previously out of reach,” Nordlund says. “With this type of sensitivity, this is when it gets really interesting for chemistry.”

Nordlund and his colleagues—Sangjun Lee, a SLAC postdoctoral research fellow, and Jamie Titus, a Stanford University doctoral student (pictured above at SSRL, from left: Lee, Titus and Nordlund)—have already used the transition-edge-sensor spectrometer at SSRL to probe for nitrogen impurities in nanodiamonds and graphene, as well as closely examine the metal centers of proteins and bioenzymes, such as hemoglobin and photosystem II. The project at SLAC was developed with ?support by the Department of Energy’s Laboratory Directed Research and Development.

The early experiments at Brookhaven looked at bonding and the chemical structure of nitrogen-bearing explosives. With the spectrometer at Argonne, a research team recently took scattering measurements on high-temperature superconducting materials.

“The instruments are very similar from a technical standpoint—same number of sensors, similar resolution and performance,” Swetz says. “But it’s interesting, the labs are all doing different science with the same basic equipment.”

At NIST, Swetz says they’re working to pair these detectors with less intense light sources, which could enable researchers to do X-ray experiments in their personal labs.

There are plans to build transition-edge-sensor spectrometers that will work in the higher energy hard X-ray region, which scientists at Argonne are working on for the next upgrade of Advanced Photon Source.

To complement this, the SLAC and NIST collaboration is engineering spectrometers that will handle the high repetition rate of X-ray laser pulses such as LCLS-II, the next generation of the free-electron X-ray laser at SLAC. This will require faster readout systems. The goal is to create a transition-edge-sensor array with as many as 10,000 pixels that can capture more than 10,000 pulses per second.

Irwin points out that the technology developed for synchrotrons, LCLS-II and future cosmic-microwave-background experiments provides shared benefit.

“The information really keeps bouncing back and forth between X-ray science and cosmology,” Irwin says.

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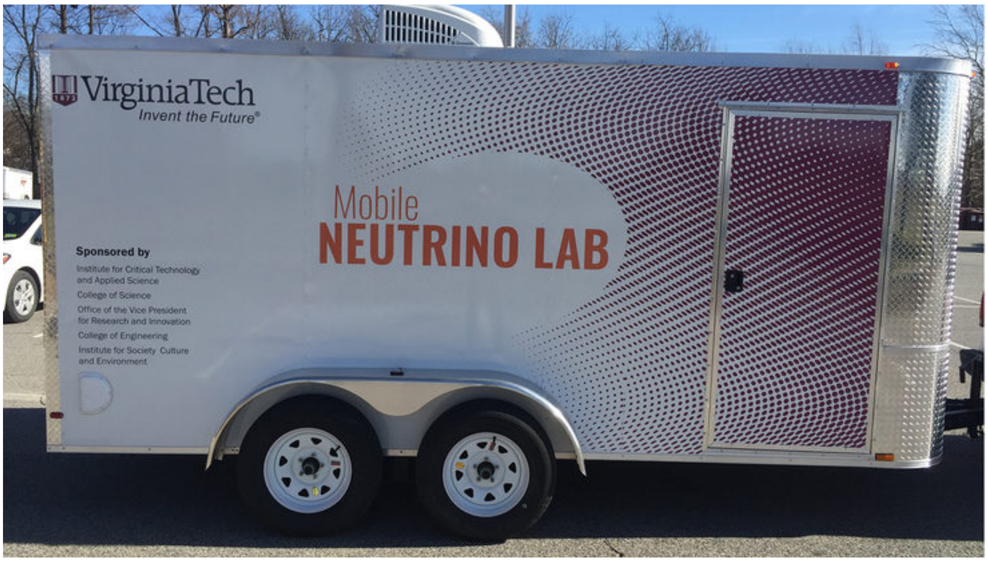
Mobile Neutrino Lab makes its debut (http://www.symmetrymagazine.org/article/mobile-neutrino-lab-makes-its-debut?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Feb 21, 2017

The Mystery Machine for particles hits the road.



It’s not as flashy as Scooby Doo’s Mystery Machine, but scientists at Virginia Tech hope that their new vehicle will help solve mysteries about a ghost-like phenomenon: neutrinos.

The Mobile Neutrino Lab (http://cnp.phys.vt.edu/mnl/) is a trailer built to contain and transport a 176-pound neutrino detector named MiniCHANDLER (Carbon Hydrogen AntiNeutrino Detector with a Lithium Enhanced Raghavan-optical-lattice). When it begins operations in mid-April, MiniCHANDLER will make history as the first mobile neutrino detector in the US.

“Our main purpose is just to see neutrinos and measure the signal to noise ratio,” says Jon Link, a member of the experiment and a professor of physics at Virginia Tech’s Center for Neutrino Physics. “We just want to prove the detector works.”

Neutrinos are fundamental particles with no electric charge, a property that makes them difficult to detect. These elusive particles have confounded scientists on several fronts for more than 60 years. MiniCHANDLER is specifically designed to detect neutrinos' antimatter counterparts, antineutrinos, produced in nuclear reactors, which are prolific sources of the tiny particles.

Fission at the core of a nuclear reactor splits uranium atoms, whose products themselves undergo a process that emits an electron and electron antineutrino. Other, larger detectors such as Daya Bay have capitalized on this abundance to measure neutrino properties.

MiniCHANDLER will serve as a prototype for future mobile neutrino experiments up to 1 ton in size.

Link and his colleagues hope MiniCHANDLER and its future counterparts will find answers to questions about sterile neutrinos, an undiscovered, theoretical kind of neutrino and a candidate for dark matter. The detector could also have applications for national security by serving as a way to keep tabs on material inside of nuclear reactors.

MiniCHANDLER echoes a similar mobile detector concept from a few years ago. In 2014, a Japanese team published results from another mobile neutrino detector, but their data did not meet the threshold for statistical significance. Detector operations were halted after all reactors in Japan were shut down for safety inspections.

“We can monitor the status from outside of the reactor buildings thanks to [a] neutrino’s strong penetration power,” Shugo Oguri, a scientist who worked on the Japanese team, wrote in an email.

Link and his colleagues believe their design is an improvement, and the hope is that MiniCHANDLER will be able to better reject background events and successfully detect neutrinos.

Neutrinos, where are you?

To detect neutrinos, which are abundant but interact very rarely with matter, physicists typically use huge structures such as Super-Kamiokande, a neutrino detector in Japan that contains 50,000 tons of ultra-pure water. Experiments are also often placed far underground to block out signals from other particles that are prevalent on Earth’s surface.

With its small size and aboveground location, MiniCHANDLER subverts both of these norms.

The detector uses solid scintillator technology, which will allow it to record about 100 antineutrino interactions per day. This interaction rate is less than the rate at large detectors, but MiniCHANDLER makes up for this with its precise tracking of antineutrinos.

Small plastic cubes pinpoint where in MiniCHANDLER an antineutrino interacts by detecting light from the interaction. However, the same kind of light signal can also come from other passing particles like cosmic rays. To distinguish between the antineutrino and the riffraff, Link and his colleagues look for multiple signals to confirm the presence of an antineutrino.

Those signs come from a process called inverse beta decay. Inverse beta decay occurs when an antineutrino collides with a proton, producing light (the first event) and also kicking a neutron out of the nucleus of the atom. These emitted neutrons are slower than the light and are picked up as a secondary signal to confirm the antineutrino interaction.

“[MiniCHANDLER] is going to sit on the surface; it's not shielded well at all. So it's going to have a lot of background,” Link says. “Inverse beta decay gives you a way of rejecting the background by identifying the two-part event.”

Monitoring the reactors

Scientists could find use for a mobile neutrino detector beyond studying reactor neutrinos. They could also use the detector to measure properties of the nuclear reactor itself.

A mobile neutrino detector could be used to determine whether a reactor is in use, Oguri says. “Detection unambiguously means the reactors are in operation—nobody can cheat the status.”

The detector could also be used to determine whether material from a reactor has been repurposed to produce nuclear weapons. Plutonium, an element used in the process of making weapons-grade nuclear material, produces 60 percent fewer detectable neutrinos than uranium, the primary component in a reactor core.

“We could potentially tell whether or not the reactor core has the right amount of plutonium in it,” Link says.

Using a neutrino detector would be a non-invasive way to track the material; other methods of testing nuclear reactors can be time-consuming and disruptive to the reactor’s processes.

But for now, Link just wants MiniCHANDLER to achieve a simple—yet groundbreaking—goal: Get the mobile neutrino lab running.

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#AskSymmetry Twitter chat with Anne Schukraft (http://www.symmetrymagazine.org/article/asksymmetry-twitter-chat-with-anne-schukraft?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Feb 17, 2017

See Fermilab physicist Anne Schukraft's answers to readers’ questions about neutrinos.

Scientist Anne Schukraft surrounded by Harry Potter-inspired imagery and the phrase

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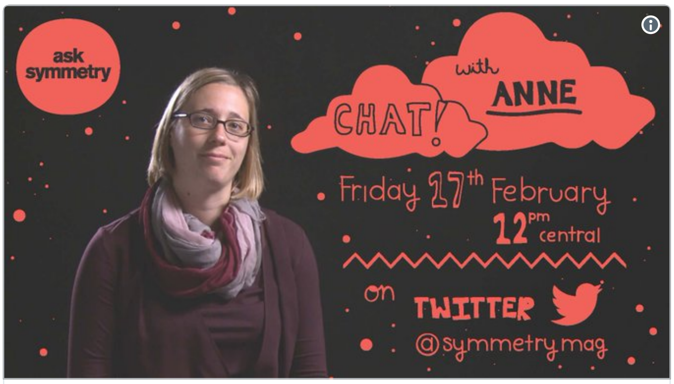

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Starting soon! Scientist Anne Schukraft is taking over our handle to talk all things neutrino. Get your questions ready for #AskSymmetry!

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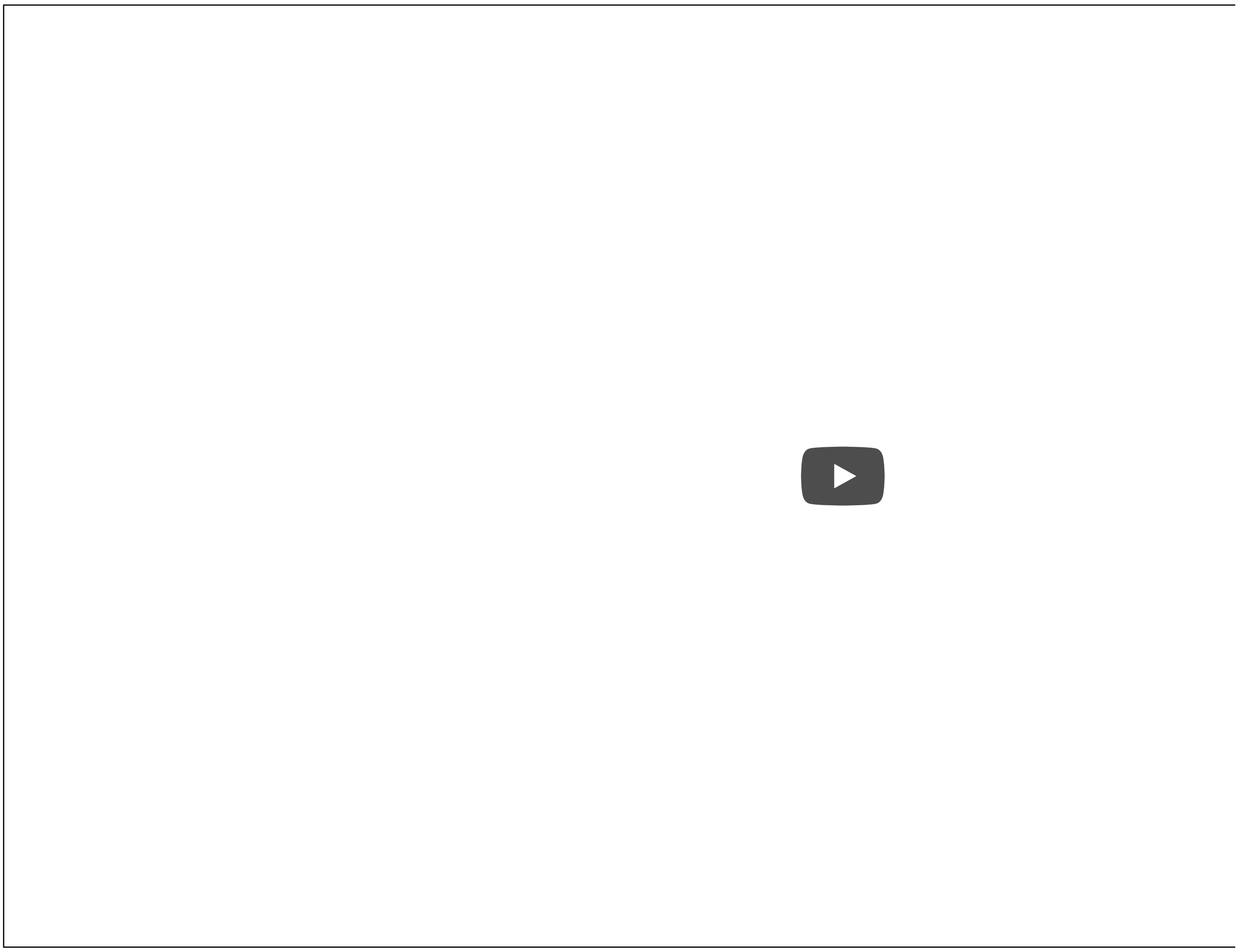
Wizardly neutrinos (http://www.symmetrymagazine.org/article/wizardly-neutrinos?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Feb 16, 2017

Why can a neutrino pass through solid objects?

Scientist Anne Schukraft surrounded by Harry Potter-inspired imagery and the phrase
Physicist Anne Schukraft of Fermi National Accelerator Laboratory explains.



Have a burning question about particle physics? Let us know via email (mailto:info@symmetrymagazine.org?subject=%23AskSymmetry) or Twitter (https://twitter.com/symmetrymag) (using the hashtag #AskSymmetry). We might answer you in a future video!

You can watch a playlist of the #AskSymmetry videos here (https://www.youtube.com/watch?v=ZvrVhB_kEqA&list=PLVuf4hejm7rVZMMwarDwTYknZXA120jyJ). You can see Anne Schukraft's answers to readers' questions about neutrinos on Twitter here (http://www.symmetrymagazine.org/article/asksymmetry-twitter-chat-with-anne-schukraft).?

