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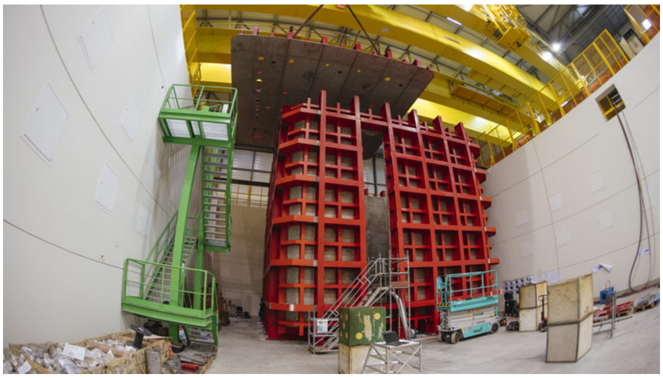
CERN ramps up neutrino program (http://www.symmetrymagazine.org/article/cern-ramps-up-neutrino-program?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

3 days ago

The research center aims to test two large prototype detectors for the DUNE experiment.



In the midst of the verdant French countryside is a workshop the size of an aircraft hangar bustling with activity. In a well lit new extension, technicians cut through thick slices of steel with electric saws and blast metal joints with welding torches.

Inside this building sits its newest occupant: a two-story-tall cube with thick steel walls that resemble castle turrets. This cube will eventually hold a prototype detector for the Deep Underground Neutrino Experiment, or DUNE, the flagship research program hosted at the Department of Energy's Fermi National Accelerator Laboratory to better understand the weird properties of neutrinos.

Neutrinos are the second-most abundant fundamental particle in the visible universe, but because they rarely interact with atoms, little is known about them. The little that is known presents a daunting challenge for physicists since neutrinos are exceptionally elusive and incredibly lightweight.

They're so light that scientists are still working to pin down the masses of their three different types. They also continually morph from one of their three types into another—a behavior known as oscillation, one that keeps scientists on their toes.

"We don't know what these masses are or have a clear understanding of the flavor oscillation," says Stefania Bordoni, a CERN researcher working on neutrino detector development. "Learning more about neutrinos could help us better understand how the early universe evolved and why the world is made of matter and not antimatter."

In 2015 CERN and the United States signed a new cooperation agreement that affirmed the United States' continued participation in the Large Hadron Collider research program and CERN's commitment to serve as the European base for the US-hosted neutrino program. Since this agreement, CERN has been chugging full-speed ahead to build and refurbish neutrino detectors.

"Our past and continued partnerships have always shown the United States and CERN are stronger together," says Marzio Nessi, the head of CERN's neutrino platform. "Our big science project works only because of international collaboration."

The primary goal of CERN's neutrino platform is to provide the infrastructure to test two large prototypes for DUNE's far detectors. The final detectors will be constructed at Sanford Lab in South Dakota. Eventually they will sit 1.5 kilometers underground, recording data from neutrinos generated 1300 kilometers away at Fermilab.

Two 8-meter-tall cubes, currently under construction at CERN, will each contain 770 metric tons of liquid argon permeated with a strong electric field. The international DUNE collaboration will construct two smaller, but still large, versions of the DUNE detector to be tested inside these cubes.

In the first version of the DUNE detector design, particles traveling through the liquid knock out a trail of electrons from argon atoms. This chain of electrons is sucked toward the 16,000 sensors lining the inside of the container. From this data, physicists can derive the trajectory and energy of the original particle.

In the second version, the DUNE collaboration is working on a new type of technology that introduces a thin layer of argon gas hovering above the liquid argon. The idea is that the additional gas will amplify the signal of these passing particles and give scientists a higher sensitivity to low-energy neutrinos. Scientists based at CERN are currently developing a 3-cubic-meter model, which they plan to scale up into the much larger prototype in 2017.

In addition to these DUNE prototypes, CERN is also refurbishing a neutrino detector, called ICARUS, which was used in a previous experiment at the Italian Institute for Nuclear Physics' Gran Sasso National Laboratory in Italy. ICARUS will be shipped to Fermilab in March 2017 and incorporated into a separate experiment.

CERN plans to serve as a resource for neutrino programs hosted elsewhere in the world as scientists delve deeper into this enigmatic niche of particle physics.

A version of this article was published by Fermilab (http://news.fnal.gov/2017/01/cern-ramps-neutrino-program/).

Read More... (http://www.symmetrymagazine.org/article/cern-ramps-up-neutrino-program?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Anything to declare? (http://www.symmetrymagazine.org/article/anything-to-declare?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

4 days ago

Sometimes being a physicist means giving detector parts the window seat.

John Conway knows the exact width of airplane aisles (15 inches). He also personally knows the Transportation Security Administration operations manager at Chicago's O'Hare Airport. That's because Conway has spent the last decade transporting extremely sensitive detector equipment in commercial airline cabins.

"We have a long history of shipping particle detectors through commercial carriers and having them arrive broken," says Conway, who is a physicist

We have a long history of shipping particle detectors through commercial carriers and having them arrive broken,” says Conway, who is a physicist at the University of California, Davis. “So in 2007 we decided to start carrying them ourselves. Our equipment is our baby, so who better to transport it than the people whose work depends on it?”

Their instrument isn’t musical, but it’s just as fragile and irreplaceable as a vintage Italian cello, and it travels the same way. Members of the collaboration for the CMS experiment at CERN research center tested different approaches for shipping the instrument by embedding accelerometers in the packages. Their best method for safety and cost-effectiveness? Reserving a seat on the plane for the delicate cargo.

In November Conway accompanied parts of the new CMS pixel detector from the Department of Energy's Fermi National Accelerator Laboratory in Chicago to CERN in Geneva. The pixels are very thin silicon chips mounted inside a long cylindrical tube. This new part will sit in the heart of the CMS experiment and record data from the high-energy particle collisions generated by the Large Hadron Collider.

“It functions like the sensor inside a digital camera,” Conway said, “except it has 45 megapixels and takes 40 million pictures every second.”

Scientists and engineers assembled and tested these delicate silicon disks at Fermilab before Conway and two colleagues escorted them to Geneva. The development and construction of the component pieces took place at Fermilab and universities around the United States.

Conway and his colleagues reserved each custom-made container its own economy seat and then accompanied these precious packages through check-in, security and all the way to their final destination at CERN. And although these packages did not leave Fermilab through the shipping department, each carried its own official paperwork.

“We’d get a lot of weird looks when rolling them onto the airplane,” Conway says. “One time the flight crew kept joking that we were transporting dinosaur eggs.”

After four trips by three people across the Atlantic, all 12 components of the US-built pixel detectors are at CERN and ready for integration with their European counterparts. This winter the completed new pixel detector will replace its time-worn predecessor currently inside the CMS detector.

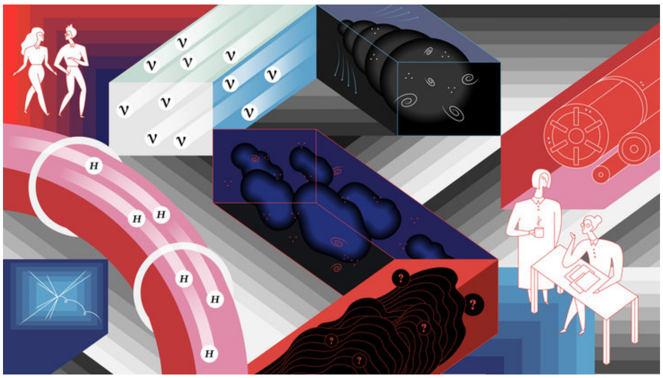
A version of this article was published by Fermilab (http://news.fnal.gov/2017/01/anything-to-declare/).

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

2016 year in particle physics (http://www.symmetrymagazine.org/article/2016-year-in-particle-physics?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Dec 20, 2016

Scientists furthered studies of the Higgs boson, neutrinos, dark matter, dark energy and cosmic inflation and continued the search for undiscovered particles, forces and principles.

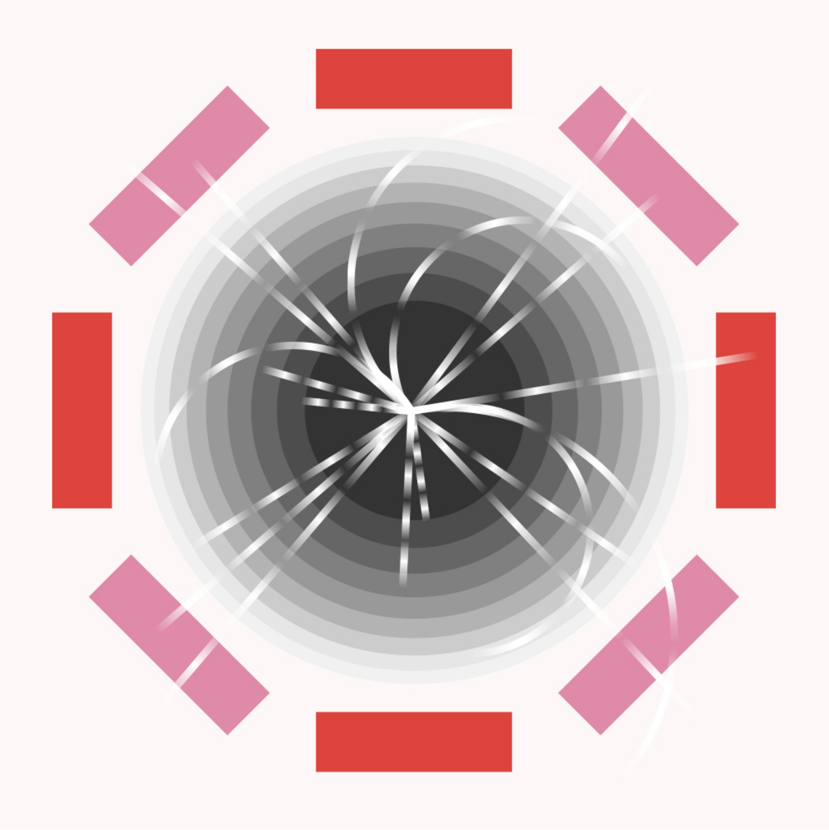


Working together, particle physicists from the US and around the globe made exciting advances this year in our understanding of the universe at the smallest and largest scales.

The LIGO experiment made the first detection of gravitational waves, originally predicted by Albert Einstein in 1916 in his general theory of relativity. And scientists have pushed closer to the next big discovery at experiments such as those at the Large Hadron Collider and at ultra-sensitive underground neutrino detectors.

The pursuit of particle physics is a truly international effort. It takes the combined resources and expertise of partnering nations to develop and use unique world-class facilities and advanced technology detectors.

Efforts in particle physics can be divided into five intertwined lines of inquiry: explorations of the Higgs boson, neutrinos, dark matter, cosmic acceleration and the unknown. Following this community vision enabled physicists to make major scientific advances in 2016 and set the stage for a fascinating future.



(http://www.symmetrymagazine.org/sites/default/files/images/standard/Inline_1_YearInReview_Higgs.jpg)

Illustration by Sandbox Studio, Chicago with Ana Kova

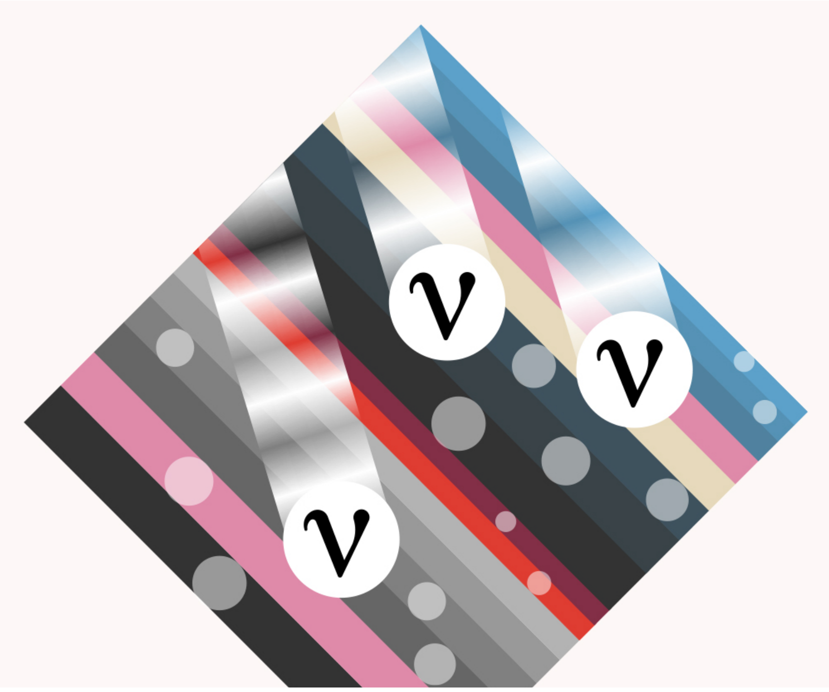
Using the Higgs boson as a new tool for discovery

The discovery of the Higgs boson in 2012 at the Large Hadron Collider at CERN opened a new door to understanding the universe. In 2016, the LHC produced roughly the same number of particle collisions that it did during all of its previous years of operation combined. At its current collision rate, it produces a Higgs boson about once per second.

While it will take time for the ATLAS and CMS experiment collaborations to digest this deluge of data, early results are already probing for any signs of unexpected Higgs boson behavior. In August, the ATLAS and CMS collaborations used data from the highest energy LHC collisions to “rediscover” the Higgs boson and confirm that it agrees with the predictions of the Standard Model of particle physics—so far. Deviations from the predictions would signal new physics beyond the Standard Model.