Read More... (http://www.symmetrymagazine.org/article/wizardly-neutrinos?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

LHCb observes rare decay (http://www.symmetrymagazine.org/article/lhcb-observes-rare-decay?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Feb 14, 2017

Standard Model predictions align with the LHCb experiment’s observation of an uncommon decay.

The Standard Model is holding strong after a new precision measurement of a rare subatomic process.

For the first time, the LHCb experiment at CERN has independently observed (http://lhcb-public.web.cern.ch/lhcb-public/Welcome.html#BsMuMu2017) the decay of the B_s^0 particle—a heavy composite particle consisting of a bottom antiquark and a strange quark—into two muons. The LHCb experiment co-discovered (http://www.symmetrymagazine.org/article/may-2015/lhc-experiments-first-to-observe-rare-process) this rare process in 2015 after combining results with the CMS experiment.

Theorists predicted that this particular decay would occur only a few times out of a billion.

“Our measurement is slightly lower than predictions, but well within the range of experimental uncertainty and fully compatible with our models,” says Flavio Archilli, one of the co-leaders of this analysis and a postdoc at Nikhef National Institute for Subatomic Physics. “The theoretical predictions are very accurate, so now we want to improve our precision to see if our measurement is sitting right on top of the expected value or slightly outside, which could be an indication of new physics.”

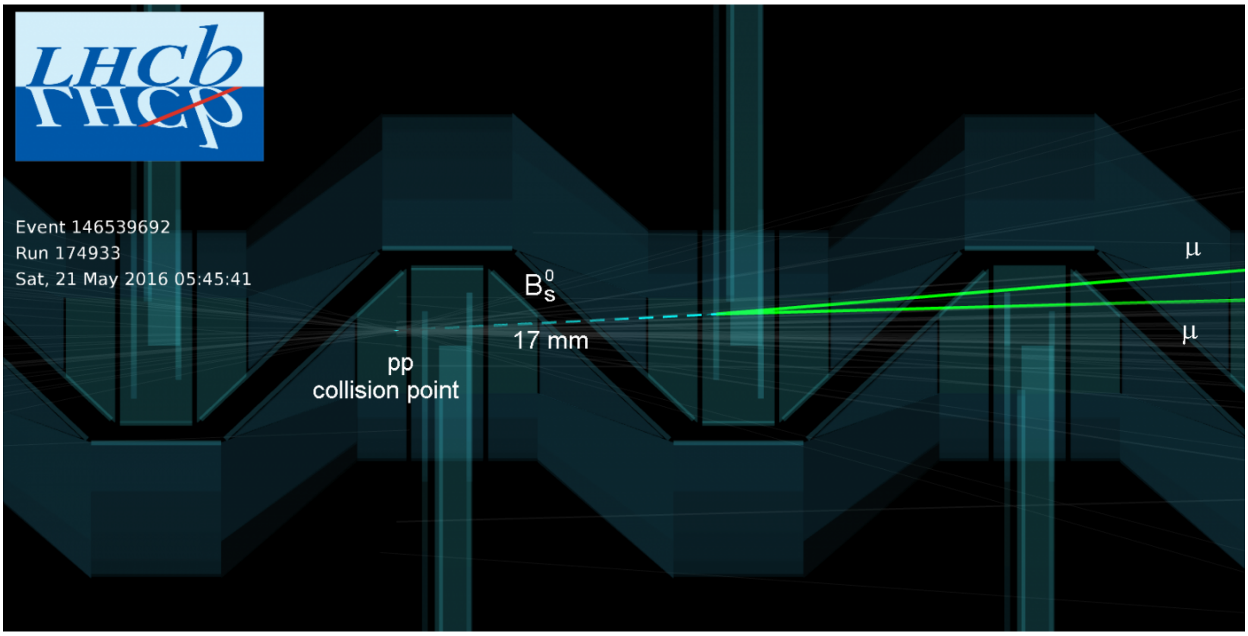
The LHCb experiment examines the properties and decay patterns of particles to search for cracks in the Standard Model, our best description of the fundamental particles and forces. Any deviations from the Standard Model’s predictions could be evidence of new physics at play.

Supersymmetry, for example, is a popular theory that adds a host of new particles to the Standard Model and ameliorates many of its shortcomings—such as mathematical imbalances between how the different types of particles contribute to subatomic interactions.

“We love this decay because it is one of the most promising places to search for any new effects of supersymmetry,” Archilli says. “Scientists searched for this decay for more than 30 years and now we finally have the first single-experiment observation.”

This new measurement by the LHCb experiment combines data taken from Run 1 and Run 2 of the Large Hadron Collider and employs more refined analysis techniques, making it the most precise measurement of this process to date. In addition to measuring the rate of this rare decay, LHCb researchers also measured how long the B_s^0 particle lives before it transforms into the two muons—another measurement that agrees with the Standard Model's predictions.

"It's gratifying to have achieved these results," says Universita di Pisa scientist Matteo Rama, one of the co-leaders of this analysis. "They reward the efforts made to improve the analysis techniques, to exploit our data even further. We look forward to updating the measurement with more data with the hope to observe, one day, significant deviations from the Standard Model predictions."



(http://www.symmetrymagazine.org/sites/default/files/images/standard/bsmumuvertex.png)

Event display of a typical Bs0 decay into two muons. The two muon tracks from the Bs0 decay are seen as a pair of green tracks traversing the whole detector.

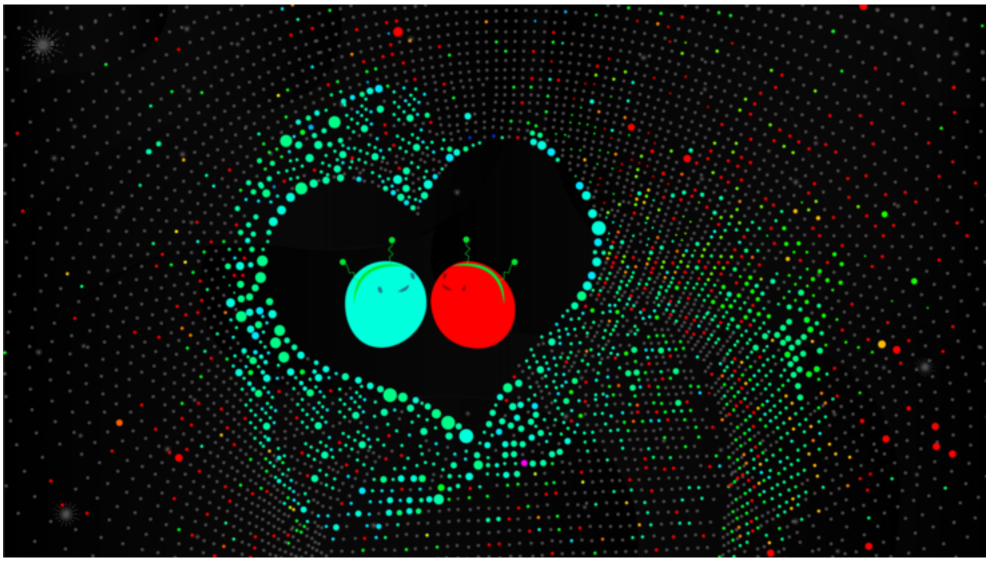
LHCb collaboration

Read More... (http://www.symmetrymagazine.org/article/lhcb-observes-rare-decay?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Physics love poems (http://www.symmetrymagazine.org/article/physics-love-poems?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Feb 14, 2017

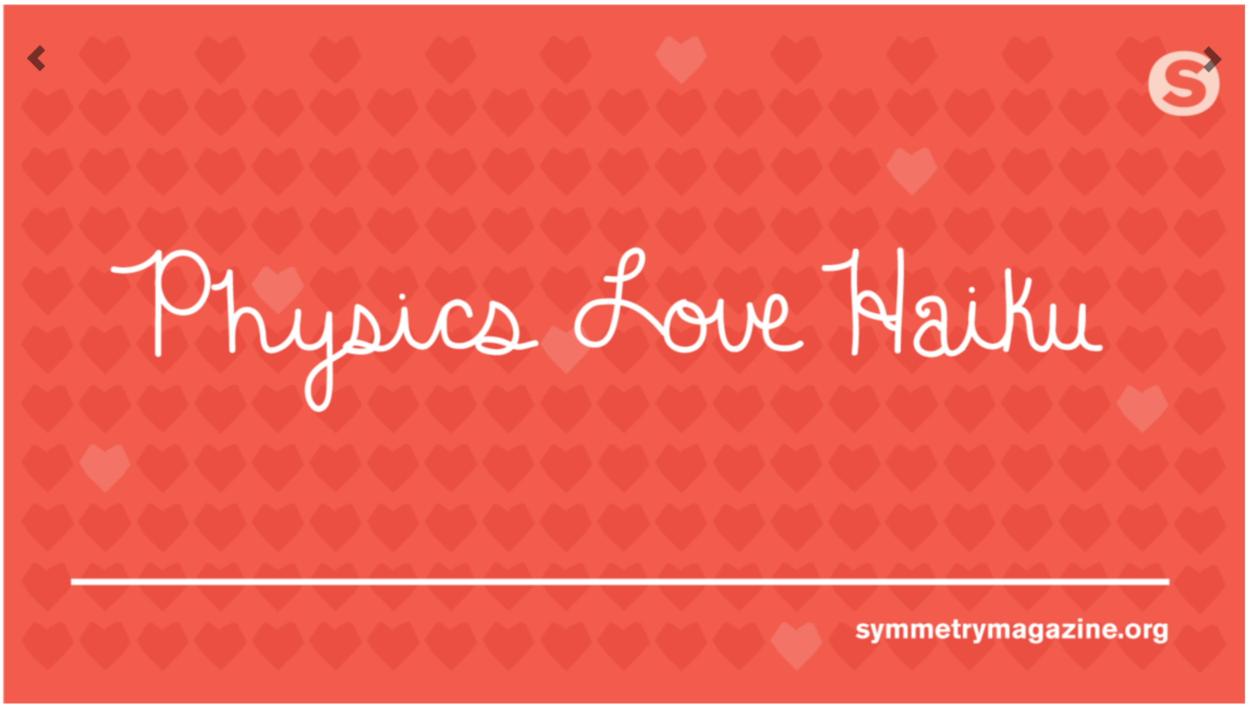
Advance your romance with science.



This Valentine's Day, we challenged our readers to send us physics-inspired love poems. You answered the call: We received dozens of submissions—in four different languages! You can find some of our favorite entries below.

But first, as a warm-up, enjoy a video of real scientists at Fermi National Accelerator Laboratory reciting physics-related Valentine's Day haiku:

Or read the haiku for yourself:



Artwork by Sandbox Studio, Chicago

Reader poems

Thanks to all of our readers who submitted poems! In no particular order, here are some of our favorites:

For now, I'm seeing other quarks, some charming and some strange
But when we meet, I know we will all physics rearrange
For you, stop squark, will soon reveal the standard model as deficient
To me, you are my superpartner; the only one sufficient.
Without you, I just spin one-half of what our world could be

But you and I will couple soon in perfect symmetry.
All fundamental forces, we are meant to unify
In brilliant theory only love itself could clarify
Now though I may seem hypercharged and strongly interactive,
I must show my true colors if I hope to be attractive.
Without you, I just don't feel really quite just like a top
But I'm confident I will yet find love in the name of stop.

- Jared Sagoff

The gravity that
Pulls my soul to you dilates:
Your beauty slows time.

- Philip Michaels

A Valentine for Two Quarks

Some people wish for one true love,
like dear old Ma and Pa.
That lifestyle's not for us; we like
our quark ménage à trois.

You see, some like a threesome,
and I love both of you.
No green quark would be seen without
a red quark and a blue.

The sea is full of other quarks,
but darlings, I don't heed 'em.
You must believe I don't exploit
my asymptotic freedom.

And when you pull away from me,
I just can't take the stress.
My attraction just grows stronger
(coefficient alpha-s).

With you, my life is colourless;
you bring stability.
Without you, I'm unstable,
so I need you, Q.C.D.

I love our quirky, quarky love.
My Valentines, let's carry on
exchanging gluons wantonly,
and make a little baryon.

- Cheryl Patrick

Will it work this time?
The wavefunction collapses.
Single once again.

- Anonymous

Our hearts were once close; two nucleons held tight
By a force that was strong, and a love that burned bright.
But, that force became weaker as the days faded 'way,
And with it, our bond began to decay.

I've realize that opposites don't always attract
(Otherwise, the atom would be more compact),
And opposites we were, our differences great,
Continuing this way, we'd annihilate.

In truth, I've quite had it with your duality,
Your warm disposition; cold mentality.
We must be entangled - what else can explain
How, though we are distant, you still cause me pain?

We've exchanged mediators, but our half-lives were short,
All data suggests we should promptly abort.
Our collision is over, and signatures thereof
Have vanished, leaving us not a quantum of love.

- Peter Voznyuk

Love ignited light,
Eternal and everywhere:
A Cosmic Background

- Akshay Jogoo

Like energy dear
our love will last forever,
theoretically

- L. Brennan

Read More... (http://www.symmetrymagazine.org/article/physics-love-poems?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

LZ dark matter detector on fast track (http://www.symmetrymagazine.org/article/lz-dark-matter-detector-on-fast-track?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Feb 13, 2017

Construction has officially launched for the LZ next-generation dark matter experiment.

The race is on to build the most sensitive US-based experiment designed to directly detect dark matter particles. Department of Energy officials have formally approved a key construction milestone that will propel the project toward its April 2020 goal for completion.

The LUX-ZEPLIN experiment, which will be built nearly a mile underground at the Sanford Underground Research Facility in Lead, South Dakota, is considered one of the best bets yet to determine whether theorized dark matter particles known as WIMPs (weakly interacting massive particles) actually exist.

The fast-moving schedule for LZ will help the US stay competitive with similar next-gen dark matter direct-detection experiments planned in Italy and China.

On February 9, the project passed a DOE review and approval stage known as Critical Decision 3, which accepts the final design and formally launches construction.

“We will try to go as fast as we can to have everything completed by April 2020,” says Murdock “Gil” Gilchriese, LZ project director and a physicist at Lawrence Berkeley National Laboratory, the lead lab for the project. “We got a very strong endorsement to go fast and to be first.” The LZ collaboration now has about 220 participating scientists and engineers who represent 38 institutions around the globe.

The nature of dark matter—which physicists describe as the invisible component or so-called “missing mass” in the universe —has eluded scientists since its existence was deduced through calculations by Swiss astronomer Fritz Zwicky in 1933.

The quest to find out what dark matter is made of, or to learn whether it can be explained by tweaking the known laws of physics in new ways, is considered one of the most pressing questions in particle physics.

Successive generations of experiments have evolved to provide extreme sensitivity in the search that will at least rule out some of the likely candidates and hiding spots for dark matter, or may lead to a discovery.

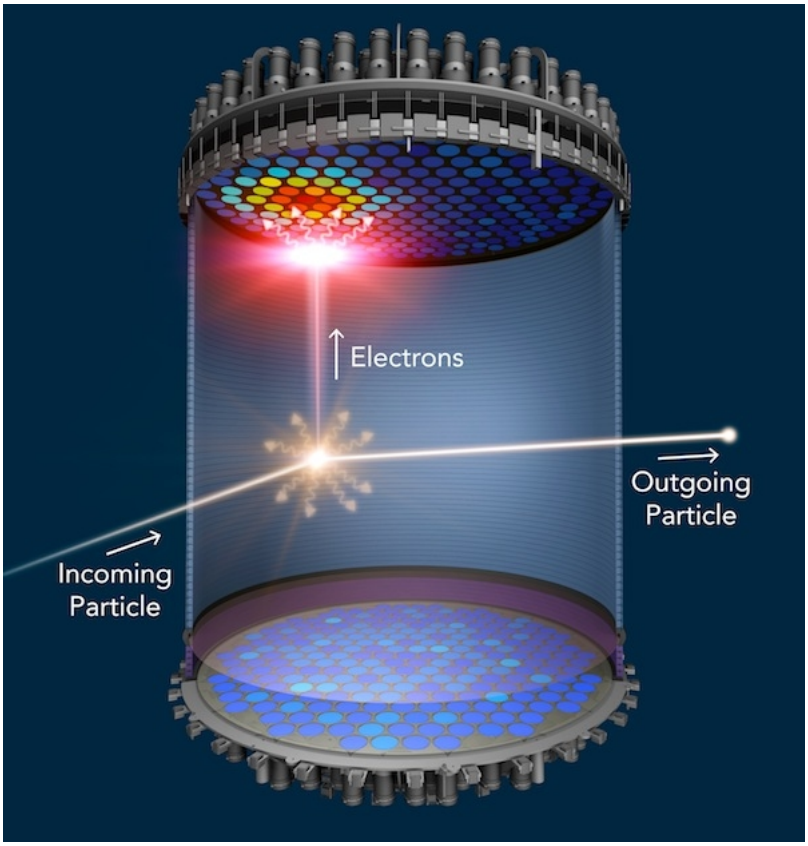
LZ will be at least 50 times more sensitive to finding signals from dark matter particles than its predecessor, the Large Underground Xenon experiment, which was removed from Sanford Lab last year to make way for LZ. The new experiment will use 10 metric tons of ultra-purified liquid xenon to tease out possible dark matter signals.

“The science is highly compelling, so it’s being pursued by physicists all over the world,” says Carter Hall, the spokesperson for the LZ collaboration and an associate professor of physics at the University of Maryland. “It's a friendly and healthy competition, with a major discovery possibly at stake.”

A planned upgrade to the current XENON1T experiment at National Institute for Nuclear Physics’ Gran Sasso Laboratory in Italy, and China's plans to advance the work on PandaX-II, are also slated to be leading-edge underground experiments that will use liquid xenon as the medium to seek out a dark matter signal. Both of these projects are expected to have a similar schedule and scale to LZ, though LZ participants are aiming to achieve a higher sensitivity to dark matter than these other contenders.

Hall notes that while WIMPs are a primary target for LZ and its competitors, LZ’s explorations into uncharted territory could lead to a variety of surprising discoveries. “People are developing all sorts of models to explain dark matter,” he says. “LZ is optimized to observe a heavy WIMP, but it’s sensitive to some less-conventional scenarios as well. It can also search for other exotic particles and rare processes.”

LZ is designed so that if a dark matter particle collides with a xenon atom, it will produce a prompt flash of light followed by a second flash of light when the electrons produced in the liquid xenon chamber drift to its top. The light pulses, picked up by a series of about 500 light-amplifying tubes lining the massive tank—over four times more than were installed in LUX—will carry the telltale fingerprint of the particles that created them.



(http://www.symmetrymagazine.org/sites/default/files/images/standard/lz_science_final-SLAC.jpg)

When a theorized dark matter particle known as a WIMP collides with a xenon atom, the xenon atom emits a flash of light (gold) and electrons. The flash of light is detected at the top and bottom of the liquid xenon chamber. An electric field pushes the electrons to the top of the chamber, where they generate a second flash of light (red).

SLAC National Accelerator Laboratory

Daniel Akerib, Thomas Shutt and Maria Elena Monzani are leading the LZ team at SLAC National Accelerator Laboratory. The SLAC effort includes a program to purify xenon for LZ by removing krypton, an element that is typically found in trace amounts with xenon after standard refinement processes. "We have already demonstrated the purification required for LZ and are now working on ways to further purify the xenon to extend the science reach of LZ," Akerib says.

SLAC and Berkeley Lab collaborators are also developing and testing hand-woven wire grids that draw out electrical signals produced by particle interactions in the liquid xenon tank. Full-size prototypes will be operated later this year at a SLAC test platform. "These tests are important to ensure that the grids don't produce low-level electrical discharge when operated at high voltage, since the discharge could swamp a faint signal from dark matter," Shutt says.

Hugh Lippincott, a Wilson Fellow at Fermi National Accelerator Laboratory and the physics coordinator for the LZ collaboration, says, "Alongside the effort to get the detector built and taking data as fast as we can, we're also building up our simulation and data analysis tools so that we can understand what we'll see when the detector turns on. We want to be ready for physics as soon as the first flash of light appears in the xenon." Fermilab is responsible for implementing key parts of the critical system that handles, purifies, and cools the xenon.

All of the components for LZ are painstakingly measured for naturally occurring radiation levels to account for possible false signals coming from the components themselves. A dust-filtering cleanroom is being prepared for LZ's assembly and a radon-reduction building is under construction at the South Dakota site—radon is a naturally occurring radioactive gas that could interfere with dark matter detection. These steps are necessary to remove background signals as much as possible.

The vessels that will surround the liquid xenon, which are the responsibility of the UK participants of the collaboration, are now being assembled in Italy. They will be built with the world's most ultra-pure titanium to further reduce background noise.

To ensure unwanted particles are not misread as dark matter signals, LZ's liquid xenon chamber will be surrounded by another liquid-filled tank and a separate array of photomultiplier tubes that can measure other particles and largely veto false signals. Brookhaven National Laboratory is handling the production of another very pure liquid, known as a scintillator fluid, that will go into this tank.

The cleanrooms will be in place by June, Gilchriese says, and preparation of the cavern where LZ will be housed is underway at Sanford Lab. Onsite assembly and installation will begin in 2018, he adds, and all of the xenon needed for the project has either already been delivered or is under contract. Xenon gas, which is costly to produce, is used in lighting, medical imaging and anesthesia, space-vehicle propulsion systems, and the electronics industry.

"South Dakota is proud to host the LZ experiment at SURF and to contribute 80 percent of the xenon for LZ," says Mike Headley, executive director of the South Dakota Science and Technology Authority (SDSTA) that oversees the facility. "Our facility work is underway and we're on track to support LZ's timeline."

UK scientists, who make up about one-quarter of the LZ collaboration, are contributing hardware for most subsystems. Henrique Araújo, from Imperial College London, says, "We are looking forward to seeing everything come together after a long period of design and planning."

Kelly Hanzel, LZ project manager and a Berkeley Lab mechanical engineer, adds, "We have an excellent collaboration and team of engineers who are dedicated to the science and success of the project." The latest approval milestone, she says, "is probably the most significant step so far," as it provides for the purchase of most of the major components in LZ's supporting systems.

Major support for LZ comes from the DOE Office of Science's Office of High Energy Physics, South Dakota Science and Technology Authority, the UK's Science & Technology Facilities Council, and by collaboration members in South Korea and Portugal.

Editor's note: This article is based on a press release (http://newscenter.lbl.gov/2017/02/13/next-gen-dark-matter-detector-race-finish-line/) published by Berkeley Lab.

Read More... (http://www.symmetrymagazine.org/article/lz-dark-matter-detector-on-fast-track?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Physics love poem challenge (http://www.symmetrymagazine.org/article/physics-love-poem-challenge?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Feb 10, 2017

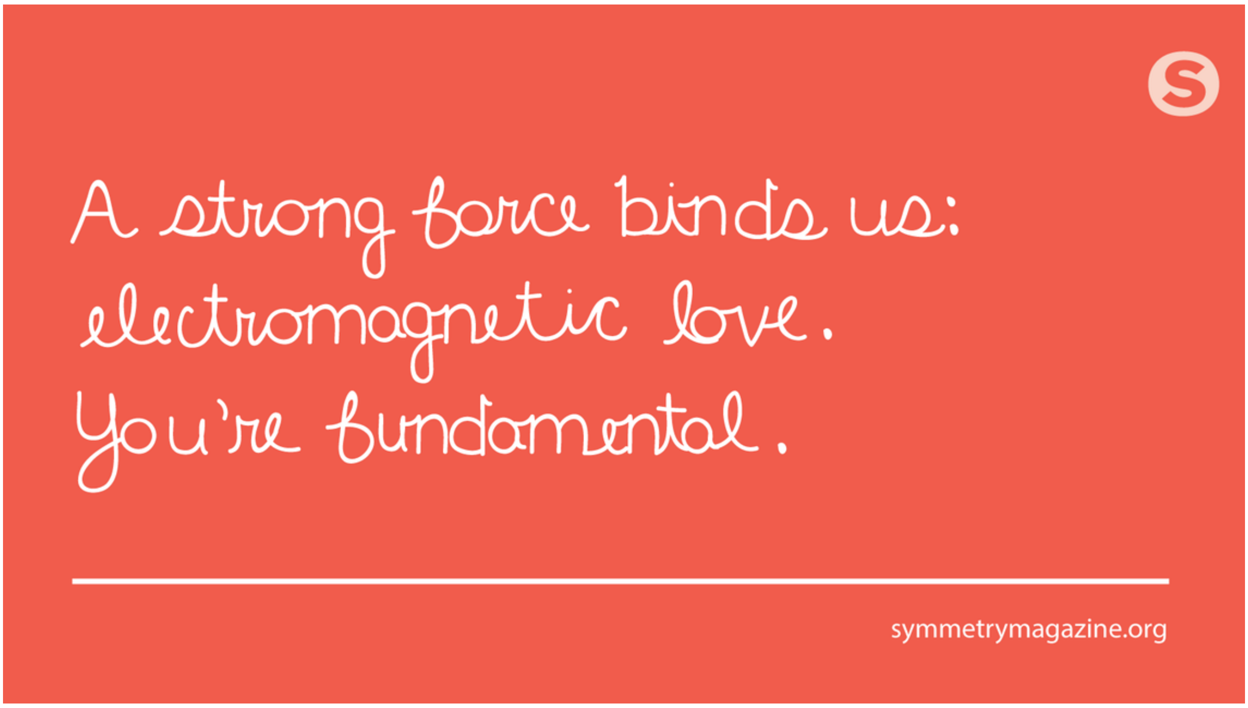
Think you can do better than the *Symmetry* staff? Send us your poems!

Has the love of your life fallen for particle physics? Let the *Symmetry* team help you reach their heart—with haiku.

On Valentine's Day, we will publish a collection of physics-related love poems written by *Symmetry* staff and—if you are so inclined—by readers like you!

Send your poems (haiku format optional) to letters@symmetrymagazine.org (mailto:letters@symmetrymagazine.org) by Monday, February 13, at 10 a.m. Central. If we really like yours, we may send you a prize.

For inspiration, consider the following:



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Sandbox Studio, Chicago with Colleen Ehrhart

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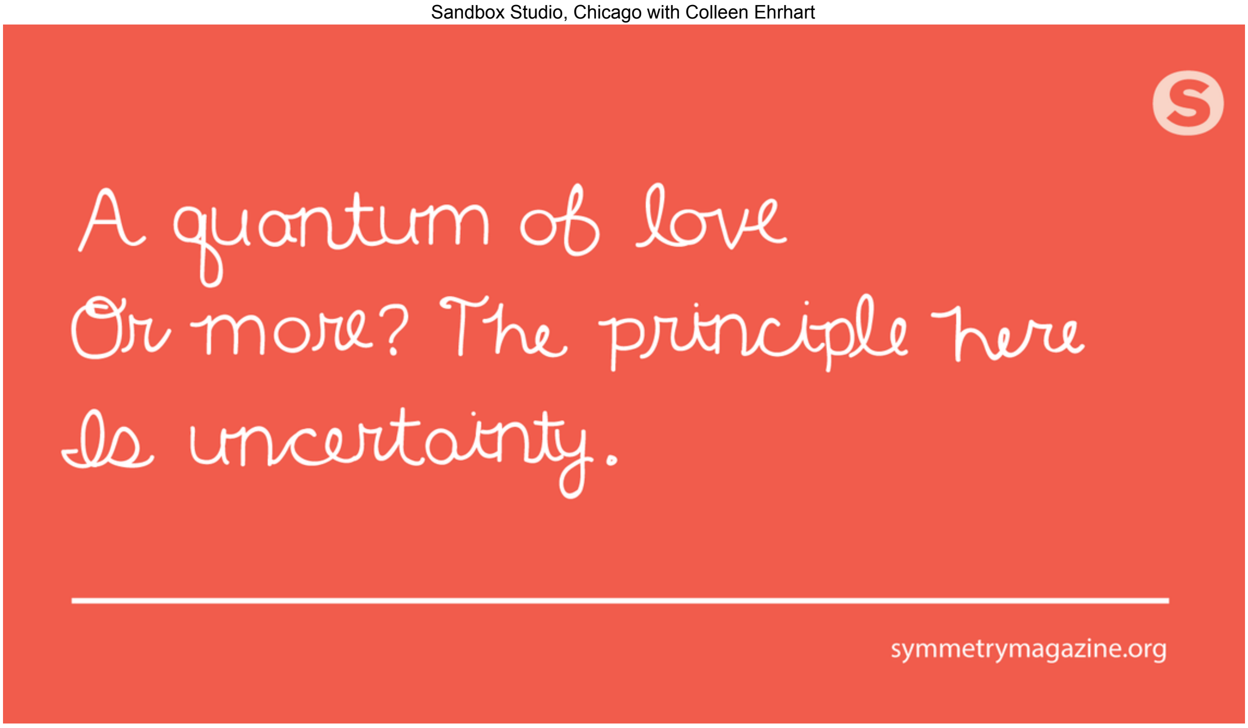
Sandbox Studio, Chicago with Colleen Ehrhart



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Sandbox Studio, Chicago with Colleen Ehrhart

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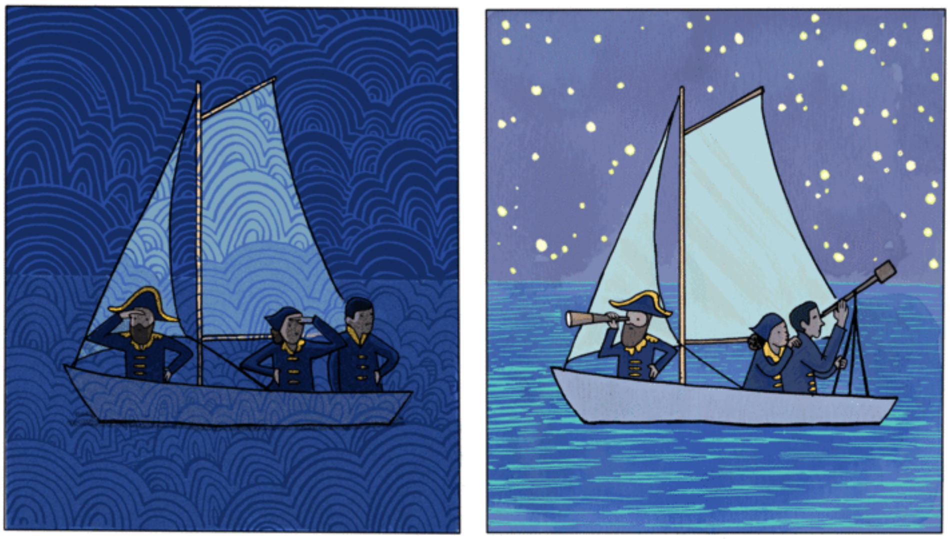
What ended the dark ages of the universe? (http://www.symmetrymagazine.org/article/what-ended-the-dark-ages-of-the-universe?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Feb 7, 2017

New experiments will help astronomers uncover the sources that helped make the universe transparent.