Since the LHC aims to continue running at its record pace for the next two years and more than double the delivered particle collisions to the experiments, this window to the universe is only beginning to open. The latest theoretical calculations of all of the major ways a Higgs boson can be produced and decay will enable rigorous new tests of the Standard Model.

US scientists are also ramping up efforts with their international partners to develop future upgrades for a High-Luminosity LHC that would provide 10 times the collisions and launch an era of high-precision Higgs-boson physics. Scientists have made significant progress this year in the development of more powerful superconducting magnets for the HL-LHC, including the production of a successful prototype that is currently the strongest accelerator magnet ever created.



(http://www.symmetrymagazine.org/sites/default/files/images/standard/Inline_2_YearInReview_Neutrinos.jpg)

Illustration by Sandbox Studio, Chicago with Ana Kova

Pursuing the physics associated with neutrino mass

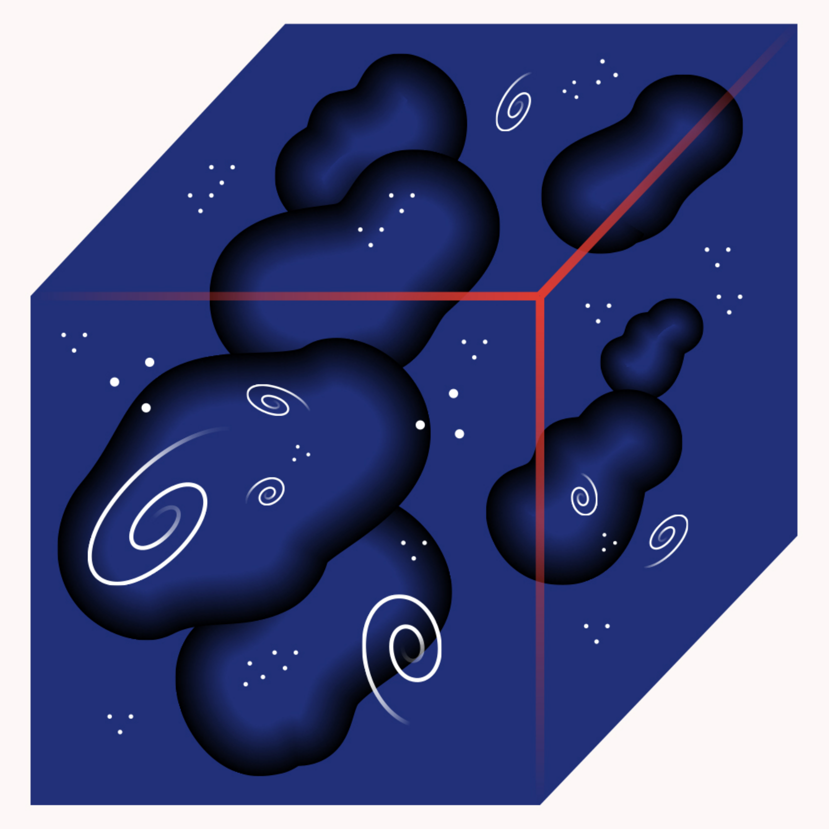
In 2016, several experiments continued to study ghostly neutrinos—particles so pervasive and aloof that 100 trillion of them pass through you each second. In the late '90s and early '00s, experiments in Japan and Canada found proof that these peculiar particles have some mass and that they can transform between types of neutrino as they travel.

A global program of experiments aims to address numerous remaining questions about neutrinos. Long-baseline experiments study the particles as they fly through the earth between Tokai and Kamioka in Japan or between Illinois and Minnesota in the US. These experiments aim to discern what masses neutrinos have and whether there are differences between the transformations of neutrinos and their antimatter partners, antineutrinos.

In July, the T2K experiment in Japan announced that their data showed a possible difference between the rate at which a muon neutrino turns into an electron neutrino and the rate at which a muon antineutrino turns into an electron antineutrino. The T2K data hint at a combination of neutrino properties that would also give the NOvA experiment in the US their most favorable chance of making a discovery about neutrinos in the next few years.

In China, construction is underway for the Jiangmen Underground Neutrino Observatory, which will investigate neutrino mass in an effort to determine which neutrino is the lightest.

In the longer term, particle physicists aim to definitively determine these answers by hosting the world-class Long-Baseline Neutrino Facility, which would send a high-intensity neutrino beam 800 miles from Illinois to South Dakota. There, the international Deep Underground Neutrino Experiment a mile beneath the surface would enable precision neutrino science.



(http://www.symmetrymagazine.org/sites/default/files/images/standard/Inline_3_YearInReview_DarkMatter.jpg)

Illustration by Sandbox Studio, Chicago with Ana Kova

Identifying the new physics of dark matter

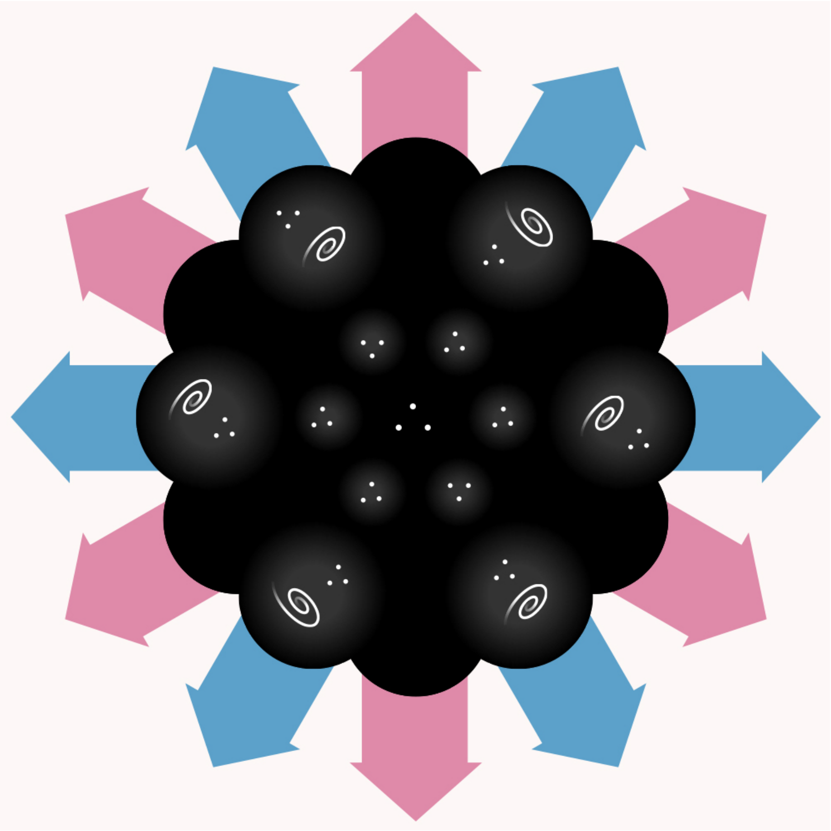
Overwhelming indirect evidence indicates that more than a quarter of the mass and energy in the observable universe is made up of an invisible substance called dark matter. But the nature of dark matter remains a mystery. Little is known about it other than that it interacts through gravity.

To guide the experimental search for dark matter, theorists have studied the possible interactions that known particles might have with a wide variety of potential dark matter candidates with possible masses ranging over more than a dozen orders of magnitude.

Huge sensitive detectors, such as the Large Underground Xenon, or LUX, experiment located a mile beneath the Black Hills of South Dakota, directly search for the dark matter particles that may be continually passing through Earth. This year, LUX completed the world's most sensitive search for direct evidence of dark matter, improving upon its own previous world's best search by a factor of four and narrowing the hiding space for an important class of theoretical dark matter particles.

In addition, data from the Fermi Gamma-ray Space Telescope and other facilities continued to tighten constraints on dark matter through indirect searches.

This sets the stage for a suite of complementary next-generation experiments—including LZ, SuperCDMS-SNOLAB and ADMX-G2 in the US—that aim to significantly improve sensitivity and reveal the nature of dark matter.



(http://www.symmetrymagazine.org/sites/default/files/images/standard/Inline_4_YearInReview_Inflation.jpg)

Illustration by Sandbox Studio, Chicago with Ana Kova

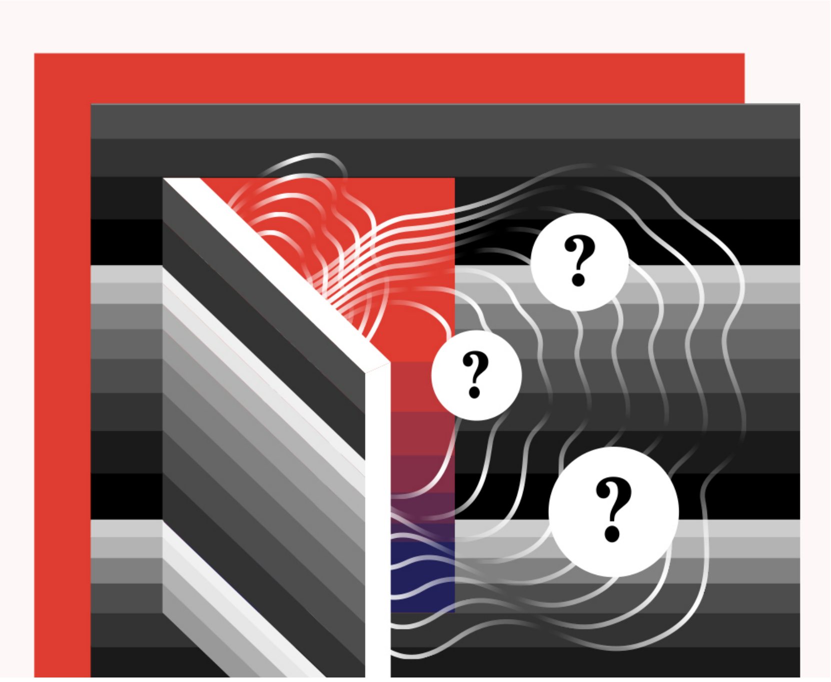
Understanding cosmic acceleration

Particle physicists turn to the sky in their efforts investigate a different mystery: Our universe is expanding at an accelerating rate. Scientists seek to understand the nature of dark energy, responsible for overcoming the force of gravity and pushing our universe apart.

Large-scale, ground-based cosmic surveys aim to measure the long-term expansion history of the universe and improve our understanding of dark energy. This year, scientists on the Baryon Oscillation Spectroscopic Survey used their final data set, comprising 1.5 million galaxies and quasars, to make improved measurements of the cosmological scale of the universe and the rate of cosmic structure growth. These measurements will allow theorists to test and refine models that aim to explain the origin of the current era of cosmic acceleration.

Through efforts that include private sector partnerships and international collaborations, US physicists aim to rapidly usher in the era of precision cosmology—and shed light on dark energy—with the ongoing Dark Energy Survey and the upcoming Dark Energy Spectroscopic Instrument and Large Synoptic Survey Telescope.

Community efforts are also underway to develop a next-generation cosmic microwave background experiment, CMB-S4. Precision measurements from CMB-S4 will not only advance dark energy studies and provide cosmic constraints on neutrino properties, but offer a way to probe the early era of cosmic acceleration known as inflation, which occurred at energies far greater than can be achieved in an accelerator on Earth.



(http://www.symmetrymagazine.org/sites/default/files/images/standard/Inline_5_YearInReview_Unknown.jpg)

Illustration by Sandbox Studio, Chicago with Ana Kova

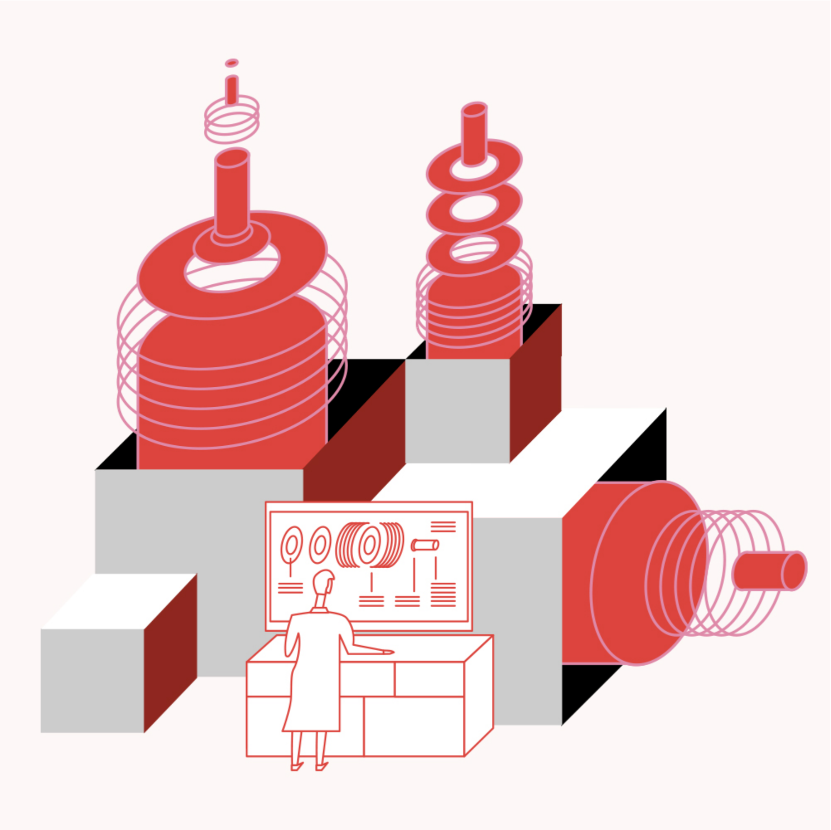
Exploring the unknown

Oftentimes, results from an experiment show a hint of something new and unexpected, and scientists must design new technology to determine if what they've seen is real. But between 2015 and 2016, scientists at the LHC both raised and answered their own question.