When we peer through our telescopes into the cosmos, we can see stars and galaxies reaching back billions of years. This is possible only because the intergalactic medium we're looking through is transparent. This was not always the case.

Around 380,000 years after the Big Bang came recombination, when the hot mass of particles that made up the universe cooled enough for electrons to pair with protons, forming neutral hydrogen. This brought on the dark ages, during which the neutral gas in the intergalactic medium absorbed most of the high-energy photons around it, making the universe opaque to these wavelengths of light.

Then, a few hundred million years later, new sources of energetic photons appeared, stripping hydrogen atoms of their electrons and returning them to their ionized state, ultimately allowing light to easily travel through the intergalactic medium. After this era of reionization was complete, the universe was fully transparent once again.

Physicists are using a variety of methods to search for the sources of reionization, and finding them will provide insight into the first galaxies, the structure of the early universe and possibly even the properties of dark matter.

Energetic sources

Current research suggests that most—if not all—of the ionizing photons came from the formation of the first stars and galaxies. "The reionization process is basically a competition between the rate at which stars produce ionizing radiation and the recombination rate in the intergalactic medium," says Brant Robertson, a theoretical astrophysicist at the University of California, Santa Cruz.

However, astronomers have yet to find these early galaxies, leaving room for other potential sources. The first stars alone may not have been enough. "There are undoubtedly other contributions, but we argue about how important those contributions are," Robertson says.

Active galactic nuclei, or AGN, could have been a source of reionization. AGN are luminous bodies, such as quasars, that are powered by black holes and release ultraviolet radiation and X-rays. However, scientists don't yet know how abundant these objects were in the early universe.

Another, more exotic possibility, is dark matter annihilation. In some models of dark matter, particles collide with each other, annihilating and producing matter and radiation. "If through this channel or something else we could find evidence for dark matter annihilation, that would be fantastically interesting, because it would immediately give you an estimate of the mass of the dark matter and how strongly it interacts with Standard Model particles," says Tracy Slatyer, a particle physicist at MIT.

Dark matter annihilation and AGN may have also indirectly aided reionization by providing extra heat to the universe.

Probing the cosmic dawn

To test their theories of the course of cosmic reionization, astronomers are probing this epoch in the history of the universe using various methods including telescope observations, something called "21-centimeter cosmology" and probing the cosmic microwave background.

Astronomers have yet to find evidence of the most likely source of reionization—the earliest stars—but they're looking.

By assessing the luminosity of the first galaxies, physicists could estimate how many ionizing photons they could have released. "[To date] there haven't been observations of the actual galaxies that are reionizing the universe—even Hubble can't deliver any of those—but the hope is that the James Webb Space Telescope can," says John Wise, an astrophysicist at Georgia Tech.

Some of the most telling information will come from 21-centimeter cosmology, so called because it studies 21-centimeter radio waves. Neutral hydrogen gives off radio waves of this frequency, ionized hydrogen does not. Experiments such as the forthcoming Hydrogen Epoch of Reionization Array will detect neutral hydrogen using radio telescopes tuned to this frequency. This could provide clinching evidence about the sources of reionization.

"The basic idea with 21-centimeter cosmology is to not look at the galaxies themselves, but to try to make direct measurements of the intergalactic medium—the hydrogen between the galaxies," says Adrian Liu, a Hubble fellow at UC Berkeley. "This actually lets you, in principle, directly see reionization, [by seeing how] it affects the intergalactic medium."

By locating where the universe is ionized and where it is not, astronomers can create a map of how neutral hydrogen is distributed in the early universe. "If galaxies are doing it, then you would have ionized bubbles [around them]. If it is dark matter—dark matter is everywhere—so you're ionizing everywhere, rather than having bubbles of ionizing gas," says Steven Furlanetto, a theoretical astrophysicist at the University of California, Los Angeles.

Physicists can also learn about sources of reionization by studying the cosmic microwave background, or CMB.

When an atom is ionized, the electron that is released scatters and disrupts the CMB. Physicists can use this information to determine when reionization happened and put constraints on how many photons were needed to complete the process.

For example, physicists reported last year that data released from the Planck satellite was able to lower its estimate of how much ionization was caused by sources other than galaxies. “Just because you could potentially explain it with star-forming galaxies, it doesn't mean that something else isn't lurking in the data,” Slatyer says. “We are hopefully going to get much better measurements of the reionization epoch using experiments like the 21-centimeter observations.”

It is still too early to rule out alternative explanations for the sources of reionization, since astronomers are still at the beginning of uncovering this era in the history of our universe, Liu says. “I would say that one of the most fun things about working in this field is that we don't know exactly what happened.”

Read More... (http://www.symmetrymagazine.org/article/what-ended-the-dark-ages-of-the-universe?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Road trip science (http://www.symmetrymagazine.org/article/road-trip-science?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Feb 2, 2017

The Escaramujo Project delivered detector technology by van to eight universities in Latin America.

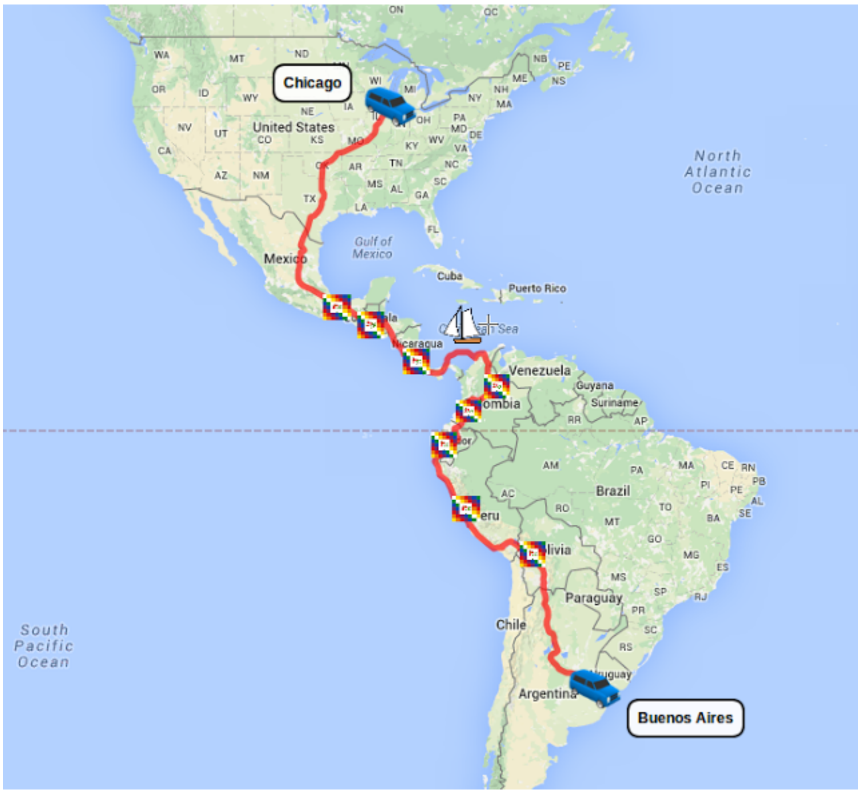
Professors and students of physics in Latin America have much to offer the world of physics. But for those interested in designing and building the complex experiments needed to gather physics data, hands-on experimentation in much of Central and South America has been lacking. It was that gap that something called the Escaramujo Project aimed to fill by bringing basic components to students who could then assemble them into fully functional detectors.

“It was something completely new,” says Luis Rodolfo Pérez Sánchez, a student at the Universidad Autónoma de Chiapas, Mexico, who is writing his thesis based on measurements taken with the detector. “Until now, there was no device at the university where one could work directly with their hands.”

Each group of students built a detector, which they used to measure cosmic-ray muons (particles coming from space). But they did more than that. They used a Linux open-source computer operating system for the first time, calibrated the equipment, plotted data using the software ROOT and became part of an international community. The students used their detectors to participate in International Cosmic Day, an annual event where scientists around the world measure cosmic rays and share their data.

The Escaramujo Project is led by Federico Izraelevitch, who worked at Fermi National Accelerator Laboratory near Chicago during its planning stages and is now a professor at Instituto Dan Beninson in Argentina. During the project, Izraelevitch and his wife, Eleonora, traveled with three canine companions on a road trip from Chicago to Buenos Aires, stopping to teach workshops in Mexico, Guatemala, Costa Rica, Colombia, Ecuador, Peru and Bolivia. Many nights found them in spots with no tourist lodging or even places to camp with their van.

“People received us with a smile and gave us a cup of coffee, or food, or whatever we needed at the time,” Izraelevitch says. “People are amazing.”



(http://www.symmetrymagazine.org/sites/default/files/images/standard/Chicago-BuenosAires_0.png)

Federico and Eleonora Izraelevitch traveled by van from Chicago to Buenos Aires.

Escaramujo Project

In many locations, students took their detector on a field trip shortly after assembling it. The group in Pasto, Colombia, turned theirs into a muon telescope and carted it to the nearby Galeras volcano, where a kind local lent them a power supply to get things running. They studied an effect of the volcano: muon attenuation, or weakening of the muon signal. Students in La Paz, Bolivia, placed the detector in the back of a van and drove it to a lofty observatory, measuring how the muon flux changed with altitude.

The Escaramujo Project forged direct connections between students at eight universities, who can now use their detectors to collect and share data with other Escaramujo participants.

“This state is one of the poorest states in Mexico,” says Karen Caballero, a professor at UNACH who brought the Escaramujo Project to the university. “The students in Chiapas don’t have the opportunity to participate in international initiatives, so this has been very, very important for them.”

Caballero says there are plans for the full Escaramujo cohort to use their detectors to calibrate expansions of the Latin American Giant Observatory, used for an experiment that began in 2005. LAGO uses multiple sites throughout Central and South America to study gamma-ray bursts, some of the most powerful explosions in the universe, as well as space weather.

While the workshops for the program wrapped up in early 2016, Izraelevitch says he hopes to visit more universities and lead more workshops in the future.

“Hopefully all these sites can continue growing and working as a collaboration in the future,” he says. “These people are capable and have all the knowledge and enthusiasm for being part of a major, first-class experiment.”

(http://www.symmetrymagazine.org/sites/default/files/images/standard/EscaramujoChiapas-s_0.jpg)

Students at the Universidad Autónoma de Chiapas in Mexico built a detector with the Escaramujo Project.

Federico Izraelevitch

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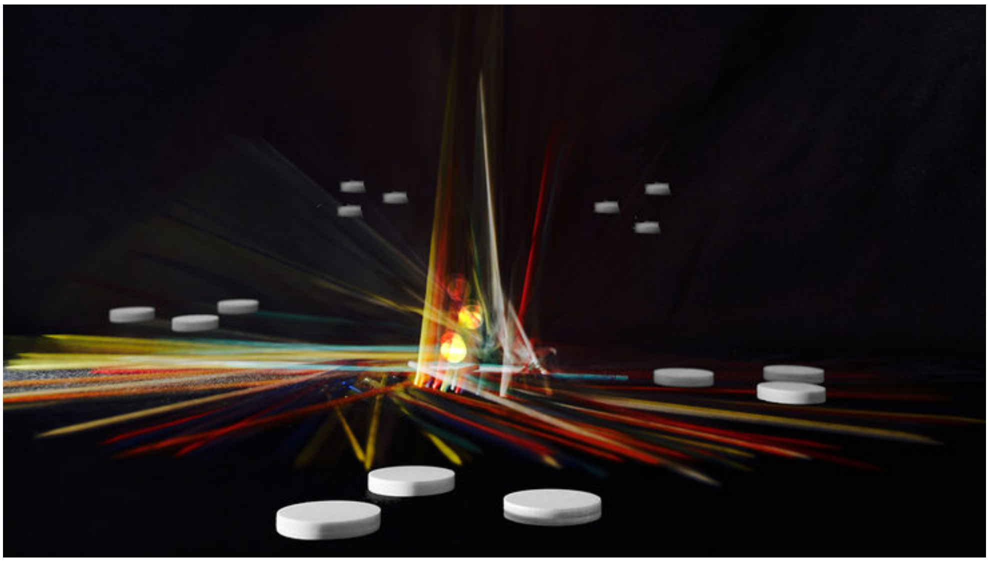
Sign of a long-sought asymmetry (http://www.symmetrymagazine.org/article/sign-of-a-long-sought-asymmetry?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Jan 30, 2017

A result from the LHCb experiment shows what could be the first evidence of matter and antimatter baryons behaving differently.



A new result from the LHCb experiment at CERN could help explain why our universe is made of matter and not antimatter.

Matter particles, such as protons and electrons, all have an antimatter twin. These antimatter twins appear identical in nearly every respect except that their electric and magnetic properties are opposite.

Cosmologists predict that the Big Bang produced an equal amount of matter and antimatter, which is a conundrum because matter and antimatter annihilate into pure energy when they come into contact. Particle physicists are looking for any minuscule differences between matter and antimatter, which might explain why our universe contains planets and stars and not a sizzling broth of light and energy instead.

The Large Hadron Collider doesn't just generate Higgs bosons during its high-energy proton collisions—it also produces antimatter. By comparing the decay patterns of matter particles with their antimatter twins, the LHCb experiment is looking for minuscule differences in how these rival particles behave.

"Many antimatter experiments study particles in a very confined and controlled environment," says Nicola Neri, a researcher at Italian research institute INFN and one of the leaders of the study. "In our experiment, the antiparticles flow and decay, so we can examine other properties, such as the momenta and trajectories of their decay products."

The result, published today in *Nature Physics* (http://www.nature.com/nphys/journal/vaop/ncurrent/full/nphys4021.html), examined the decay products of matter and antimatter baryons (a particles containing three quarks) and looked at the spatial distribution of the resulting daughter particles within the detector. Specifically, Neri and his colleagues looked for a very rare decay of the lambda-b particle (which contains an up quark, down quark and bottom quark) into a proton and three pions (which contain an up quark and anti-down quark).

Based on data from 6000 decays, Neri and his team found a difference in the spatial orientation of the daughter particles of the matter and antimatter lambda-bs.

"This is the first time we've seen evidence of matter and antimatter baryons behaving differently," Neri says. "But we need more data before we can make a definitive claim."

Statistically, the result has a significant of 3.3 sigma, which means its chances of being a just a statistical fluctuation (and not a new property of nature) is one out of a thousand. The traditional threshold for discovery is 5 sigma, which equates to odds of one out of more than a million.

For Neri, this result is more than early evidence of a never before seen process—it is a key that opens new research opportunities for LHCb physicists.

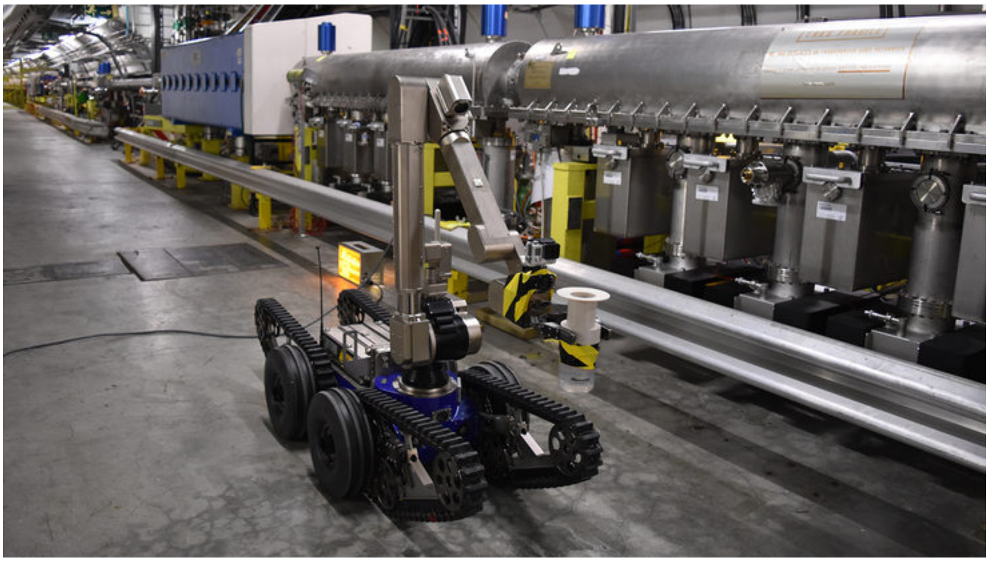
"We proved that we are there," Neri says, "Our experiment is so sensitive that we can start systematically looking for this matter-antimatter asymmetry in heavy baryons at LHCb. We have this capability, and we will be able to do even more after the detector is upgraded next year."

Read More... (http://www.symmetrymagazine.org/article/sign-of-a-long-sought-asymmetry?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

The robots of CERN (http://www.symmetrymagazine.org/article/the-robots-of-cern?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Jan 26, 2017

TIM and other mechanical friends tackle jobs humans shouldn't.



The Large Hadron Collider is the world's most powerful particle accelerator. Buried in the bedrock beneath the Franco-Swiss border, it whips protons through its nearly 2000 magnets 11,000 times every second.

As you might expect, the subterranean tunnel which houses the LHC is not always the friendliest place for human visitors.

"The LHC contains 120 tons of liquid helium kept at 1.9 Kelvin," says Ron Suykerbuyk, an LHC operator. "This cooling system is used to keep the electromagnets in super conducting state capable of carrying up to 13,000 Amps of current through its wires. Even with all the safety systems we have in place, we prefer to limit our underground access when the cryogenic systems are on".

But as with any machine, sometimes the LHC needs attention: inspections, repairs, tuning. The LHC is so secure that even with perfect conditions, it takes 30 minutes after the beam is shut off for the first humans to even arrive at the entrance to the tunnel.

But the robotics team at CERN asks: Why do we need humans for this job anyway?

Enter TIM—the Train Inspection Monorail. TIM is a chain of wagons, sensors and cameras that snake along a track bolted to the LHC tunnel's ceiling. In the 1990s, the track held a cable car that transported machinery and people around the Large Electron-Position Collider, the first inhabitant of the tunnel. With the installation of the LHC, there was no longer room for both accelerator and the cable car, so the monorail was reconfigured for the sleeker TIM robots.

There are currently two TIM robots and plans to install two more in the next couple of years. These four TIM robots will patrol the different quadrants of the LHC, enabling operators to reach any part of the 17-mile tunnel within 20 minutes. As TIM slithers along the ceiling, an automated eye keeps watch for any changes in the tunnel and a robotic arm drops down to measure radiation. Other sensors measure the temperature, oxygen level and cell phone reception.

"In addition to performing environmental measurements, TIM is a safety system which can be the eyes and ears for members of the CERN Fire Brigade and operations team," says Mario Di Castro, the leader of CERN's robotics team. "Eventually we'd like to equip TIM with a fire extinguisher and other physical operations so that it can be the first responder in case of a crisis."

TIM isn't alone in its mission to provide a safer environment for its human coworkers. CERN also has three teleoperated robots that can assess troublesome areas, provide assessments of hazards and carry tools.

The main role of these three robots is to access radioactive areas.

Radiation is a type of energy carried by free-moving subatomic particles. As protons race around CERN's accelerator complex, special equipment called collimators constrict their passage and absorb particles that have wandered away from the center of the beam pipe. This trimming process ensures that the proton stream is compact and tidy.

After a couple weeks of operation, the collimators have absorbed so many particles that they will reemit their energy—even after the beam is shut off. There is no radiation hazard to humans unless they are within a few meters of the collimators, and because the machine is fully automated, humans rarely need to perform check-ups. But occasionally, material in these restricted areas required attention.

By replacing humans with robots, engineers can quickly fix small problems without needing to wait long periods of time for the radiation to dissipate or sending personnel into potentially unsafe environments.

"CERN robots help perform repetitive and dangerous tasks that humans either prefer to avoid or are unable to do because of hazards, size constraints or the extreme environments in which they take place, such CERN experimental areas," Di Castro says.

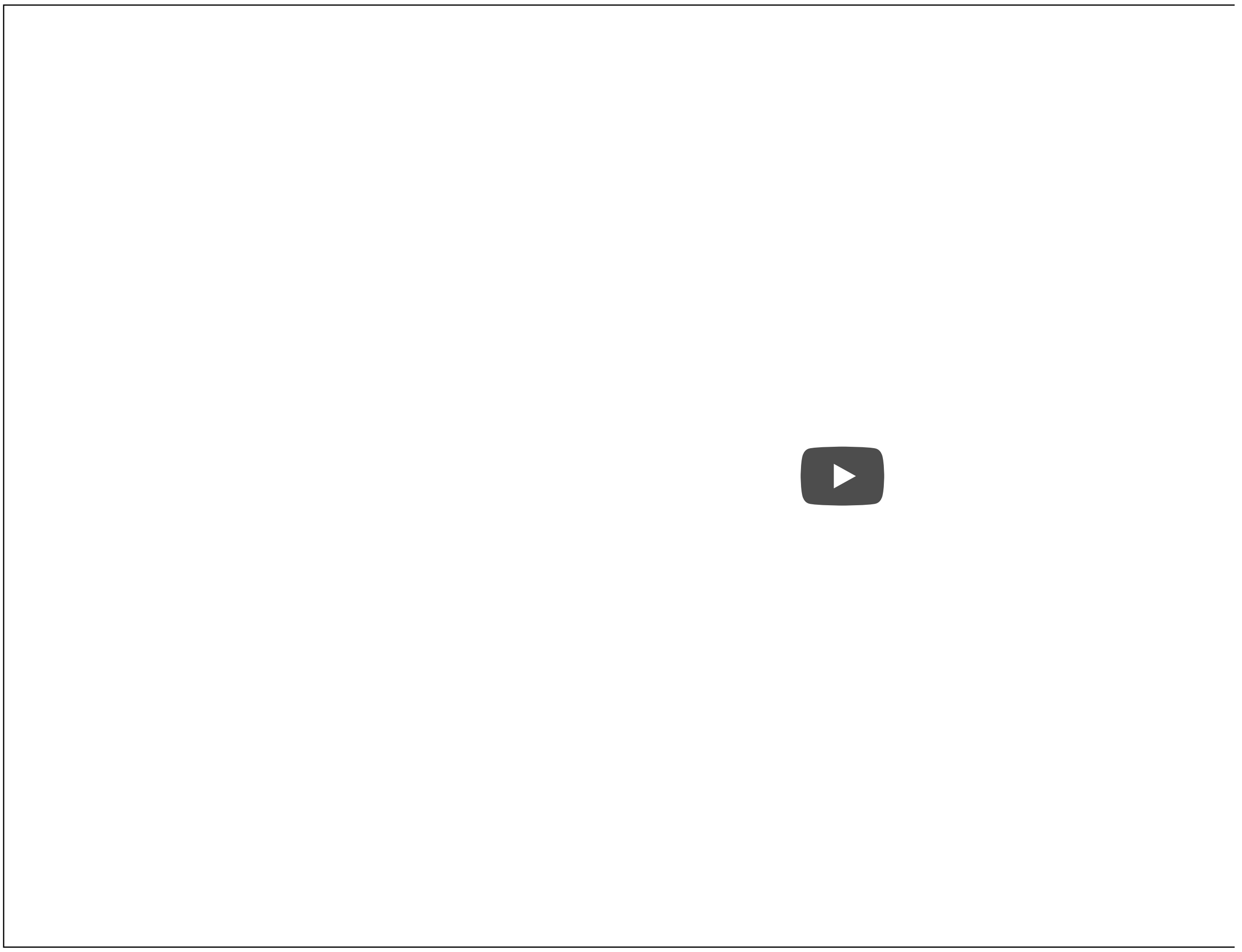
About half the time, these tasks are very simple, such as performing a visual assessment of the area or taking measurements. "Robots can replace humans for these simple tasks and improve the quality and timeliness of work," he says.

Last year the SPS accelerator (which starts the acceleration process for particles that eventually move to the LHC) needed an oil refill to keep its parts running smoothly. But the accelerator itself was too radioactive for humans to visit, so one of the CERN robotics team's robots rolled in gripping an oil can in its flexible arm.

In June 2016, scientists needed to dispose of radioactive Cobalt, Cesium and Americium they had used to calibrate radiation sensors. Two CERN robots cycled in with several tools, extracted the radioactive sources and packed them in thick protective containers for removal.

Over the last two years, these two robots have performed more than 30 interventions, saving humans both time and radiation doses.

As the LHC increases the power and particle collisions over the next decade, Di Castro and his team are preening these robot companions to increase their capabilities. "We are putting a strong commitment to adapt and develop existing robotic solutions to fit CERN's evolving needs," Di Castro says.



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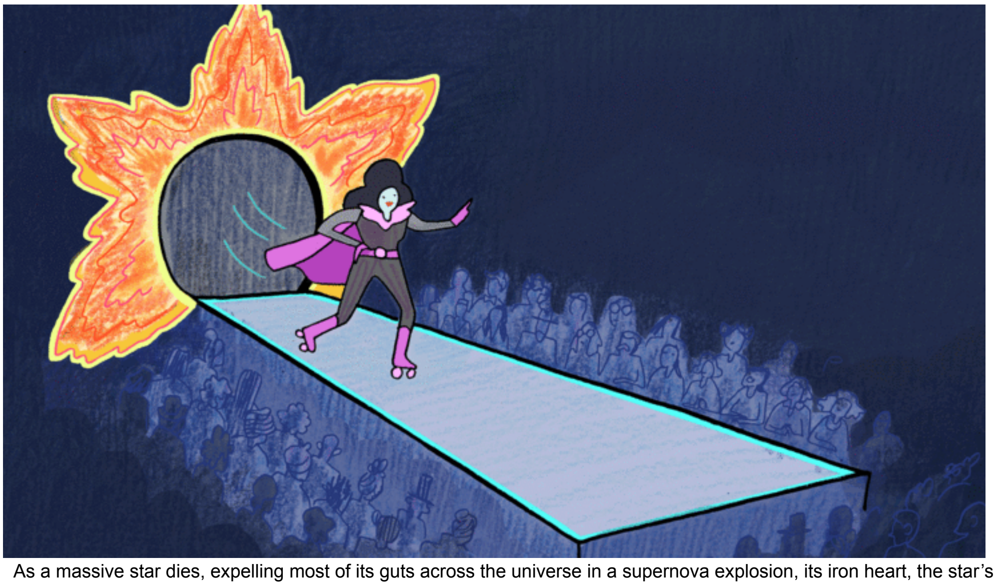
Five extreme facts about neutron stars (http://www.symmetrymagazine.org/article/five-extreme-facts-about-neutron-stars?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Jan 24, 2017

Neutron stars have earned their share of superlatives since their discovery in 1967.



As a massive star dies, expelling most of its guts across the universe in a supernova explosion, its iron heart, the star's core, collapses to create the densest form of observable matter in the universe: a neutron star.

A neutron star is basically a giant nucleus, says Mark Alford, a professor at Washington University.