In late 2015, LHC scientists found an unexpected bump in their data, a possible first hint of a new particle. Theorists were on the case; early in 2016 they laid the framework for possible interpretations of the data and explored how it might impact the Standard Model of particle physics. But in August, experimentalists had gathered enough new data to deem the hint a statistical fluctuation.

Stimulated by the discovery of pentaquark and tetraquark states, some theorists have predicted that bound states of four b quarks should soon be observable at the LHC.

Experimentalists continue to test theorists' predictions against data by performing high-precision measurements or studying extremely rare particle decays at experiments such as the LHCb experiment at the LHC, the upcoming Belle II experiment in Japan and the Muon g-2 and Muon to Electron Conversion experiments at Fermi National Accelerator Laboratory.



(http://www.symmetrymagazine.org/sites/default/files/images/standard/Inline_6_YearInReview_Investment.jpg)

Illustration by Sandbox Studio, Chicago with Ana Kova

Investing in the future of discovery science

The world-class facilities and experiments that enable the global program of particle physics are built on a foundation of advanced technology. Ongoing research and development of particle accelerator and detector technology seed the long-term future prospects for discovery.

In 2016, scientists and engineers continued to make advances in particle accelerator technology to prepare to build next-generation machines and possible far-future facilities.

Advances in the efficiency of superconducting radio-frequency cavities will lead to cost savings in building and operating machines such as the Linac Coherent Light Source II. In February, researchers at the Berkeley Lab Laser Accelerator, or BELLA, demonstrated the first multi-stage accelerator based on "tabletop" laser-plasma technology. This key step is necessary to push toward far-future particle colliders that could be thousands of times shorter than conventional accelerators.

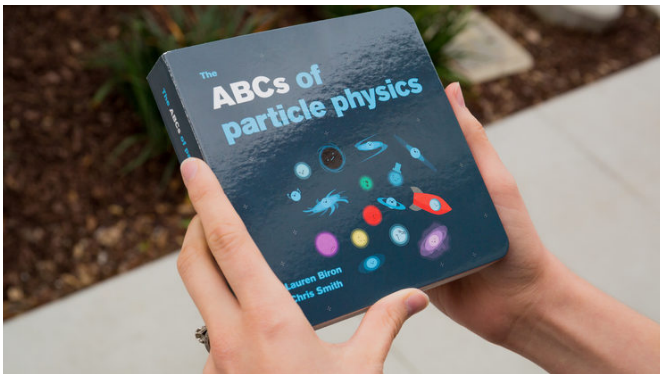
These results reflect only a small portion of the total scientific output of the particle physics community in 2016. The stage is set for exciting discoveries that will advance our understanding of the universe.

Read More... (http://www.symmetrymagazine.org/article/2016-year-in-particle-physics?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

The ABCs of Particle Physics board book (http://www.symmetrymagazine.org/article/the-abcs-of-particle-physics-board-book?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Dec 16, 2016

The ABCs of Particle Physics is currently available at public libraries and stores near Fermilab and SLAC.



For lovers of rhymes and anthropomorphic Higgs bosons, *Symmetry* presents its first published board book, *The ABCs of Particle Physics*. Use it as an illustrated guide to basic particle- and astrophysics terms, or read it to your infant at bedtime, if you don't mind their first word being "quark."

Find *The ABCs of Particle Physics* at these locations near Fermi National Accelerator Laboratory and SLAC National Accelerator Laboratory:

- Batavia Public Library (http://www.bataviapubliclibrary.org/)
- CuriOdyssey (http://curiodyssey.org/)
- Kepler's Books (http://www.keplers.com/)
- Lederman Science Center (http://ed.fnal.gov/lsc/)
- Menlo Park Library (http://menlopark.org/389/Library)
- Stanford Bookstore (http://www.bkstr.com/stanfordstore/shop/books/general-books-print)

The ABCs of Particle Physics is not yet available online.

Symmetry is published by Fermilab and SLAC. *The ABCs of Particle Physics* is educational in nature and the national laboratories do not profit from its sale.

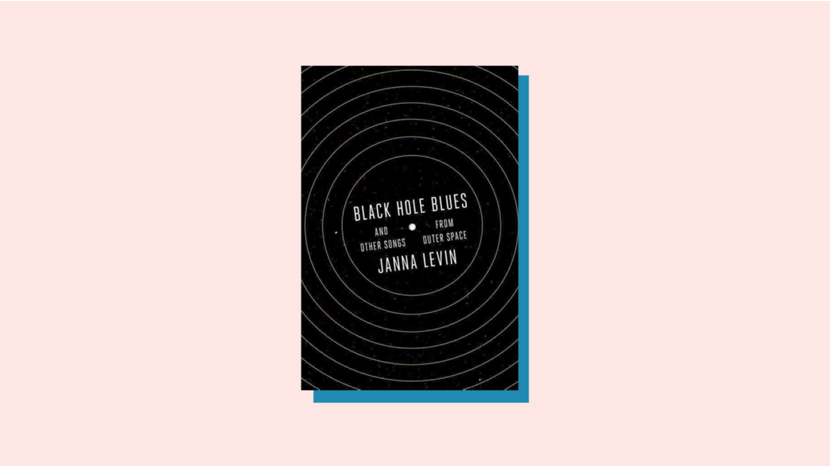
Read More... (http://www.symmetrymagazine.org/article/the-abcs-of-particle-physics-board-book?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Physics books of 2016 (http://www.symmetrymagazine.org/article/physics-books-of-2016?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Dec 15, 2016

As 2016 comes to a close, *Symmetry* writer Mike Perricone takes us through the latest additions to his collection of popular science books related to particle physics.

The year 2016 brought us books on topics such as gravitational waves, the "Pope" of physics, the history of science from the paper of record, and the concept of "now."

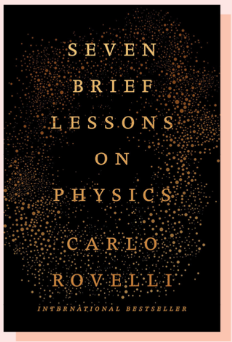


(http://www.symmetrymagazine.org/sites/default/files/images/standard/InLine_BookReview_2016_1.png)

Black Hole Blues, and Other Songs From Outer Space, by Janna Levin

The oldest sound scientists have ever heard was the "chirp" of gravitational waves emanating from a billions-of-years-old collision of two black holes. The sound was intercepted by the Laser Interferometer Gravitational-Wave Observatory, 40 years after the proposal for the detector was rejected.

With the deft touch of a novelist (*A Madman Dreams of Turing Machines, How the Universe Got its Spots*), Janna Levin, professor of physics and astronomy at Columbia University, follows the struggles of the project's original 1970s troika—Rai Weiss, Ron Drever and theorist Kip Thorne—and the eventual success of director Barry Barish, who spent 1994 to 2004 putting the project on solid footing.



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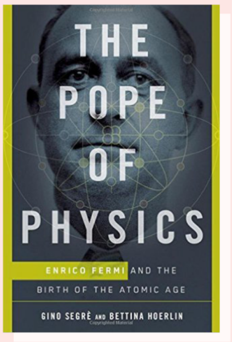
Seven Brief Lessons on Physics, by Carlo Rovelli

Carlo Rovelli, one of the founders of the loop quantum gravity theory and head of the quantum gravity group at the Centre de Physique Theorique of Aix-Marseille Université, takes readers through a history of physics from Einstein and Bohr to Heisenberg to Hawking.

Special acclaim goes to his translators, Simon Carnell and Erica Segre, who bring us phrases such as these from Rovelli's original Italian: "[B]efore experiments, measurements, mathematics and rigorous deductions, science is above all about visions. Science begins with a vision. Scientific thought is fed by the capacity to 'see' things differently than they have previously been seen." You'll want to memorize this poetic gem.



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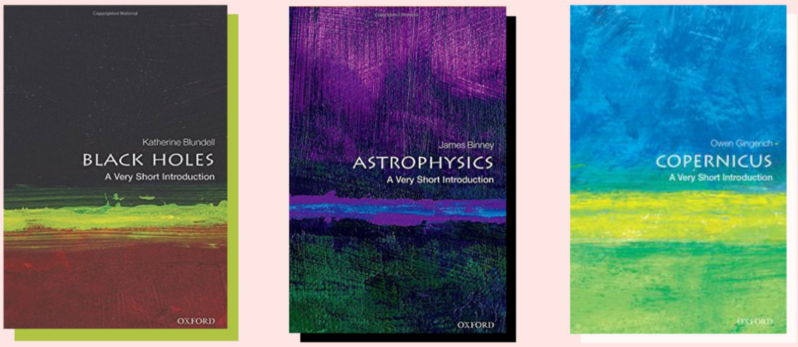
The Pope of Physics: Enrico Fermi and the Birth of the Atomic Age, by Bettina Hoerlein and Gino Segré

Fermi method. Fermi questions. Fermi surface. Fermi sea. Fermions. Fermi Institute. Fermi Gamma-ray Space Telescope. Physicist Enrico Fermi, known in part for creating the world's first nuclear reactor, definitely left his mark on physics.

Fermi won the Nobel Prize in 1938, and in the following years the prize went to no less than six of Fermi's students. As a scientist, he was considered infallible: Colleagues and students in Rome dubbed him "the Pope."

Co-authors Bettina Hoerlein and spouse Gino Segré—the nephew of Nobel Laureate Emilio Segré, Fermi's student and lifelong friend—piece together a human picture of the brilliant scientist.



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A Very Short Introduction to . . .

Part of a long-running and incredibly far-reaching series from Oxford University Press, *Very Short Introductions* combines sound science with brisk, accessible writing by eminent scientists. Averaging about 150 pages, this year's top physics-related offerings include:

- *Black Holes*, by Katherine Blundell: What we know and don't know about black holes; how they are created and discovered; separating fact from fiction. This title is especially timely this year with LIGO's detection of gravitational waves from the collision of two black holes. Blundell is a Professor of Astronomy at Oxford.
- *Astrophysics*, by James Binney: The physics of supernovae, planetary systems, and the application of special and general relativity. Binney,

an astronomer at Oxford University, has won the Maxwell and Dirac Medals.

- *Copernicus*, by Owen Gingerich: Regarded as the major authority on Copernicus, Gingerich places Copernicus in the context of his time and his place in the scientific revolution. Gingerich is Senior Astronomer Emeritus at Smithsonian Astrophysical Observatory.

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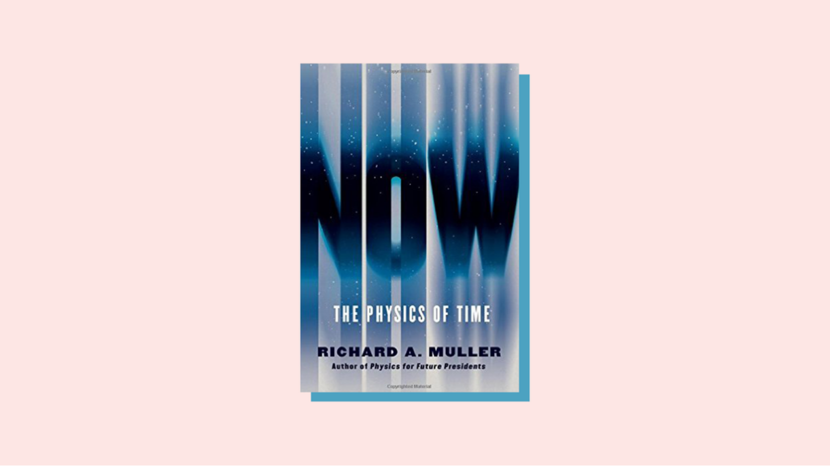
The New York Times Book of Science: 150 Years of Science Reporting in the New York Times, Edited by David Corcoran, former editor of weekly Science Times

In this tour through a century and a half of science reporting by *The New York Times*, the sections on astronomy and physics are not to be missed.

From the archives come headlines such as “Star Birth Sudden, Lemaitre Asserts,” from a 1933 conference in Britain (with quotes from early cosmology luminaries William deSitter and Sir Arthur Eddington) and “Einstein Expounds His New Theory,” written in 1919. In the 1919 article, Einstein insists to the reporter endeavoring to explain his extraordinary concepts to lay readers, “I am trying to talk as plainly as possible.”



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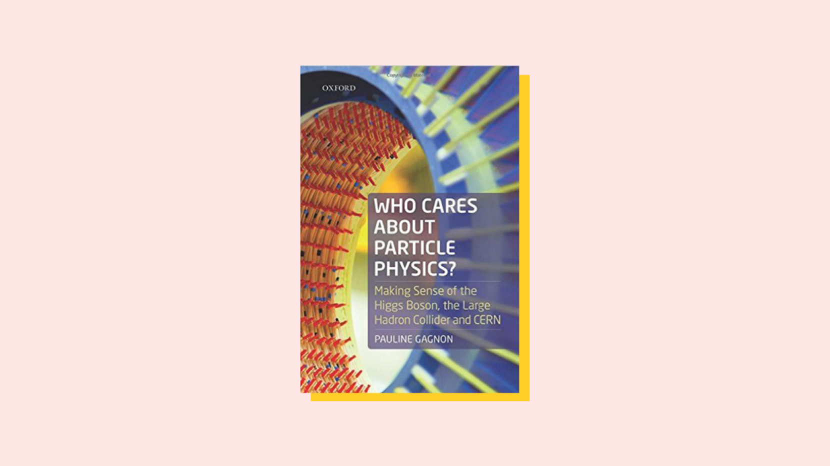
NOW: The Physics of Time, by Richard A. Muller

Einstein was somewhat casual about time, saying “The only reason for time is so that everything doesn’t happen at once.”