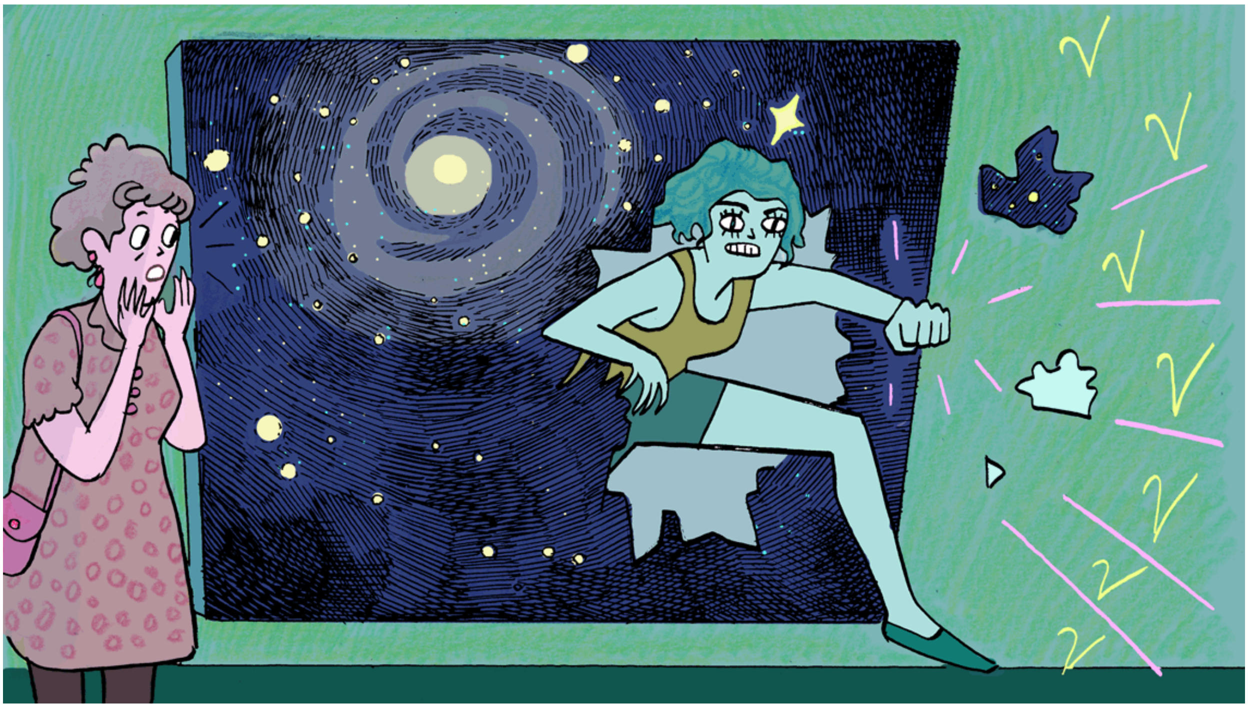
"Imagine a little lead pellet with cotton candy around it," Alford says. "That's an atom. All the of mass is in the little lead pellet in the middle, and there's this big puffy cloud of electrons around it like cotton candy."

In neutron stars, the atoms have all collapsed. The electron clouds have all been sucked in, and the whole thing becomes a single entity with electrons running around side-by-side with protons and neutrons in a gas or fluid.

Neutron stars are pretty small, as far as stellar objects go. Although scientists are still working on pinning down their exact diameter, they estimate that they're somewhere around 12 to 17 miles across, just about the length of Manhattan. Despite that, they have about 1.5 times the mass of our sun.

If a neutron star were any denser, it would collapse into a black hole and disappear, Alford says. "It's the next to last stop on the line."

These extreme objects offer intriguing test cases that could help physicists understand the fundamental forces, general relativity and the early universe. Here are some fascinating facts to get you acquainted:



(http://www.symmetrymagazine.org/sites/default/files/images/standard/Inline_1_Neutron_stars.gif)

Illustration by Corinne Mucha

1. In just the first few seconds after a star begins its transformation into a neutron star, the energy leaving in neutrinos is equal to the total amount of light emitted by all of the stars in the observable universe.

Ordinary matter contains roughly equal numbers of protons and neutrons. But most of the protons in a neutron star convert into neutrons—neutron stars are made up of about 95 percent neutrons. When protons convert to neutrons, they release ubiquitous particles called neutrinos.

Neutron stars are made in supernova explosions which are giant neutrino factories. A supernova radiates 10 times more neutrinos than there are particles, protons, neutrons and electrons in the sun.

(http://www.symmetrymagazine.org/sites/default/files/images/standard/Inline_2_Neutron_stars.gif)

Illustration by Corinne Mucha

2. It’s been speculated that if there were life on neutron stars, it would be two-dimensional.

Neutron stars have some of the strongest gravitational and magnetic fields in the universe. The gravity is strong enough to flatten almost anything on the surface. The magnetic fields of neutron stars can be a billion times to a million billion times the magnetic field on the surface of Earth.

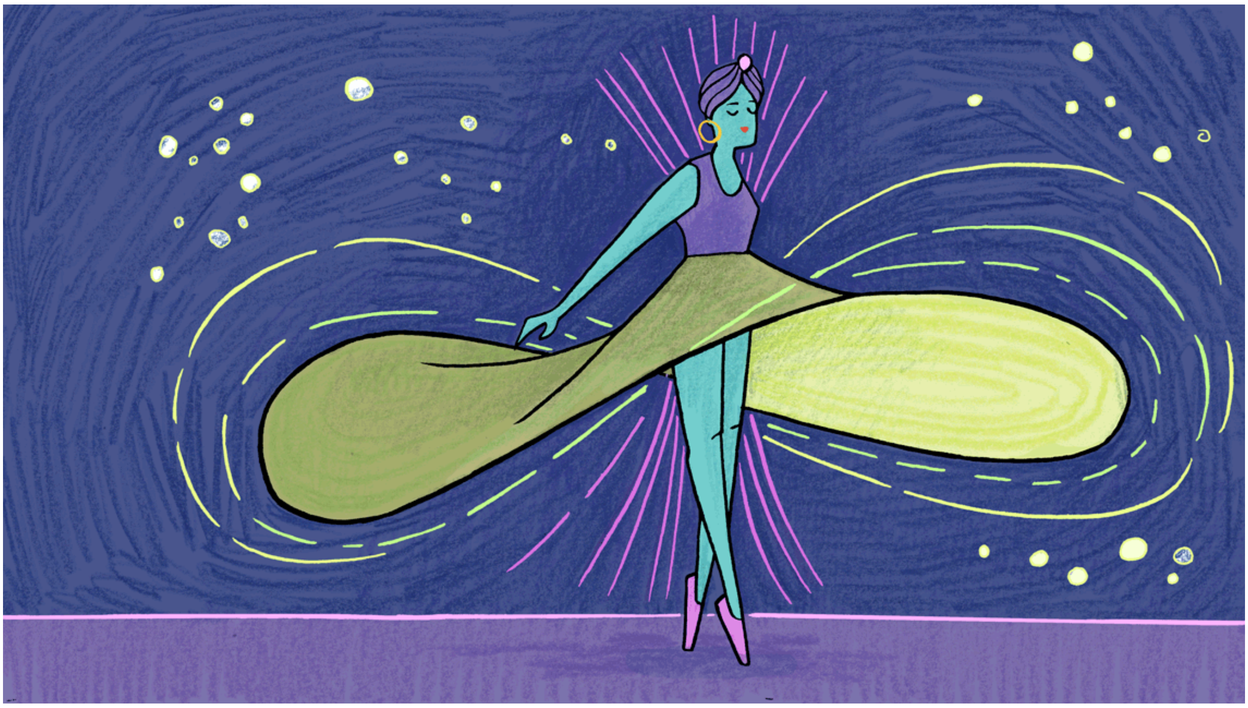
“Everything about neutron stars is extreme,” says James Lattimer, a professor at Stony Brook University. “It goes to the point of almost being ridiculous.”

Because they’re so dense, neutron stars provide the perfect testbed for the strong force, allowing scientists to probe the way quarks and gluons interact under these conditions. Many theories predict that the core of a neutron star compresses neutrons and protons, liberating the quarks of which they are constructed. Scientists have created a hotter version of this freed “quark matter” in the Relativistic Heavy Ion Collider and the Large Hadron Collider.

The intense gravity of neutron stars requires scientists to use the general theory of relativity to describe the physical properties of neutron stars. In fact, measurements of neutron stars give us some of the most precise tests of general relativity that we currently have.

Despite their incredible densities and extreme gravity, neutron stars still manage to maintain a surprising amount of internal structure, housing crusts, oceans and atmospheres. “They’re a weird mixture of something the mass of a star with some of the other properties of a planet,” says Chuck Horowitz, a professor at Indiana University.

But while here on Earth we’re used to having an atmosphere that extends hundreds of miles into the sky, because a neutron star’s gravity is so extreme, its atmosphere may stretch up less than a foot.



(http://www.symmetrymagazine.org/sites/default/files/images/standard/Inline_3_Neutron_stars.gif)

Illustration by Corinne Mucha

3. The fastest known spinning neutron star rotates about 700 times each second.

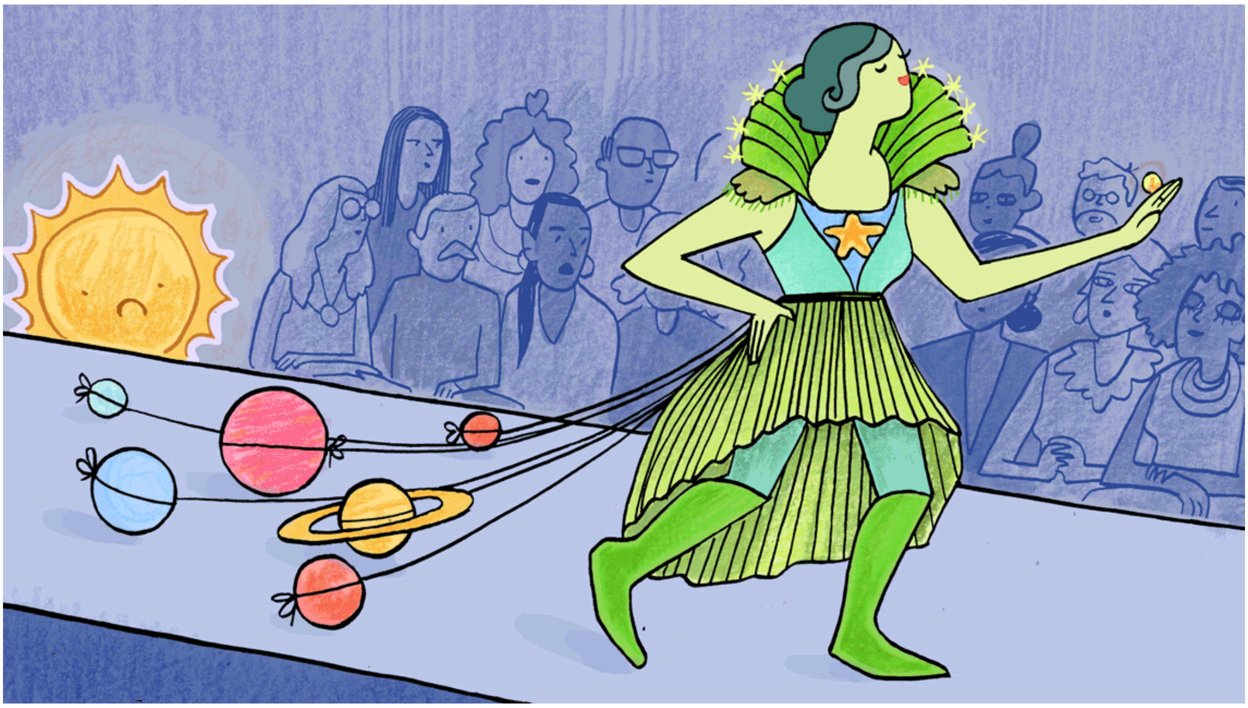
Scientists believe that most neutron stars either currently are or at one point have been pulsars, stars that spit out beams of radio waves as they rapidly spin. If a pulsar is pointed toward our planet, we see these beams sweep across Earth like light from a lighthouse.

Scientists first observed neutron stars in 1967, when a graduate student named Jocelyn Bell noticed repeated radio pulses arriving from a pulsar outside our solar system. (The 1974 Nobel Prize in Physics went to her thesis advisor, Anthony Hewish, for the discovery.)

Pulsars can spin anywhere from tens to hundreds of times per second. If you were standing on the equator of the fastest known pulsar, the rotational velocity would be about 1/10 the speed of light.

The 1993 Nobel Prize in Physics went to scientists who measured the rate at which a pair of neutron stars orbiting each other were spiraling together due to the emission of gravitational radiation, a phenomenon predicted by Albert Einstein's general theory of relativity.

Scientists from the Laser Interferometer Gravitational-Wave Observatory, or LIGO, announced in 2016 that they had directly detected gravitational waves for the first time. In the future, it might be possible to use pulsars as giant, scaled-up versions of the LIGO experiment, trying to detect the small changes in the distance between the pulsars and Earth as a gravitational wave passes by.



(http://www.symmetrymagazine.org/sites/default/files/images/standard/Inline_4_Neutron_stars.gif)

Illustration by Sandbox Studio, Chicago

4. The wrong kind of neutron star could wreak havoc on Earth.

Neutron stars can be dangerous because of their strong fields. If a neutron star entered our solar system, it could cause chaos, throwing off the orbits of the planets and, if it got close enough, even raising tides that would rip the planet apart.

But the closest known neutron star is about 500 light-years away. And considering Proxima Centauri, the closest star to Earth at a little over 4 light-years away, has no bearing on our planet, it's unlikely we'll feel these catastrophic effects anytime soon.

Probably even more dangerous would be radiation from a neutron star's magnetic field. Magnetars are neutron stars with magnetic fields a thousand times stronger than the extremely strong fields of "normal" pulsars. Sudden rearrangements of these fields can produce flares somewhat like solar flares but much more powerful.

On December 27, 2004, scientists observed a giant gamma-ray flare from Magnetar SGR 1806-20, estimated to be about 50,000 light years away. In 0.2 seconds the flare radiated as much energy as the sun produces in 300,000 years. The flare saturated many spacecraft detectors and produced detectable disturbances in the Earth's ionosphere.

Fortunately, we are not aware of any nearby magnetars powerful enough to cause any damage.

(http://www.symmetrymagazine.org/sites/default/files/images/standard/Inline_5_Neutron_stars.gif)

Illustration by Corinne Mucha

5. Despite the extremes of neutron stars, researchers still have ways to study them.

There are many things we don't know about neutron stars—including just how many of them are out there, Horowitz says. "We know of about 2000 neutron stars in our own galaxy, but we expect there to be billions more. So most neutron stars, even in our own galaxy, are completely unknown."

Many radio, X-ray and optical light telescopes are used to investigate the properties of neutron stars. NASA's upcoming Neutron Star Interior Composition ExploreR Mission (NICER), which is scheduled to attach to the side of the International Space Station in 2017, is one mission devoted to learning more about these extreme objects. NICER will look at X-rays coming from rotating neutron stars to try to more accurately pin down their mass and radii.

We could also study neutron stars by detecting gravitational waves. LIGO scientists hope to detect gravitational waves produced by the merger of two neutron stars. Studying those gravitational waves might clue scientists in to the properties of the extremely dense matter that neutron stars are made of.

Studying neutron stars might help us figure out the origin of the heavy chemical elements, including gold and platinum, in our universe. There's a possibility that when neutron stars collide, not everything gets swallowed up into a more massive neutron star or black hole, but instead some fraction gets flung out and forms these heavy nuclei.

"If you want to use the lab of 24th or 25th century," says Roger Romani, a professor at Stanford University, "then studying neutron stars is a way of looking at conditions that we cannot produce in labs on Earth."

Read More... (http://www.symmetrymagazine.org/article/five-extreme-facts-about-neutron-stars?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Matter-antimatter mystery remains unsolved (http://www.symmetrymagazine.org/article/matter-antimatter-mystery-remains-unsolved?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Jan 19, 2017

Measuring with high precision, physicists at CERN found a property of antiprotons perfectly mirrored that of protons.

There is little wiggle room for disparities between matter and antimatter protons, according to a new study published by the BASE experiment at CERN.

Charged matter particles, such as protons and electrons, all have an antimatter counterpart. These antiparticles appear identical in every respect to their matter siblings, but they have an opposite charge and an opposite magnetic property. This recalcitrant parity is a head-scratcher for cosmologists who want to know why matter triumphed over antimatter in the early universe.

"We're looking for hints," says Stefan Ulmer, spokesperson of the BASE collaboration. "If we find a slight difference between matter and antimatter particles, it won't tell us why the universe is made of matter and not antimatter, but it would be an important clue."

Ulmer and his colleagues working on the BASE experiment at CERN closely scrutinize the properties of antiprotons to look for any miniscule divergences from protons. In a paper published today in the journal *Nature Communications*, the BASE collaboration at CERN reports the most precise measurement ever made of the magnetic moment of the antiproton.

"Each spin-carrying charged particle is like a small magnet," Ulmer says. "The magnetic moment is a fundamental property which tells us the strength of that magnet."

The BASE measurement shows that the magnetic moments of the proton and antiproton are identical, apart from their opposite signs, within the experimental uncertainty of 0.8 parts per million. The result improves the precision of the previous best measurement (http://press.cern/press-releases/2013/03/atrap-experiment-makes-worlds-most-precise-measurement-antiproton-magnetic) by the ATRAP collaboration in 2013, also at CERN, by a factor of six. This new measurement shows an almost perfect symmetry between matter and antimatter particles, thus further constricting leeway for incongruencies which might have explained the cosmic asymmetry between matter and antimatter.

The measurement was made at the Antimatter Factory at CERN, which generates antiprotons by first crashing normal protons into a target and then focusing and slowing the resulting antimatter particles using the Antiproton Decelerator. Because matter and antimatter annihilate upon contact, the BASE experiment first traps antiprotons in a vacuum using sophisticated electromagnetics and then cools them to about 1 degree Celsius above absolute zero. These electromagnetic reservoirs can store antiparticles for long periods of time; in some cases, over a year. Once in the reservoir, the antiprotons are fed one-by-one into a trap with a superimposed magnetic bottle, in which the antiprotons oscillate along the magnetic field lines. Depending on their North-South alignment in the magnetic bottle, the antiprotons will vibrate at two slightly different rates. From these oscillations (combined with nuclear magnetic resonance methods), physicists can determine the magnetic moment.

The challenge with this new measurement was developing a technique sensitive to the miniscule differences between antiprotons aligned with the magnetic field versus those anti-aligned.

"It's the equivalent of determining if a particle has vibrated 5 million times or 5 million-plus-one times over the course of a second," Ulmer says. "Because this measurement is so sensitive, we stored antiprotons in the reservoir and performed the measurement when the antiproton decelerator was off and the lab was quiet."

BASE now plans to measure the antiproton magnetic moment using a new trapping technique that should enable a precision at the level of a few parts per billion—that is, a factor of 200 to 800 improvement.

Members of the BASE experiment hope that a higher level of precision might provide clues as to why matter flourishes while cosmic antimatter lingers on the brink of extinction.

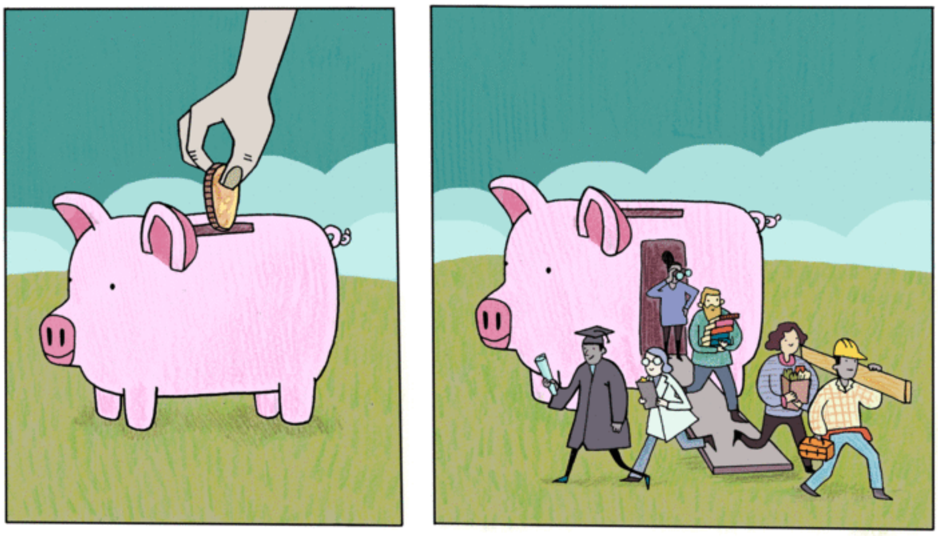
"Every new precision measurement helps us complete the framework and further refine our understanding of antimatter's relationship with matter," Ulmer says.

Read More... (http://www.symmetrymagazine.org/article/matter-antimatter-mystery-remains-unsolved?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

The value of basic research (http://www.symmetrymagazine.org/article/the-value-of-basic-research?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Jan 17, 2017

How can we measure the worth of scientific knowledge? Economic analysts give it a shot.



Before building any large piece of infrastructure, potential investors or representatives from funding agencies or governments have to decide whether it's worth it. Teams of economists perform a cost-benefit analysis to help them determine how a project will affect a region and whether it makes sense to back and build it.

But when it comes to building infrastructure for basic science, the process gets a little more complicated. It's not so easy to pin an exact value on the benefits of something like the Large Hadron Collider.

"The main goal is priceless and therefore has no price attached," says Stefano Forte, a professor of theoretical physics at the University of Milan and part of a team that developed a new method of economic analysis for fundamental science. "We give no value to discovering the Higgs boson in the past or supersymmetry or extra dimensions in the future, because we wouldn't be able to say what the value of the discovery of extra dimensions is."

Forte's team was co-led by two economists, academic Massimo Florio, also of the University of Milan, and private business consultant Silvia Vignetti. They answered a 2012 call by the European Investment Bank's University Sponsorship Program, which provides grants to university research centers, for assistance with this issue. The bank funded their research into a new way to evaluate proposed investments in science.

Before anyone can start evaluating any sort of impact, they have to define what they're measuring. Generally, economic impact analyses are highly local, measuring exclusively money flowing in and out of a particular area.

Because of the complicated nature of financing any project, the biggest difficulty for economists performing an analysis is usually coming up with an appropriate counterfactual: If the project isn't built, what will happen? As Forte asks, "If you hadn't spent the money there, where else would you have spent it, and are you sure that by spending it there rather than somewhere else you actually gain something?"

Based on detailed information about where a scientific collaboration intends to spend their money, economists can take the first step in painting a picture of how that funding will affect the region. The next step is accounting for the secondary spending that this brings.

Companies are paid to do construction work for a scientific project, "and then it sort of cascades throughout the region," says Jason Horwitz of Anderson Economic Group, which regularly performs economic analyses for universities and physics collaborations. "As they hire more people, the employees themselves are probably going to local grocery stores, going to local restaurants, they might go to a movie now and then—there's just more local spending."

These first parts of the analysis account only for the tangible, concrete-and-steel process of building and maintaining an experiment, though.

"If you build a bridge, the main benefit is from people who use the build—transportation of goods over the bridge and whatnot," Forte says. But the benefit of constructing a telescope array or a huge laser interferometer is knowledge-formation, "which is measured in papers and publications, references and so on," he says.

One way researchers like Horwitz and Forte have begun to assign value to such projects is by measuring the effect of the project on the people who run it. Like attending university, working on a scientific collaboration gives you an education—and an education changes your earning capabilities.

"Fundamental research has a huge added value in terms of human capital formation, even if you work there for two years and then you go and work in a company on Wall Street," Forte says. Using the same methods used by universities, they found doing research at the LHC would raise students' earning potential by about 11 percent over a 40-year career.

This method of measuring the value of scientific projects still has limitations. In it, the immeasurable, grander purpose of a fundamental science experiment is still assigned no value at all. When it comes down to it, Forte says, if all we cared about were a big construction project, technology spinoffs and the earning potential of students, we wouldn't have fundamental physics research.

"The actual purpose of this is not a big construction project," Horwitz says. "It's to do this great research which obviously has other benefits of its own, and we really don't capture any of that." Instead, his group appends qualitative explanations of the knowledge to be gained to their economic reports.

Forte explains, "The fact that this kind of enterprise exists is comparable and evaluated in the same way as, say, the value of the panda not being extinct. If the panda is extinct, there is no one who's actually going to lose money or make money—but many taxpayers would be willing to pay money for the panda not to be extinct."

Forte and his colleagues found a 90 percent chance of the LHC's benefits exceeding its costs (by 2.9 billion euros, they estimate). But even in the 10 percent chance that its economics aren't quite so Earth-shaking, its discoveries could change the way we understand our universe.

Read More... (http://www.symmetrymagazine.org/article/the-value-of-basic-research?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

STOMP visits CERN (http://www.symmetrymagazine.org/article/stomp-visits-cern?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Jan 13, 2017

A group known for making music with everyday objects recently got their hands on some extraordinary props.

CERN, home to the Large Hadron Collider, is known for high-speed, high-energy feats of coordination, so it's only fitting that the touring percussion group STOMP would stop by for a visit.

After taking a tour of the research center, STOMP performers were game to share their talent by turning three pieces of retired scientific equipment into a gigantic drum set. Check out the video below to hear the beat of an LHC dipole magnet, the Gargamelle bubble chamber and a radiofrequency cavity from the former Large Electron-Positron Collider.

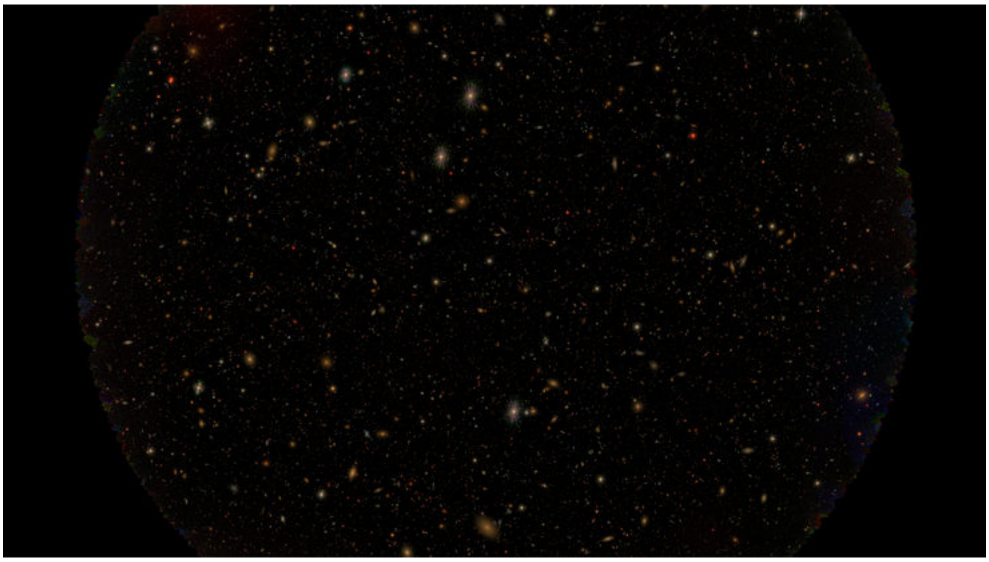
As CERN notes (http://home.cern/cern-people/updates/2017/01/big-bangs-stomp-cern), these are trained professionals who were briefed on how to avoid damaging the equipment they used. Lab visitors are generally discouraged from hitting the experiments.

Read More... (http://www.symmetrymagazine.org/article/stomp-visits-cern?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Twinkle, twinkle, little supernova (http://www.symmetrymagazine.org/article/twinkle-twinkle-little-supernova?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Jan 12, 2017

Using Twinkles, the new simulation of images of our night sky, scientists get ready for a gigantic cosmological survey unlike any before.



Almost every worthwhile performance is preceded by a rehearsal, and scientific performances are no exception. Engineers test a car's airbag deployment using crash test dummies before incorporating them into the newest model. Space scientists fire a rocket booster in a test environment before attaching it to a spacecraft in flight.

One of the newest "training grounds" for astrophysicists is called Twinkles. The Twinkles dataset, which has not yet been released, consists of thousands of simulated, highly realistic images of the night sky, full of supernovae and quasars. The simulated-image database will help scientists rehearse a future giant cosmological survey called LSST.

LSST, short for the Large Synoptic Survey Telescope, is under construction in Chile and will conduct a 10-year survey of our universe, covering the entire southern sky once a year. Scientists will use LSST images to explore our galaxy to learn more about supernovae and to shine a light on the mysterious dark energy that is responsible for the expansion of our universe.