Richard Muller, experimental cosmologist, professor of physics at the University of California, Berkeley and author of *Physics for Future Presidents*, has more use for the concept. In this book, he explains that “the flow of time is the continual creation of new *nows*.” Muller takes on all comers and gets into plenty of arguments along the way.



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Who Cares About Particle Physics? Making Sense of the Higgs Boson, the Large Hadron Collider and CERN, by Pauline Gagnon

Pauline Gagnon, an experimenter on the LHC’s CMS experiment, cut her teeth writing a widely read blog during the final two years of the search for the Higgs boson. In her first book, Gagnon explains the experimental process to non-scientists.

Each chapter concludes with summaries of key points, and in the final chapter, she assures readers the LHC is still in its early stages. Don’t miss the appendix on the possible (and probable) contributions to Einstein’s stunning early work by his first wife, Mileva Maric Einstein.

(http://www.symmetrymagazine.org/sites/default/files/images/standard/InLine_BookReview_2016_10.png)

Welcome to the Universe: An Astrophysical Tour, by Neil deGrasse Tyson, Michael A. Struss and J. Richard Gott

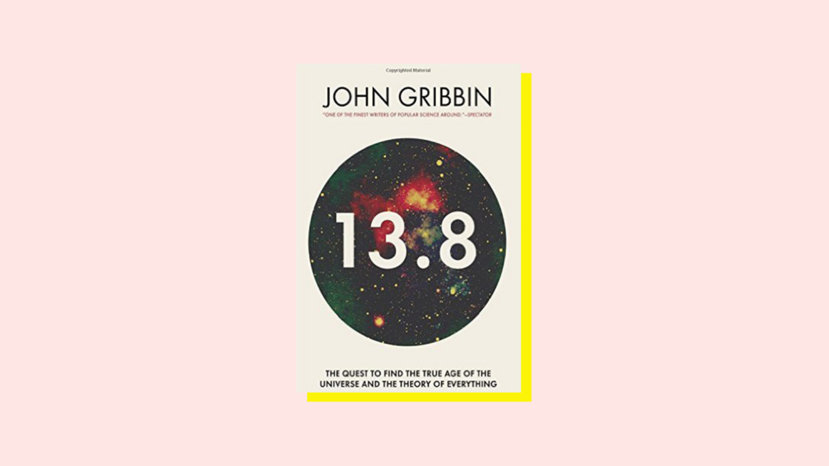
Looking like a cross between a textbook and a coffee-table book, *Welcome to the Universe* is an extremely readable compilation of introductory astronomy lectures for non-science students given by Neil deGrasse Tyson, Michael A. Strauss and J. Richard Gott at Princeton University. Their talks present physics with clarity and a little levity—with references to pop culture items such as *Toy Story* and *Bill and Ted's Excellent Adventure*. Gott even tackles time travel. What's not to like?

(http://www.symmetrymagazine.org/sites/default/files/images/standard/InLine_BookReview_2016_7.png)

The Cosmic Web: Mysterious Architecture of the Universe, by J. Richard Gott

J. Richard Gott was one of the first to describe the structure of the universe as being similar to a sponge, made up of holey surfaces divided into equal, interlocked parts. The concept may sound strange, but it has since been confirmed by numerous surveys of the sky.

A combination of anecdotes, physics and math, this one is a challenge. You'll need your cosmic thinking cap.



(http://www.symmetrymagazine.org/sites/default/files/images/standard/InLine_BookReview_2016_5.png)

13.8: The Quest to Find the True Age of the Universe and the Theory of Everything, by John Gribbin

Visiting Fellow in Astronomy at the University of Sussex in the UK and veteran science author John Gribbin (best known for *In Search of Shrödinger's Cat*) wants to synthesize the great theories of the 20th century—general relativity and quantum mechanics—into his own search for a Theory of Everything.

In his explanation, related to the estimated age of the universe—13.8 billion years—Gribbin pays special attention to often-overlooked women scientists Henrietta Swan Leavitt (who proposed using Cepheid variable stars as standard candles) and Cecilia Payne (who first predicted that hydrogen was the most common element in the universe).

Read More... (http://www.symmetrymagazine.org/article/physics-books-of-2016?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Science with sprinkles (http://www.symmetrymagazine.org/article/science-with-sprinkles?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Dec 13, 2016

Holiday guests will gravitate toward these physics cookies.

Want your holiday cookies to stand out this year among the usual snowflakes and Santa Clauses? Show your smarts with these scientific cookie decorations.

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

Gravitational wave cookies

Cookies by Sandbox Studio, Chicago with Jill Preston

This winter, why not celebrate the recent discovery of gravitational waves (http://www.symmetrymagazine.org/article/ligo-sees-gravitational-waves)? Albert Einstein first predicted them 100 years ago in his general theory of relativity. Now you can depict them in dessert form.

Two dark brown M&Ms in the center of this physics cookie represent massive black holes that merged billions of years ago in a collision whose impact was, according to Caltech physicist Kip Thorne, “50 times greater than all the power put out by all the stars in the universe put together.”

The swirl design of the pinwheel sugar cookie represents the resulting ripples in space-time, which eventually made their way to the twin detectors of the Laser Interferometer Gravitational-Wave Observatory. Sprinkles around the edge are just for show.

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

Neutrino cookies

Cookies by Sandbox Studio, Chicago with Jill Preston

Neutrinos (http://www.symmetrymagazine.org/article/june-2015/how-do-you-solve-a-puzzle-like-neutrinos) come in three types, appropriately called “flavors.” The symbol for neutrinos is the Greek letter “nu,” which resembles a lowercase “v.” Three nu’s, each drawn in a different flavor of icing, will fit perfectly on a snowflake- or flower-shaped cookie.

If you spin your cookie, you can observe a fascinating behavior of neutrinos: oscillation. Neutrinos change from one flavor into the other as they travel, a fact that might have influenced the evolution of our universe.

Just like snowflakes, neutrinos are elusive; even if you catch them you can't enjoy them for long. But they are also one of the most abundant particles in the universe, so don't skimp on the sprinkles.

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

Detector cookies

Cookies by Sandbox Studio, Chicago with Jill Preston

To learn more about the building blocks of our universe, scientists build particle accelerators such as the Large Hadron Collider and cause particles to collide at velocities close to the speed of light. Huge detectors are built around collision points to spot new particles, such as the Higgs boson, that are created out of the impact's energy.

What could be sweeter than a sugar cookie that depicts the beautiful layering of the cross-section of one of these gigantic detectors?

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

Penguin diagram cookies

Cookies by Sandbox Studio, Chicago with Jill Preston

In 1977 John Ellis, a theoretical physicist, lost a bet in a pub to Melissa Franklin, same profession, and was compelled to use the word "penguin" in his next scientific publication.

He decided a drawing called a Feynman diagram—a way to sketch a particle decay process—somewhat resembled the flightless Antarctic bird. He dubbed the diagram for a decay of the bottom quark a "penguin diagram (http://www.symmetrymagazine.org/article/june-2013/the-march-of-the-penguin-diagrams)." It caught on, and now the term is well known in the particle physics community.

If you happen to have a penguin cookie cutter, you're in luck. Decorate it as you'd like (add a scarf if you want) and add the lines of the Feynman diagram in icing on top. See? It fits!

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

Universe cookies

Cookies by Sandbox Studio, Chicago with Jill Preston

Now you can make a cookie that is not only delicious, but also shows how much we don't know about the contents of our universe.

To make a universe cookie, cover 73 percent of it with Oreo chunks representing dark energy (http://www.symmetrymagazine.org/article/june-2015/what-is-dark-energy). Dark energy is responsible for the accelerating expansion of our universe, but there's a lot we don't know about it.

Cover another 23 percent of your cookie with glitter representing dark matter (http://www.symmetrymagazine.org/article/what-could-dark-matter-be). Scientists have seen the gravitational effect of dark matter on galaxies and stars, but they've never seen it directly.

Cover the last 4 percent of your cookie with a tiny stripe of crushed peppermint representing the known matter in the universe. This includes all of the planets and stars that we can see.

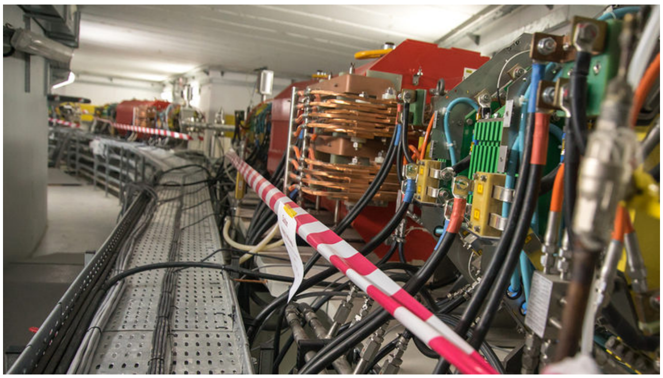
These eye-catching physics cookies aren't just delicious, they're also great conversation-starters. So grab your mug of hot cocoa and be ready to talk about sprinkles, the universe and everything.

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

SESAME to open in 2017 (http://www.symmetrymagazine.org/article/sesame-to-open-in-2017?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Dec 9, 2016

The first synchrotron radiation source in the Middle East is running tests before its planned 2017 start.



Scientists and engineers at the first synchrotron radiation source in the Middle East have begun commissioning, a major milestone before officially starting operations in 2017.

When fully operational, the facility in Allan, Jordan, called SESAME, will mark a major victory for science in the region and also for its international backers. Like CERN, SESAME was established under the auspices of UNESCO, but it is now an independent intergovernmental organization and aims to facilitate peace through scientific collaboration that might supersede political divisions. Countries and labs the world over have responded to that vision by contributing to SESAME's design, instrumentation and construction.

SESAME, which stands for The Synchrotron-light for Experimental Science and Applications in the Middle East, is a 133-meter circumference storage ring built to produce intense radiation ranging from infrared to X-rays, given off by electrons circling inside it at high energies. At the heart of SESAME are injector components from BESSY I, a Berlin-based synchrotron that was decommissioned in 1999, donated to SESAME and upgraded to support a completely new 2.5-GeV storage ring. With funding provided in part by the European Commission and construction led by CERN in collaboration with SESAME, the new ring is on par with most modern synchrotrons.

Now that the machine is largely complete, technicians can perform quality testing before researchers gain access and determine whether the light source can accomplish its scientific mission.

"The first scientific mission of SESAME is to promote excellence in science in the Middle East," says Zehra Sayers, chair of SESAME's scientific committee and also a faculty member at Sabanci University in Istanbul, Turkey.

Over the past decade, SESAME has organized regular users meetings each year to discuss and develop proposed research plans. That community is now over 200 strong. The international facility hosts members from Bahrain, Cyprus, Egypt, Iran, Israel, Jordan, Pakistan, the Palestinian Authority and Turkey.

(http://www.symmetrymagazine.org/sites/default/files/images/standard/SESAME2-s.jpg)

14th SESAME users' meeting

Noemi Caraban, SESAME

"It is very important for us to be able to perform high quality science at SESAME," Sayers says. "Because that is what will make it viable, only then people will want to come here to do experiments, and only then people will think that this is really where they can find answers to their questions."

Dozens of synchrotrons in other locations throughout the world have already proven themselves as research hubs. Synchrotrons create ultra-bright light radiation and channel it into instruments used for advanced imaging research, with applications ranging from materials science to drug discovery.

No synchrotrons existed in the Middle East until now. Political turbulence can make access to other facilities abroad challenging. Sayers says she is confident that SESAME will fill the need for a local laboratory.

The new facility creates an opportunity for regional scientists to collaborate, for example, to study shared cultural heritage. The SESAME light source will be used to identify materials in ancient, cultural artifacts such as textiles and dyes, parchments and inks, and could reveal new information about how the materials were originally prepared.

Researchers will initially have access to two beamlines of different wavelengths when operations begin. The facility has capacity for 25 beamlines, and it is expected that within a year two more beamlines will become available. As beamlines are added, the number of applications will grow to encompass diverse fields such as archeology, molecular biology, materials science and environmental science.

The potential diversity is one of SESAME's greatest strengths, says Maher Attal, who is coordinating the commissioning process. Twelve straight sections of the machine have the capacity for installing insertion devices, series of small dipole magnets that tune the spectrum of the emitted synchrotron light. This makes SESAME a "third generation" light source. SESAME's materials science beamline, which will come into operation in 2017 or 2018 will be the first to be supplied with light from such a device.

SESAME is undergoing a period of testing and quality control that usually takes several months. After technicians install and test the individual components, they will guide the beam through the whole machine at low energy to allow scientists to perfect its alignment, then to make measurements and corrections if its performance deviates too far from predicted values. The machine then must pass the same inspections at its maximum energy before the synchrotron officially opens.

"We expect to deliver the first photon beam to the users in April 2017," Attal says.

Scientists will be watching and waiting.

"We owe it to the region to make SESAME a success," Sayers says. "It will be a ray of hope in a time of turmoil."

Read More... (http://www.symmetrymagazine.org/article/sesame-to-open-in-2017?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

A syllabus in cosmic rays (http://www.symmetrymagazine.org/article/a-syllabus-in-cosmic-rays?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Dec 8, 2016

What have scientists learned in five years of studying cosmic rays with the Alpha Magnetic Spectrometer experiment?

On May 19, 2011, astronauts used a remote-controlled robotic arm to attach a nearly 17,000-pound payload to the side of the International Space Station. That payload was the Alpha Magnetic Spectrometer, or AMS-02, an international experiment sponsored by the US Department of Energy and NASA.

AMS was designed to detect cosmic rays, highly energetic particles and nuclei that bombard the Earth from space. Since its installation, AMS has collected data from more than 90 billion cosmic ray events, experiment lead Sam Ting reported today in a colloquium at the experiment's headquarters, CERN European research center.

Ting, a Nobel Laureate and Thomas Dudley Cabot Professor of Physics at the Massachusetts Institute of Technology, shared a mix of new and recent results during his talk. Together they spelled out the persistent message of the AMS experiment: We have a lot left to learn from cosmic rays.

For one, cosmic rays could tell us about the imbalance between matter and antimatter in the universe.

Because matter and antimatter particles are created in pairs, scientists think the Big Bang should have produced half of each. But those evenly matched partners would have annihilated one another, and we would not exist.

The generally accepted theory is that this imbalance came about thanks to processes in the very young universe that favor matter over antimatter. But an alternative idea is that a large amount of antimatter is still out there; it just hasn't had a chance to collide with our matter-filled universe.

One clue that this is the case would be finding an antimatter nucleus in the wild.

With the negligible amount of antimatter that exists in our universe, "it's almost impossible to make anything bigger than a proton," says AMS Deputy Principal Investigator Mike Capell of MIT. "Getting the antimatter together to collide into an antihelium or anticarbon nucleus is not very probable."

AMS scientists do not claim to have detected antihelium, but they did announce that they have not ruled out "a few" candidate events.

"Given the success of the standard cosmological model and the absence of gamma rays from hypothetical matter-antimatter interfaces, I think it's very implausible that there'd be whole galaxies made of antimatter," says theoretical astrophysicist Roger Blandford of the Kavli Institute for Particle Astrophysics and Cosmology, a joint institute of Stanford University and SLAC National Accelerator Laboratory. "But it's the sort of investigation that could still give us a surprising discovery."

Cosmic rays could also tell us something about dark matter, which has never been detected directly.

Cosmic rays can consist of a variety of particles, such as electrons or their antimatter counterparts, positrons. In previous measurements, AMS detected a surprising number of positrons on the higher end of its energy range. It is possible that collisions between dark matter particles created this excess of antimatter particles.

An updated analysis—this one using almost double the number of electrons and positrons—continues to show this excess. But dark matter isn't the only possible cause, Blandford says.

"One interpretation is that one is seeing the annihilation of dark matter particles," he says. "But there might be equally reasonable explanations associated with traditional astrophysics that could make the same sort of signal."

Pulsars are a particularly difficult alternative source to rule out. But AMS scientists anticipate that they will collect enough data to better discriminate between models by 2024, Ting said in his presentation.

Cosmic rays could tell us about their history.

As particles in cosmic rays approach light speed, time effectively slows down for them, as Albert Einstein predicted in his theory of relativity. We can see evidence of time dilation in the extended lifetimes of particles traveling near light speed.

In a forthcoming AMS result, scientists look at just how much the lifetimes of isotopes of beryllium stretch as they travel in cosmic rays. Based on that measurement, they estimate the cosmic rays we see in our galaxy are about 12 million years old.

Cosmic rays could tell us about what they go through on their trip to Earth.

Both observation and theory have a ways to go in this area, Blandford says. "They are both works in progress and, despite great advances, we still do not understand how cosmic rays propagate from their sources—mainly supernova remnants—to Earth. "

When cosmic rays get into collisions, they can produce secondary cosmic rays, which are made up of different ingredients. In a recently published result studying the ratio of boron (found only in secondary cosmic rays) to carbon (found in primary cosmic rays) at different energies, AMS scientists found possible evidence of turbulence in the cosmic rays' path to our planet—but nothing that would explain the positron excess.

Finally, cosmic rays could tell us that we don't know what we think we know.

In an unpublished analysis, AMS scientists found that their measurements of the spectra and ratios of different nuclei—protons, lithium and helium—did not fit well with predictions. This could mean that scientists' assumptions about cosmic rays need to be reexamined.

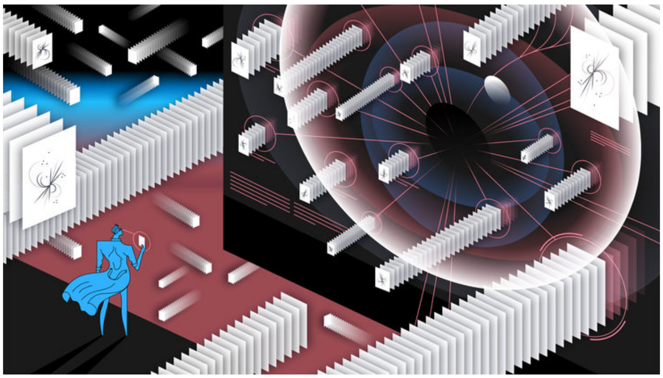
AMS scientists want to help with that. They plan to collect data from hundreds of billions of primary cosmic rays in the coming years as their experiment continues its orbit about 240 miles above the Earth.

Read More... (http://www.symmetrymagazine.org/article/a-syllabus-in-cosmic-rays?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Deep learning takes on physics (http://www.symmetrymagazine.org/article/deep-learning-takes-on-physics?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Dec 6, 2016

Can the same type of technology Facebook uses to recognize faces also recognize particles?



When you upload a photo of one of your friends to Facebook, you set into motion a complex behind-the-scenes process. An algorithm whirs away, analyzing the pixels in the photo until it spits out your friend's name. This same cutting-edge technique enables self-driving cars to distinguish pedestrians and other vehicles from the scenery around them.

Can this technology also be used to tell a muon from an electron? Many physicists believe so. Researchers in the field are beginning to adapt it to analyze particle physics data.

Proponents hope that using deep learning will save experiments time, money and manpower, freeing physicists to do other, less tedious work. Others hope they will improve the experiments' performance, making them better able to identify particles and analyze data than any algorithm used before. And while physicists don't expect deep learning to be a cure-all, some think it could be key to warding off an impending data-processing crisis.

Neural networks

Up until now, computer scientists have often coded algorithms by hand, a task that requires countless hours of work with complex computer languages. "We still do great science," says Gabe Perdue, a scientist at Fermi National Accelerator Laboratory. "But I think we could do better science."

Deep learning, on the other hand, requires a different kind of human input.

One way to conduct deep learning is to use a convolutional neural network, or CNN. CNNs are modeled after human visual perception. Humans process images using a network of neurons in the body; CNNs process images through layers of inputs called nodes. People train CNNs by feeding them pre-processed images. Using these inputs, an algorithm continuously tweaks the weight it places on each node and learns to identify patterns and points of interest. As the algorithm refines these weights, it becomes more and more accurate, often outperforming humans.

Convolutional neural networks break down data processing in a way that short-circuits steps by tying multiple weights together, meaning fewer elements of the algorithm have to be adjusted.

CNNs have been around since the late '90s. But in recent years, breakthroughs have led to more affordable hardware for processing graphics, bigger data sets for training and innovations in the design of the CNNs themselves. As a result, more and more researchers are starting to use them.

The development of CNNs has led to advances in speech recognition and translation, as well as in other tasks traditionally completed by humans. A London-based company owned by Google used a CNN to create AlphaGo, a computer program that in March beat the second-ranked international player of Go, a strategy board game far more complex than chess.

CNNs have made it much more feasible to handle previously prohibitively large amounts of image-based data—the kind of amounts seen often in high-energy physics.

Reaching the field of physics

CNNs became practical around the year 2006 with the emergence of big data and graphics processing units, which have the necessary computing power to process large amounts of information. "There was a big jump in accuracy, and people have been innovating like wild on top of that ever since," Perdue says.

Around a year ago, researchers at various high-energy experiments began to consider the possibility of applying CNNs to their experiments. "We've turned a physics problem into, 'Can we tell a car from a bicycle?'" says SLAC National Accelerator Laboratory researcher Michael Kagan. "We're just figuring out how to recast problems in the right way."

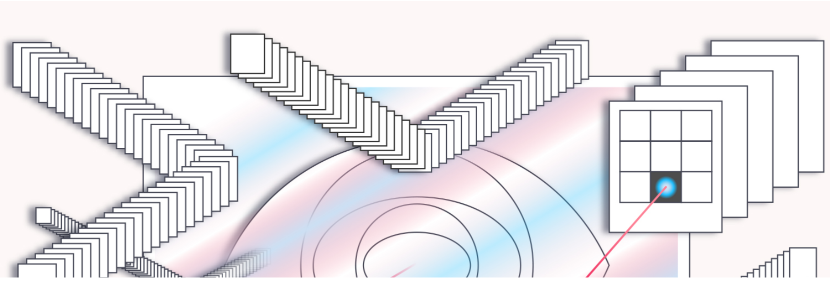
For the most part, CNNs will be used for particle identification and classification and particle-track reconstruction. A couple of experiments are already using CNNs to analyze particle interactions, with high levels of accuracy. Researchers at the NOvA neutrino experiment, for example, have applied a CNN to their data.

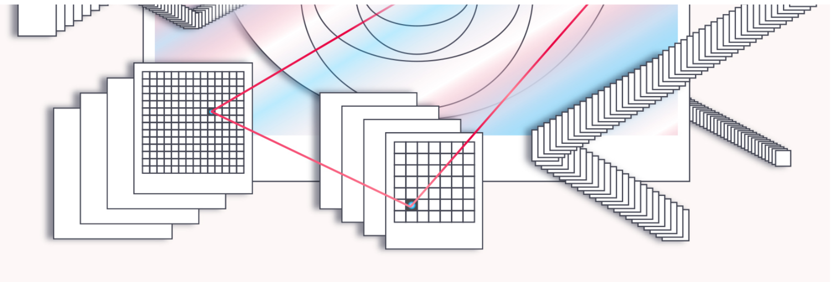
"This thing was really designed for identifying pictures of dogs and cats and people, but it's also pretty good at identifying these physics events," says Fermilab scientist Alex Himmel. "The performance was very good—equivalent to 30 percent more data in our detector."

Scientists on experiments at the Large Hadron Collider hope to use deep learning to make their experiments more autonomous, says CERN physicist Maurizio Pierini. "We're trying to replace humans on a few tasks. It's much more costly to have a person watching things than a computer."

CNNs promise to be useful outside of detector physics as well. On the astrophysics side, some scientists are working on developing CNNs that can discover new gravitational lenses, massive celestial objects such as galaxy clusters that can distort light from distant galaxies behind them. The process of scanning the telescope data for signs of lenses is highly time-consuming, and normal pattern-recognizing programs have a hard time distinguishing their features.

"It's fair to say we've only begun to scratch the surface when it comes to using these tools," says Alex Radovic, a postdoctoral fellow at The College of William & Mary who works on the NOvA experiment at Fermilab.





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

Illustration by Sandbox Studio, Chicago with Ana Kova

The upcoming data flood

Some believe neural networks could help avert what they see as an upcoming data processing crisis.

An upgraded version of the Large Hadron Collider planned for 2025 will produce roughly 10 times as much data. The Dark Energy Spectroscopic Instrument will collect data from about 35 million cosmic objects, and the Large Synoptic Survey Telescope will capture high-resolution video of nearly 40 billion galaxies.

Data streams promise to grow, but previously exponential growth in the power of computer chips is predicted to falter. That means greater amounts of data will become increasingly expensive to process.

“You may need 100 times more capability for 10 times more collisions,” Pierini says. “We are going toward a dead end for the traditional way of doing things.”

Not all experiments are equally fit for the technology, however.

“I think this'll be the right tool sometimes, but it won’t be all the time,” Himmel says. “The more dissimilar your data is from natural images, the less useful the networks are going to be.”

Most physicists would agree that CNNs are not appropriate for data analysis at experiments that are just starting up, for example—neural networks are not very transparent about how they do their calculations. “It would be hard to convince people that they have discovered things,” Pierini says. “I still think there’s value to doing things with paper and pen.”

In some cases, the challenges of running a CNN will outweigh the benefits. For one, the data need to be converted to image form if they aren’t already. And the networks require huge amounts of data for the training—sometimes millions of images taken from simulations. Even then, simulations aren’t as good as real data. So the networks have to be tested with real data and other cross-checks.

“There’s a high standard for physicists to accept anything new,” says Amir Farbin, an associate professor of physics at The University of Texas, Arlington. “There’s a lot of hoops to jump through to convince everybody this is right.”

Looking to the future

For those who are already convinced, CNNs spawn big dreams for faster physics and the possibility of something unexpected.

Some look forward to using neural networks for detecting anomalies in the data—which could indicate a flaw in a detector or possibly a hint of a new discovery. Rather than trying to find specific signs of something new, researchers looking for new discoveries could simply direct a CNN to work through the data and try to find what stands out. “You don’t have to specify which new physics you’re searching for,” Pierini says. “It’s a much more open-minded way of taking data.”

Someday, researchers might even begin to take tackle physics data with unsupervised learning. In unsupervised learning, as the name suggests, an algorithm would train with vast amounts of data without human guidance. Scientists would be able to give algorithms data, and the algorithms would be able to figure out what conclusions to draw from it themselves.

“If you had something smart enough, you could use it to do all types of things,” Perdue says. “If it could infer a new law of nature or something, that would be amazing.”

“But,” he adds, “I would also have to go look for new employment.”

Read More... (http://www.symmetrymagazine.org/article/deep-learning-takes-on-physics?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Viewing our turbulent universe (http://www.symmetrymagazine.org/article/viewing-our-turbulent-universe?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Dec 2, 2016

Construction has begun for the CTA, a discovery machine that will study the highest energy objects and events across the entire sky.