It's a tall order, and it needs a well prepared team. Scientists designed LSST using simulations and predictions for its scientific capabilities. But Twinkles' thousands of images will give them an even better chance to see how accurately their LSST analysis tools can measure the changing brightness of supernovae and quasars. That's the advantage of using simulated data. Scientists don't know about all the objects in the sky above our heads, but they *do* know their simulated sky— there, they already know the answers. If the analysis tools make a calculation error, they'll see it.

The findings will be a critical addition to LSST's measurements of certain cosmological parameters, where a small deviation can have a huge impact on the outcome.

"We want to understand the whole path of the light: From other galaxies through space to our solar system and our planet, then through our atmosphere to the telescope – and from there through our data-taking system and image processing," says Phil Marshall, a scientist at the US Department of Energy's SLAC National Accelerator Laboratory who leads the Twinkles project. "Twinkles is our way to go all the way back and study the whole picture instead of one single aspect."

Scientists simulate the images as realistically as possible to figure out if some systematic errors add up or intertwine with each other. If they do, it could create unforeseen problems, and scientists of course want to deal with them before LSST starts.

Twinkles also lets scientists practice sorting out a different kind of problem: A large collaboration spread across the whole globe that will perform numerous scientific searches simultaneously on the same massive amounts of data.

Richard Dubois, senior scientist at SLAC and co-leader of the software infrastructure team, works with his team of computing experts to create methods and plans to deal with the data coherently across the whole collaboration and advise the scientists to choose specific tools to make their life easier.

"Chaos is a real danger; so we need to keep it in check," Dubois says. "So with Twinkles, we test software solutions and databases that help us to keep our heads above water."

The first test analysis using Twinkles images will start toward the end of the year. During the first go, scientists extract type 1a supernovae and quasars and learn how to interpret the automated LSST measurements.

"We hid both types of objects in the Twinkles data," Marshall says. "Now we can see whether they look the way they're supposed to."

LSST will start up in 2022, and the first LSST data will be released at the end of 2023.

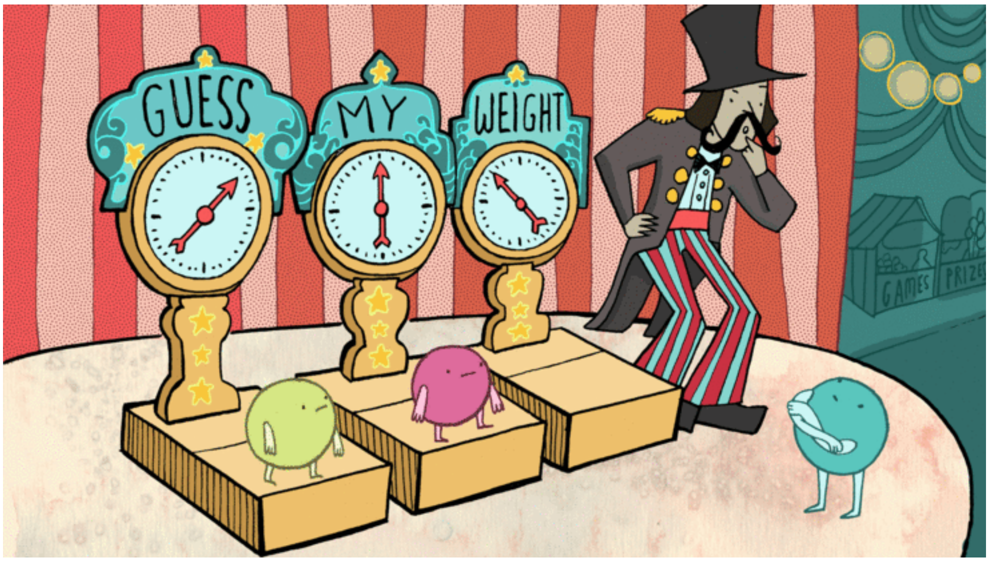
"High accuracy cosmology will be hard," Marshall says. "So we want to be ready to start learning more about our universe right away!"

Read More... (http://www.symmetrymagazine.org/article/twinkle-twinkle-little-supernova?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

How heavy is a neutrino? (http://www.symmetrymagazine.org/article/how-heavy-is-a-neutrino?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=clic

Jan 10, 2017

The question is more complicated than it seems.



Neutrinos are elementary particles first discovered six decades ago.

Over the years, scientists have learned several surprising things about them. But they have yet to answer what might sound like a basic question: How much do neutrinos weigh? The answer could be key to understanding the nature of the strange particles and of our universe.

To understand why figuring out the mass of neutrinos is such a challenge, first you must understand that there's more than one way to picture a neutrino.

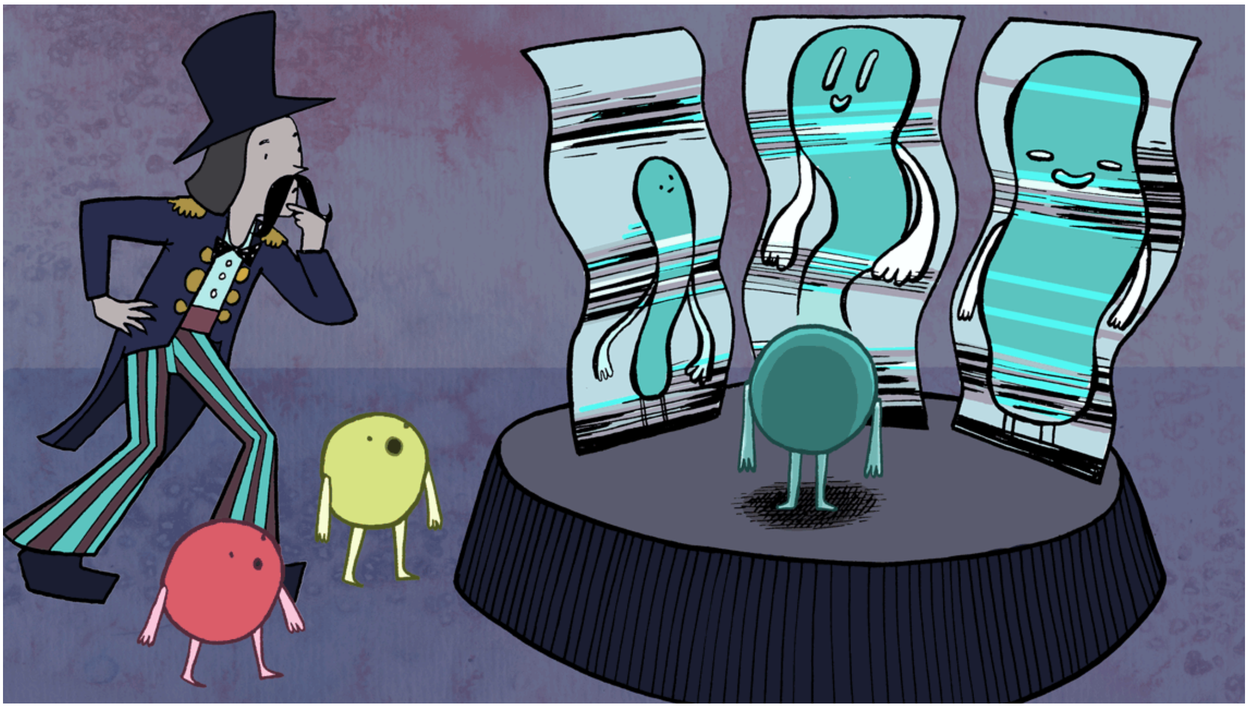
Neutrinos come in three flavors: electron, muon and tau. When a neutrino hits a neutrino detector, a muon, electron or tau particle is produced. When you catch a neutrino accompanied by an electron, you call it an electron neutrino, and so on.

Knowing this, you might be forgiven for thinking that there are three types of neutrinos: electron neutrinos, muon neutrinos and tau neutrinos. But that's not quite right.

That's because every neutrino is actually a quantum superposition of *all three* flavors. Depending on the energy of a neutrino and where you catch it on its journey, it has a different likelihood of appearing as electron-flavored, muon-flavored or tau-flavored.

Armed with this additional insight, you might be forgiven for thinking that, when all is said and done, there is actually just one type of neutrino. But that's even less right.

Scientists count three types of neutrino after all. Each one has a different mass and is a different *mixture* of the three neutrino flavors. These neutrino types are called the three neutrino mass states.



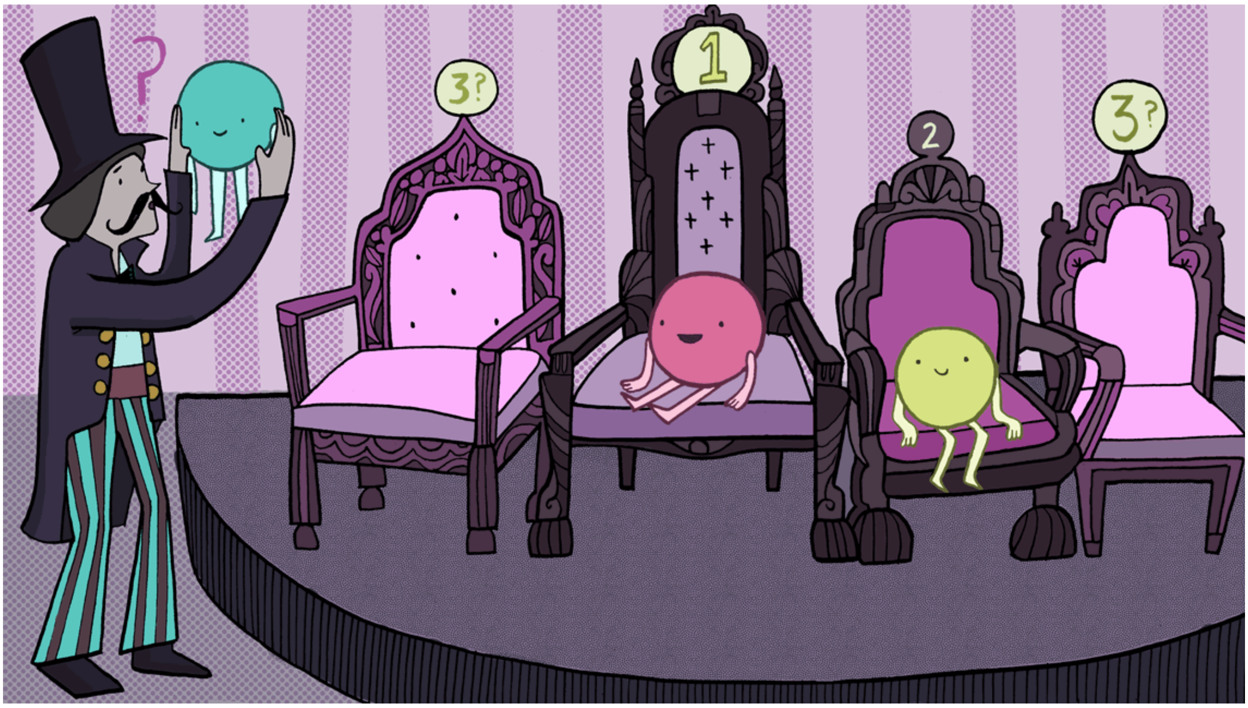
(http://www.symmetrymagazine.org/sites/default/files/images/standard/Inline_1_Mass_hierarchy.gif)
Sandbox Studio, Chicago with Corinne Mucha

A weighty problem

We know that the masses of these three types of neutrinos are small. We know that the flavor mixture of the first neutrino mass state is heavy on electron flavor. We know that the second is more of an even blend of electron, muon and tau. And we know that the third is mostly muon and tau.

We know that the masses of the first two neutrinos are close together and that the third is the odd one out. What we *don't* know is whether the third one is lighter or heavier than the others.

The question of whether this third mass state is the heaviest or the lightest mass state is called the neutrino mass hierarchy (or neutrino mass ordering) problem.



(http://www.symmetrymagazine.org/sites/default/files/images/standard/Inline_2_Mass_hierarchy.gif)

Easy as 1,2,3—or 3,1,2?

Some models that unify the different forces in the Standard Model of particle physics predict that the neutrino mass ordering will follow the pattern 1, 2, 3—what they call a normal hierarchy. Other models predict that the mass ordering will follow the pattern 3, 1, 2—an inverted hierarchy. Knowing whether the hierarchy is normal or inverted can help theorists answer other questions.

For example, four forces—the strong, weak, electromagnetic and gravitational forces—govern the interactions of the smallest building blocks of matter. Some theorists think that, in the early universe, these four forces were united into a single force. Most theories about the unification of forces predict a normal neutrino mass hierarchy.

Scientists' current best tools for figuring out the neutrino mass hierarchy are long-baseline neutrino experiments, most notably one called NOvA.

(http://www.symmetrymagazine.org/sites/default/files/images/standard/Inline_3_Mass_hierarchy.gif)

Electron drag

The NOvA detector, located in Minnesota near the border of Canada, studies a beam of neutrinos that originates at Fermi National Accelerator Laboratory in Illinois.

Neutrinos very rarely interact with other matter. That means they can travel 500 miles straight through the Earth from the source to the detector. In fact, it's important that they do so, because as they travel, they pass through trillions of electrons.

This affects the electron-flavor neutrinos—and only the electron-flavor neutrinos—making them seem more massive. Since the first and second mass states contain more electron flavor than the third, those two experience the strongest electron interactions as they move through the Earth.

This interaction has different effects on neutrinos and *anti*neutrinos—and the effects depend on the mass hierarchy. If the hierarchy is normal, muon neutrinos will be more likely to turn into electron neutrinos, and muon antineutrinos will be less likely to turn into electron *anti*neutrinos. If the hierarchy is inverted, the opposite will happen.

So if NOvA scientists see that, after traveling through miles of rock and dirt, more muon neutrinos and fewer muon antineutrinos than expected have shifted flavors, it will be a sign the mass hierarchy is normal. If they see fewer muon neutrinos and more muon antineutrinos have shifted flavors, it will be a sign that the mass hierarchy is inverted.

The change is subtle. It will take years of data collection to get the first hint of an answer. Another, shorter long-baseline neutrino experiment, T2K, is taking related measurements. The JUNO experiment under construction in China aims to measure the mass hierarchy in a different way. The definitive measurement likely won't come until the next generation of long-baseline experiments, DUNE in the US and the proposed Hyper-Kamiokande experiment in Japan.

Neutrinos are some of the most abundant particles in the universe. As we slowly uncover their secrets, they give us more clues about how our universe works.

Read More... (http://www.symmetrymagazine.org/article/how-heavy-is-a-neutrino?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)