Billions of light-years away, a supermassive black hole is spewing high-energy radiation, launching it far outside of the confines of its galaxy. Some of the gamma rays released by that turbulent neighborhood travel unimpeded across the universe, untouched by the magnetic fields threading the cosmos, toward our small, rocky, blue planet.

We have space-based devices, such as the Fermi Gamma-ray Space Telescope, that can detect those messengers, allowing us to see into the black hole’s extreme environment or search for evidence of dark matter. But Earth’s atmosphere blocks gamma rays. When they meet the atmosphere, sequences of interactions with gas molecules break them into a shower of fast-moving secondary particles. Some of those generated particles—which could be, for example, fast-moving electrons and their antiparticles, positrons—speed through the atmosphere so quickly that they generate a faint flash of blue light, called Cherenkov radiation.

A special type of telescope—large mirrors fitted with small reflective cones to funnel the faint light—can detect this blue flash in the atmosphere. Three observatories equipped with Cherenkov telescopes look at the sky during moonless hours of the night: VERITAS in Arizona has an array of four; MAGIC in La Palma, Spain, has two; and HESS in Namibia, Africa, has an array of five. All three observatories have operated for at least 10 years, revealing a gamma-ray sky to astrophysicists.

“Those telescopes really have helped to open the window, if you like, on this particular region of the electromagnetic spectrum,” says Paula Chadwick, a gamma-ray astronomer at Durham University in the United Kingdom. But that new window has also hinted at how much more there is to learn.

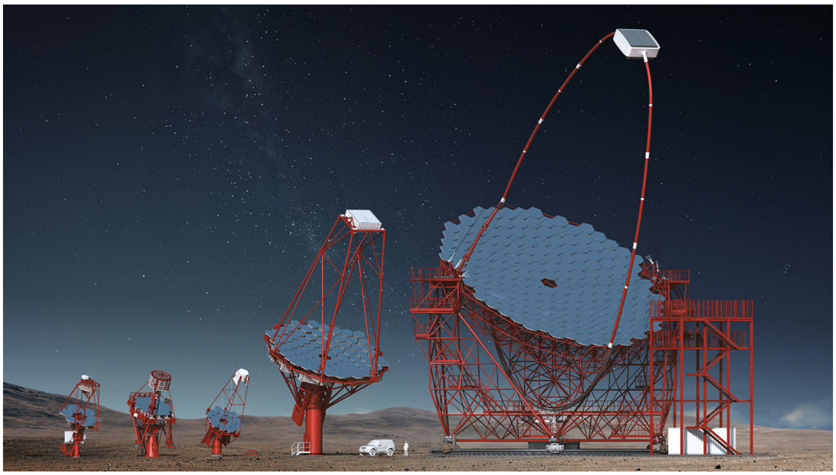
“It became pretty clear that what we needed was a much bigger instrument to give us much better sensitivity,” she says. And so gamma-ray scientists have been working since 2005 to develop the next-generation Cherenkov observatory: “a discovery machine,” as Stefan Funk of Germany’s Erlangen Centre for Astroparticle Physics calls it, that will reveal the highest energy objects and events across the entire sky. This is the Cherenkov Telescope Array (CTA), and construction has begun.

Ironing out the details

As of now, nearly 1400 researchers and engineers from 32 countries are members of the CTA collaboration, and membership continues to grow.

"If we look at the number of CTA members as a function of time, it's essentially a linear increase," says CTA spokesperson Werner Hofmann.

Technology is being developed in laboratories spread across the globe: in Germany, Italy, the United Kingdom, Japan, the United States (supported by the NSF—given the primarily astrophysics science mission of the CTA, it is not a part of the Department of Energy High Energy Physics program), and others. Those nearly 1400 researchers are collaborating and working together to gain a better understanding of how our universe works. "It's the science that's got everybody together, got everybody excited, and devoting so much of their time and energy to this," Chadwick says.



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

G. Pérez, IAC, SMM

The CTA will be split between two locations, with one array in the Northern Hemisphere and a larger one in the Southern Hemisphere. The dual location enables a view of the entire sky.

CTA's northern site will host four large telescopes (23 meters wide) and 15 medium telescopes (12 meters wide). The southern site will also host four large telescopes, plus 25 medium and 70 small telescopes (4 meters) that will use three different designs. The small telescopes are equipped to capture the highest energy gamma rays, which emanate, for example, from the center of our galaxy. That high-energy source is visible only from the Southern Hemisphere.

In July 2015, the CTA Observatory (CTAO) council—the official governing body that acts on behalf of the observatory—chose their top locations in each hemisphere. And in 2016, the council has worked to make those preferences official. On September 19 the council and the Instituto de Astrofísica de Canarias signed an agreement stating that the Roque de los Muchachos Observatory on the Canary Island of La Palma would host the northern array and its 19 constituent telescopes. This same site hosts the current-generation Cherenkov array MAGIC.

Construction of the foundation is progressing at the La Palma site to prepare for a prototype of the large telescope. The telescope itself is expected to be complete in late 2017.

"It's an incredibly aggressive schedule," Hofmann says. "With a bit of luck we'll have the first of these big telescopes operational at La Palma a year from now."

While the large telescope prototype is being built on the La Palma site, the medium and small prototype telescopes are being built in laboratories across the globe and installed at observatories similarly scattered. The prototypes' optical designs and camera technologies need to be tested in a variety of environments. For example, the team working on one of the small telescope designs has a prototype on the slope of Mount Etna in Sicily. There, volcanic ash sometimes batters the mirrors and attached camera, providing a test to ensure CTA telescopes and instruments can withstand the environment. Unlike optical telescopes, which sit in protective domes, Cherenkov telescopes are exposed to the open air.

The CTAO council expects to complete negotiations with the European Southern Observatory before the end of 2016 to finalize plans for the southern array. The current plan is to build 99 telescopes in Chile.

This year, the council also chose the location of the CTA Science Management Center, which will be the central point of data processing, software updates and science coordination. This building, which will be located at Deutsches Elektronen-Synchrotron (also known as DESY) outside of Berlin, has not yet been built, but Hofmann says that should happen in 2018.

The observatory is on track for the first trial observations (essentially, testing) in 2021 and the first regular observations beginning in 2022. How close the project's construction stays to this outlined schedule depends on funding from nations across the globe. But if the finances remain on track, then in 2024, the full observatory should be complete, and its 118 telescopes will then look for bright flashes of Cherenkov light signaling a violent event or object in the universe.

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

Hacking for humanity (http://www.symmetrymagazine.org/article/hacking-for-humanity?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Nov 29, 2016

THE Port humanitarian hackathon at CERN brings people from multiple industries together to make the world a better place.

In October, scientists, humanitarian workers and people across various industries came together at CERN for an annual hackathon to develop solutions to some of today's pressing humanitarian issues. The challenges included creating emergency housing networks, reducing counterfeit drugs and finding clean and safe ways to dispose of explosives.

The hackathon is run by an organization called THE Port. THE Port was born out of casual conversations at CERN's social events, which tend to draw people from myriad industries—scientists and engineers, people working for international companies like IBM or Proctor & Gamble, and humanitarians and human rights workers.

"During these parties and barbecues, we had a lot of discussions, especially with people from the Red Cross and United Nations, and we often found instances where the technology we have here at CERN could help them do better work," says Daniel Dobos, a physicist at CERN and a founding member of THE Port. The problem, however, was that after these events, the great ideas they generated would usually get lost in the rush of busy work lives.

In May 2014, 13 people decided to come together to try to make these ideas a reality. The best way to do this, they believed, was to host an event where people from various industries around the world could meet and tackle the challenges faced by humanitarian organizations. Later that year, they hosted their first hackathon at CERN's IdeaSquare, a collective space for innovation-related events. Since then, the core team has grown to about 35 people and has hosted five more hackathons over the last two years, including a diplomatic hackathon with United Nations ambassadors as participants and a biotech hackathon aimed at solving health-related challenges.

These hackathons are typically hosted over three days, but the organizers carefully plan for many months before the event. Unlike typical hackathons that invite people to pitch their ideas from scratch, THE Port creates challenges based on the problems international organizations, nongovernmental organizations and individuals need solved.

“We wanted to make a hackathon that is much less spontaneous than normal hackathons,” Dobos says. “We spend half a year shaping a challenge that seems appealing for outsiders, broad enough to leave room for creativity and narrow enough so that it really helps fulfill the need in a foreseeable timespan.”

THE Port aims for diversity, so the demographics of these hackathons mirrors that of CERN’s parties—a third from the scientific community, a third from the humanitarian sector and a third from everywhere else—including architects, artists and science communicators. Only about a sixth of the participants are particle physicists.

“I really loved having interactions with people who were not doing my job—normally I'm around people who more or less have a similar mind set. I think this has changed my life somehow,” says Virginia Azzolini, a particle physicist from the Massachusetts Institute of Technology currently working at CERN and a participant in THE Port’s latest hackathon. “I think what a particle physicist can bring to the hackathon is a free mind [because] we are always searching for something that is not there and we don’t have a book that tells us how to find it.”

This year, Azzolini and her teammates had the task of improving emergency housing networks that help distribute goods or services to refugees displaced by war or natural disasters. To address this challenge, they created a web application where people affected by a catastrophe could post their needs—blankets or shelter, for example—so that individuals in nearby communities could help meet those requests.

Another of this year’s challenges, posed by Handicap International—an NGO devoted to supporting people with disabilities and vulnerable populations in conflict and disaster zones—was to develop a clean and mobile solution for disposing explosives.

“The issue is that if clean elimination of explosives is much more expensive than open burning or open detonating, chances are that donors will not invest money in that approach,” says Paul Vermeulen, the Project Manager of Strategic Innovation at Handicap International.

THE Port’s team was able to think of a safe, simple and cheap solution: dissolve the explosive in a solvent then burn it with waste oil and use the steam and heat generated for electricity.

“The motivation, the energy and the good spirit of all the participants is really the strong element of this hackathon,” Vermeulen says.

For many participants, the work doesn’t end when the hackathon does. Both Azzolini and her teammates as well as the group who worked on Handicap International’s challenge continue to meet to refine their solutions in order to put these to use in the real world.

In the future, THE Port hopes to bring humanitarian hackathons to locations beyond CERN, including Berkeley Lab and Fermilab.

“The future goal is to bring this humanitarian style of hackathon around the world,” Dobos says.

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

Q&A: What more can we learn about the Higgs? (http://www.symmetrymagazine.org/article/qa-what-more-can-we-learn-about-the-higgs?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Nov 17, 2016

Four physicists discuss Higgs boson research since the discovery.

More than two decades before the discovery of the Higgs boson, four theoretical physicists wrote a comprehensive handbook called *The Higgs Hunter’s Guide*. The authors—**Sally Dawson** of the Department of Energy's Brookhaven National Laboratory; **John F. Gunion** from the University of California, Davis; **Howard E. Haber** from the University of California, Santa Cruz; and **Gordon Kane** from the University of Michigan—were recently recognized for “instrumental contributions to the theory of the properties, reactions and signatures of the Higgs boson” as recipients of the American Physical Society’s 2017 J.J. Sakurai Prize for Theoretical Physics.

They are still investigating the particle that completed the Standard Model, and some are hunting different Higgs bosons that could take particle physics beyond that model.

Dawson, Gunion and Haber recently attended the Higgs Couplings 2016 (http://www-conf.slac.stanford.edu/hc16/) workshop at SLAC National Accelerator Laboratory, where physicists gathered to talk about the present and future of Higgs research. *Symmetry* interviewed all four to find out what's on the horizon.

What is meant by "Higgs couplings"?

JG:
The Higgs is an unstable particle that lasts a very short time in the detector before it decays into pairs of things like top quarks, gluons, and photons. The rates and relative importance of these decays is determined by the couplings of the Higgs boson to these different particles. And that's what the workshop is all about, trying to determine whether or not the couplings predicted in the Standard Model agree with the couplings that are measured experimentally.

SD:
Right, we can absolutely say how much of the time we expect the Higgs to decay to the known particles, so a comparison of our predictions with the experimental measurements tells us whether there's any possible deviation from our Standard Model.

JG:
For us what would be really exciting is if we did see deviations. However, that probably requires more precision than we currently have experimentally.

GK:
But we don’t all agree on that, in the sense that I would prefer that it almost exactly agree with the Standard Model predictions because of a theory that I like that says it should. But most of the people in the world would prefer what John and Sally said.

How many people are working in Higgs research now worldwide?

GK:
I did a search for “Higgs” in the title of scientific papers after 2011 on arXiv.org and came up with 5211 hits; there are several authors per paper, of course, and some have written multiple papers, so we can only estimate.

SD:
There are roughly 5000 people on each experiment, ATLAS and CMS, and some fraction of those work on Higgs research, but it’s really too hard to calculate. They all contribute in different ways. Let's just say many thousands of experimentalists and theorists worldwide.

What are Higgs researchers hoping to accomplish?

HH:
There are basically two different avenues. One is called the precision Higgs program designed to improve precision in the current data. The other

direction addresses a really simple question: Is the Higgs boson a solo act or not? If additional Higgs-like particles exist, will they be discovered in future LHC experiments?

SD:
I think everybody would like to see more Higgs bosons. We don't know if there are more, but everybody is hoping.

JG:
If you were Gordy [Kane] who only believes in one Higgs boson, you would be working to confirm with greater and greater precision that the Higgs boson you see has precisely the properties predicted in the Standard Model. This will take more and more luminosity and maybe some future colliders like a high luminosity LHC or an e+e- collider.

HH:
The precision Higgs program is a long-term effort because the high luminosity LHC is set to come online in the mid 2020s and is imagined to continue for another 10 years. There are a lot of people trying to predict what precision could you ultimately achieve in the various measurements of Higgs boson properties that will be made by the mid 2030s. Right now we have a set of measurements with statistical and systematic errors of about 20 percent. By the end of the high luminosity LHC, we anticipate that the size of the measurement errors can be reduced to around 10 percent and maybe in some cases to 5 percent.

How has research on the topic changed since the Higgs discovery?

SD:
People no longer build theoretical models that don't have a Higgs in them. You have to make sure that your model is consistent with what we know experimentally. You can't just build a crazy model; it has to be a model with a Higgs with roughly the properties we've observed, and that is actually pretty restrictive.

JG:
Many theoretical models have either been eliminated or considerably constrained. For example, the supersymmetric models that are theoretically attractive kind of expect a Higgs boson of this mass, but only after pushing parameters to a bit of an extreme. There's also an issue called naturalness: In the Standard Model alone there is no reason why the Higgs boson should have such a light mass as we see, whereas in some of these theories it is natural to see the Higgs boson at this mass. So that's a very important topic of research—looking for those models that are in a certain sense naturally predicting what we see and finding additional experimental signals associated with such models.

GK:
For example, the supersymmetric theories predict that there will be five Higgs bosons with different masses. The extent to which the electroweak symmetry is broken by each of the five depends on their couplings, but there should be five discovered eventually if the others exist.

HH:
There's also a slightly different attitude to the research today. Before the Higgs boson was discovered it was known that the Standard Model was theoretically inconsistent without the Higgs boson. It had to be there in some form. It wasn't going to be that we ran the LHC and saw nothing—no Higgs boson and nothing else. This is called a no-lose theorem. Now, having discovered the Higgs boson, you cannot guarantee that additional new phenomenon exists that must be discovered at the LHC. In other words, the Standard Model itself, with the Higgs boson, is a theoretically consistent theory. Nevertheless, not all fundamental phenomena can be explained by Standard Model physics (such as neutrino masses, dark matter and the gravitational force), so we know that new phenomena beyond the Standard Model must be present at some very high-energy scale. However, there is no longer a no-lose theorem that states that this new phenomena must appear at the energy scale that is probed at the LHC.

How have the new capabilities of the LHC changed the game?

SD:
We have way more Higgs bosons; that's really how it's changed. Since the energy is higher we can potentially make heavier new particles.

GK:
There were about a million Higgs bosons produced in the first run of the LHC, and there will be more than twice that in the second run, but they only can find a small fraction of those in the detector because of background noise and some other things. It's very hard. It takes clever experimenters. To find a couple of hundred Higgs you need to produce a million.

SD:
Most of the time the Higgs decays into something we can't see in our detector. But as the measurements get better and better, experimentalists who have been extracting the couplings are quantifying more properties of the Higgs decays. So instead of just counting how many Higgs bosons decay to two Z bosons, they will look at where the two Z bosons are in the detector or the energy of the Z bosons.

Are there milestones you are looking forward to?

GK:
Confirming the Standard Model Higgs with even more precision. The decay the Higgs boson was discovered in—two photons—could happen in any other kind of particle. But the decay to W boson pairs is the one that you need for it to break the electroweak symmetry [a symmetry between the masses of the particles associated with the electromagnetic and weak forces], which is what it should do according to the Standard Model.

SD:
So, one of the things we will see a lot of in the next year or two is better measurements of the Higgs decay into the bottom quarks. Within a few years, we should learn whether or not there are more Higgs bosons. Measuring the couplings to the desired precision will take 20 years or more.

JG:
There's another thing people are thinking about, which is how the Higgs can be connected to the important topic of dark matter. We are working on models that establish such a connection, but most of these models, of course, have extra Higgs bosons. It's even possible that one of those extra Higgs bosons might be invisible dark matter. So the question is whether the Higgs we can see tells us something about dark matter Higgs bosons or other dark matter particles, such as the invisible particles that are present in supersymmetry.

Are there other things still to learn?

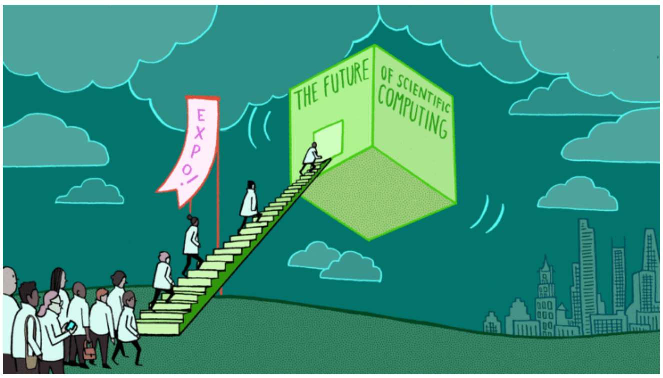
JG:
There are many possible connections between Higgs bosons, in a generic sense and the history of the universe. For example, it could be that a Higgs-like particle called the inflaton is responsible for the expansion of the universe. As a second example, generalized Higgs boson models could explain the preponderance of matter over antimatter in the current universe.

Read More... (http://www.symmetrymagazine.org/article/qa-what-more-can-we-learn-about-the-higgs?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

What to do with the data? (http://www.symmetrymagazine.org/article/what-to-do-with-the-data?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Nov 15, 2016

Physicists and scientific computing experts prepare for an onslaught of petabytes.



Rapid advances in computing constantly translate into new technologies in our everyday lives. The same is true for high-energy physics. The field has always been an early adopter of new technologies, applying them in ever more complex experiments that study fine details of nature's most fundamental processes. However, these sophisticated experiments produce floods of complex data that become increasingly challenging to handle and analyze.

Researchers estimate a decade from now, computing resources may have a hard time keeping up with the slew of data produced by state-of-theart discovery machines. CERN’s Large Hadron Collider, for example, already generates tens of petabytes (millions of gigabytes) of data per year today, and it will produce ten times more after a future high-luminosity upgrade.

Big data challenges like these are not limited to high-energy physics. When the Large Synoptic Survey Telescope begins observing the entire southern sky in never-before-seen detail, it will create a stream of 10 million time-dependent events every night and a catalog of 37 billion astronomical objects over 10 years. Another example is the future LCLS-II X-ray laser at DOE’s SLAC National Accelerator Laboratory, which will fire up to a million X-ray pulses per second at materials to provide unprecedented views of atoms in motion. It will also generate tons of scientific data.

To make things more challenging, all big data applications will have to compete for available computing resources, for example when shuttling information around the globe via shared networks.

What are the tools researchers will need to handle future data piles, sift through them and identify interesting science? How will they be able to do it as fast as possible? How will they move and store tremendous data volumes efficiently and reliably? And how can they possibly accomplish all of this while facing budgets that are expected to stay flat?

“Clearly, we’re at a point where we need to discuss in what direction scientific computing should be going in order to address increasing computational demands and expected shortfalls,” says Richard Mount, head of computing for SLAC’s Elementary Particle Physics Division.

The researcher co-chaired the 22nd International Conference on Computing in High-Energy and Nuclear Physics (CHEP 2016 (http://chep2016.org/)), held Oct. 10-14 in San Francisco, where more than 500 physicists and computing experts brainstormed possible solutions.

Here are some of their ideas.

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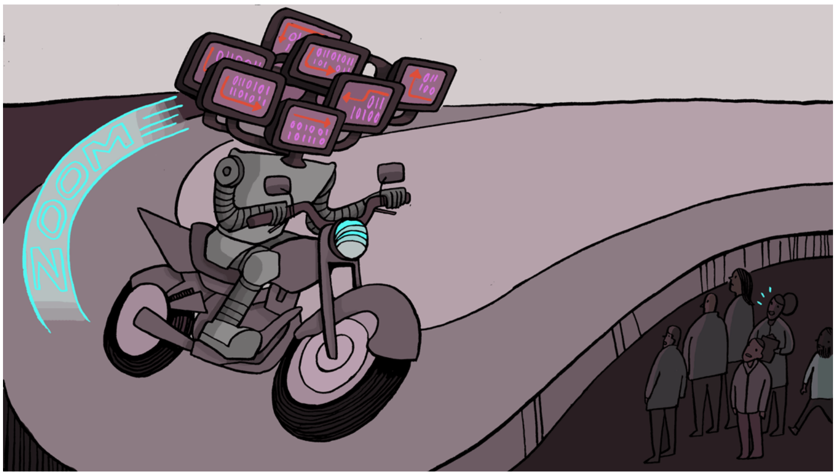

(http://www.symmetrymagazine.org/sites/default/files/images/standard/Inline_1_Scientific_computing.gif)
Illustration by Sandbox Studio, Chicago with Corinne Mucha

Exascale supercomputers

Scientific computing has greatly benefited from what is known as Moore’s law—the observation that the performance of computer chips has doubled every 18 months or so for the past decades. This trend has allowed scientists to handle data from increasingly sophisticated machines and perform ever more complex calculations in reasonable amounts of time.

Moore’s law, based on the fact that hardware engineers were able to squeeze more and more transistors into computer chips, has recently reached its limits because transistor densities have begun to cause problems with heat.

Instead, modern hardware architectures involve multiple processor cores that run in parallel to speed up performance. Today’s fastest supercomputers, which are used for demanding calculations such as climate modeling and cosmological simulations, have millions of cores and can perform tens of millions of billions of computing operations per second.

“In the US, we have a presidential mandate to further push the limits of this technology,” says Debbie Bard, a big-data architect at the National Energy Research Scientific Computing Center. “The goal is to develop computing systems within the next 10 years that will allow calculations on the exascale, corresponding to at least a billion billion operations per second.”

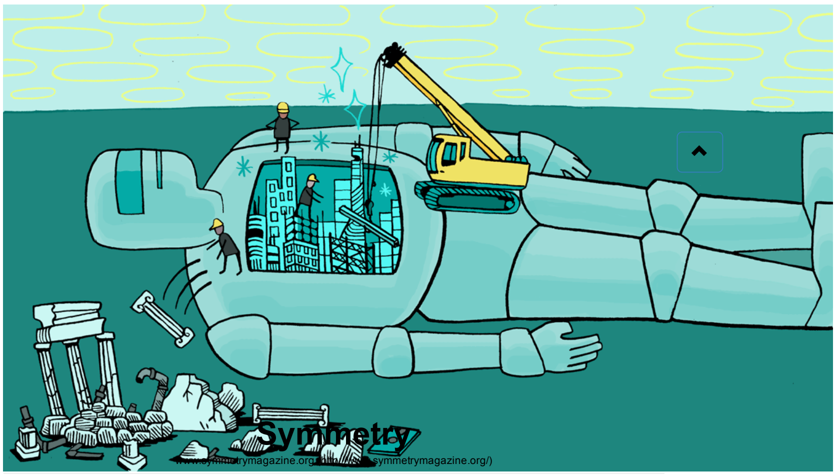

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Illustration by Sandbox Studio, Chicago with Corinne Mucha

Software reengineering

Running more data analyses on supercomputers could help address some of the foreseeable computing shortfalls in high-energy physics, but the approach comes with its very own challenges.

“Existing analysis codes have to be reengineered,” Bard says. “This is a monumental task, considering that many have been developed over several decades.”

Maria Girone, chief technology officer at CERN openlab, a collaboration of public and private partners developing IT solutions for the global LHC community and other scientific research, says, “Computer chip manufacturers keep telling us that our software only uses a small percentage of today’s processor capabilities. To catch up with the technology, we need to rewrite software in a way that it can be adapted to future hardware developments.”

Part of this effort will be educating members of the high-energy physics community to write more efficient software.

“This was much easier in the past when the hardware was less complicated,” says Makoto Asai, who leads SLAC’s team for the development of Geant4, a widely used simulation toolkit for high-energy physics and many other applications. “We must learn the new architectures and make them more understandable for physicists, who will have to write software for our experiments.”

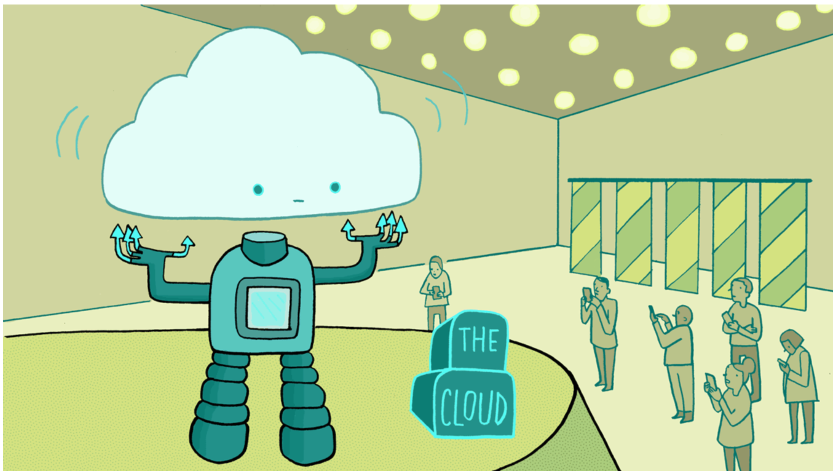

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Illustration by Sandbox Studio, Chicago with Corinne Mucha

Smarter networks and cloud computing

Today, LHC computing is accomplished with the Worldwide LHC Computing Grid, or WLCG, a network of more than 170 linked computer centers in 42 countries that provides the necessary resources to store, distribute and analyze the tens of petabytes of data produced by LHC experiments annually.

“The WLCG is working very successfully, but it doesn’t always operate in the most cost-efficient way,” says Ian Fisk, deputy director for computing at the Simons Foundation and former computing coordinator of the CMS experiment at the LHC.

“We need to move large amounts of data and store many copies so that they can be analyzed in various locations. In fact, two-thirds of the computing-related costs are due to storage, and we need to ask ourselves if computing can evolve so that we don’t have to distribute LHC data so widely.”

More use of cloud services that offer internet-based, on-demand computing could be a viable solution for remote data processing and analysis without reproducing data.

Commercial clouds have the capacity and capability to take on big data: Google, receives billions of photos per day and hundreds of hours of video every minute, posing technical challenges that have led to the development of powerful computing, storage and networking solutions.

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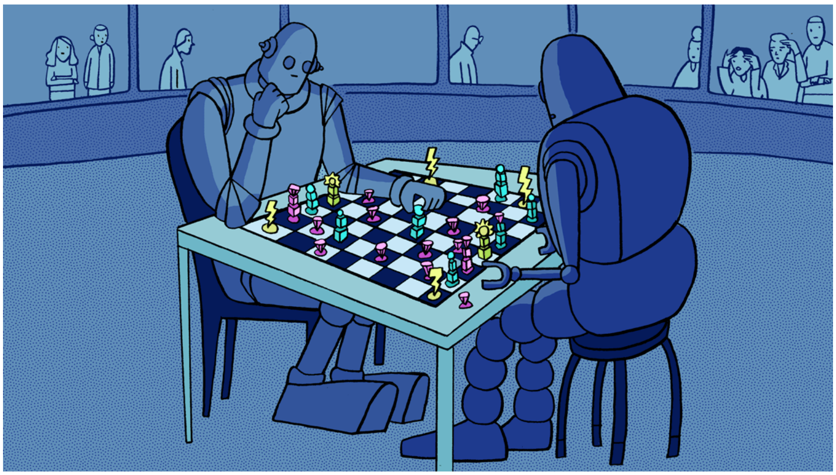

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Illustration by Sandbox Studio, Chicago with Corinne Mucha

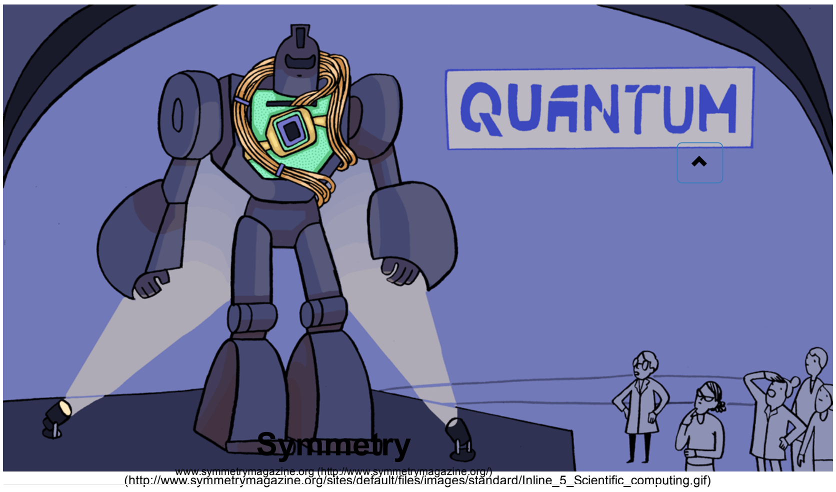
Deep machine learning for data analysis

While conventional computer algorithms perform only operations that they are explicitly programmed to perform, machine learning uses algorithms that learn from the data and successively become better at analyzing them.

In the case of deep learning, data are processed in several computational layers that form a network of algorithms inspired by neural networks. Deep learning methods are particularly good at finding patterns in data. Search engines, text and speech recognition, and computer vision are all examples.

“There are many areas where we can learn from technology developments outside the high-energy physics realm,” says Craig Tull, who co-chaired CHEP 2016 and is head of the Science Software Systems Group at Lawrence Berkeley National Laboratory. “Machine learning is a very good example. It could help us find interesting patterns in our data and detect anomalies that could potentially hint at new science.”

At present, machine learning in high-energy physics is in its infancy, but researchers have begun implementing it in the analysis of data from a number of experiments, including ATLAS at the LHC and the Daya Bay neutrino experiment in China.



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Quantum computing

The most futuristic approach to scientific computing is quantum computing, an idea that goes back to the 1980s when it was first brought up by Richard Feynman and other researchers.

Unlike conventional computers, which encode information as a series of bits that can have only one of two values, quantum computers use a series of quantum bits, or qubits, that can exist in several states at once. This multitude of states at any given time exponentially increases the computing power.

A simple one-qubit system could be an atom that can be in its ground state, excited state or a superposition of both, all at the same time.

“A quantum computer with 300 qubits will have more states than there are atoms in the universe,” said Professor John Martinis from the University of California, Santa Barbara, during his presentation at CHEP 2016. “We’re at a point where these qubit systems work quite well and can perform simple calculations.”

Martinis has teamed up with Google to build a quantum computer. In a year or so, he says, they will have built the first 50-qubit system. Then, it will take days or weeks for the largest supercomputers to validate the calculations done within a second on the quantum computer.

We might soon find out in what directions scientific computing in high-energy physics will develop: The community will give the next update at CHEP 2018 in Bulgaria.

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The origins of dark matter (http://www.symmetrymagazine.org/article/the-origins-of-dark-matter?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Nov 8, 2016

Theorists think dark matter was forged in the hot aftermath of the Big Bang.

Transitions are everywhere we look. Water freezes, melts, or boils; chemical bonds break and form to make new substances out of different arrangements of atoms.

The universe itself went through major transitions in early times. New particles were created and destroyed continually until things cooled enough to let them survive.

Those particles include ones we know about, such as the Higgs boson or the top quark. But they could also include dark matter, invisible particles which we presently know only because of their gravitational effects.

In cosmic terms, dark matter particles could be a “thermal relic,” forged in the hot early universe and then left behind during the transitions to more moderate later eras. One of these transitions, known as “freeze-out,” changed the nature of the whole universe.

(http://www.symmetrymagazine.org/sites/default/files/images/standard/Inline1_Thermal_relics.gif)

Illustration by Sandbox Studio, Chicago with Corinne Mucha

The hot cosmic freezer

On average, today's universe is a pretty boring place. If you pick a random spot in the cosmos, it's far more likely to be in intergalactic space than, say, the heart of a star or even inside an alien solar system. That spot is probably cold, dark and quiet.

The same wasn't true for a random spot shortly after the Big Bang.

“The universe was so hot that particles were being produced from photons smashing into other photons, of photons hitting electrons, and electrons hitting positrons and producing these very heavy particles,” says Matthew Buckley of Rutgers University.

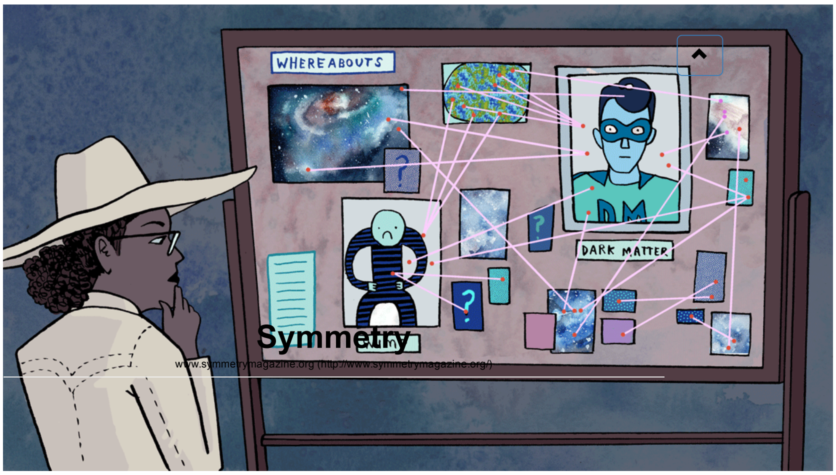
The entire cosmos was a particle-smashing party, but parties aren't meant to last. This one lasted only a trillionth of a second. After that came the cosmic freeze-out.

During the freeze-out, the universe expanded and cooled enough for particles to collide far less frequently and catastrophically.

“One of these massive particles floating through the universe is finding fewer and fewer antimatter versions of itself to collide with and annihilate,” Buckley says.

“Eventually the universe would get large enough and cold enough that the rate of production and the rate of annihilation basically goes to zero, and you just a relic abundance, these few particles that are floating out there lonely in space.”

Many physicists think dark matter is a thermal relic, created in huge numbers in before the cosmos was a half-second old and lingering today because it barely interacts with any other particle.



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A WIMPy miracle

One reason to think of dark matter as a thermal relic is an interesting coincidence known as the “WIMP miracle.”

WIMP stands for “weakly-interacting massive particle,” and WIMPs are the most widely accepted candidates for dark matter. Theory says WIMPs are likely heavier than protons and interact via the weak force, or at least interactions related to the weak force.

The last bit is important, because freeze-out for a specific particle depends on what forces affect it and the mass of the particle. Thermal relics made by the weak force were born early in the universe's history because particles need to be jammed in tight for the weak force, which only works across short distances, to be a factor.

“If dark matter is a thermal relic, you can calculate how big the interaction [between dark matter particles] needs to be,” Buckley says.

Both the primordial light known as the cosmic microwave background and the behavior of galaxies tell us that most dark matter must be slow-moving (“cold” in the language of physics). That means interactions between dark matter particles must be low in strength.

"Through what is perhaps a very deep fact about the universe," Buckley says, “that interaction turns out to be the strength of what we know as the weak nuclear force."

That's the WIMP miracle: The numbers are perfect to make just the right amount of WIMPy matter.

The big catch, though, is that experiments haven't found any WIMPs yet. It's too soon to say WIMPs don't exist, but it does rule out some of the simpler theoretical predictions about them.

Ultimately, the WIMP miracle could just be a coincidence. Instead of the weak force, dark matter could involve a new force of nature that doesn't affect ordinary matter strongly enough to detect. In that scenario, says Jessie Shelton of the University of Illinois at Urbana-Champaign, "you could have thermal freeze-out, but the freeze-out is of dark matter to some other dark field instead of [something in] the Standard Model."

In that scenario, dark matter would still be a thermal relic but not a WIMP.

For Shelton, Buckley, and many other physicists, the dark matter search is still full of possibilities.

"We have really compelling reasons to look for thermal WIMPs," Shelton says. "It's worth remembering that this is only one tiny corner of a much broader space of possibilities."

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Nov 3, 2016

A theoretical particle that adapts to its surroundings could explain the accelerating expansion of our universe.

Our universe grows a little bigger every day. Empty space is expanding, sweeping galaxies further and further apart. Even starlight traversing this swelling nothingness is stretched like a rubber band.

The astronomical evidence for the accelerating expansion of the universe is overwhelming. But what is pushing the universe apart?

Particle physicists endeavor to answer cosmic-sized questions like this using the most fundamental laws of nature. But this particular query has them in a pickle because it is unlike anything else.

"If we understand gravity correctly, then there is some other substance in the universe that makes up about two-thirds of the total energy density and that behaves totally differently from normal matter," says theorist Amol Upadhye, a postdoc at the University of Wisconsin, Madison. "So the big mystery is, what is this stuff?"

This stuff is dark energy, but besides its ostensible pushing effect in the cosmos, scientists know little else. However, theorists like Upadhye suspect that if there really is something causing empty space to expand, there is a good chance that it produces a particle. But to mesh with the cosmological observation, a dark energy particle would require a series of perplexing properties. For one, it would need to behave like a chameleon—that is, it would need to alter its properties based on its surroundings.

Cosmic chameleon: You come and go

In the depths of empty space, a chameleon particle might be almost massless, minimizing its gravitational attraction to other particles. But here on Earth (and in any other densely populated regions of space), the chameleon would need to swell to a much larger mass. This would limit its ability to easily interact with ordinary matter and make it nearly invisible to most detectors.

"If matter were music, then ordinary matter would be like the keys on a piano," Upadhye says. "Each particle has a discrete mass, just like each piano key plays a single note. But chameleon particles would be like the slide on a trombone and able to change their pitches based on the amount of background noise."

In addition to a sliding mass, the chameleons would need to exert a negative pressure. Classically, pressure is the force particles exert on their container. When the container is made of matter (like the rubber of a balloon), it expands as the internal pressure increases, and relaxes back to normal when the pressure diminishes. But when the container is made of nothing—that is, the container is spacetime itself—the reverse effect happens. For instance, when a birthday balloon fills with air, the surrounding empty space contracts slightly. But as the balloon releases air and the pressure diminishes, space relaxes back to normal.

All known particles contract space as their pressure increases and relax space as their pressure approaches zero. But to actually expand space, a particle would need to exert a negative pressure—an idea which is totally alien in our macroscopic physical world but not impossible on a subatomic scale.

"This was actually Einstein's idea," Upadhye says. "If you put in a substance with a negative pressure into the equations of general relativity you get this accelerating expansion of universe."

A mass-shifting, space-expanding particle would be unlike anything else in physics. But physicists are hopeful that if such a particle exists, it would be abundant both in the depths of space and here in our own solar system.

Several experiments have searched indirectly for chameleon particles by closely monitoring the properties of ordinary matter and looking for any chameleon-like affects. But the CERN Axion Solar Telescope, or CAST experiment, is hoping to catch chameleons directly as they radiate from the sun.

"The sun is our biggest source of particles," says Konstantin Zioutas, the spokesperson for the CAST experiment. "If chameleons exist, then they could copiously be produced in the sun."

The CAST experiment is a specialized telescope that looks for rare and exotic particles emanating from the sun and the early universe. Zioutas and his colleagues recently installed a special magnifying glass inside CAST which collects and focuses particles onto a highly sensitive membrane suspended in a resonant electromagnetic cavity. Their hope is that if chameleon particles exist and are produced by the sun, they'll see the very tiny pressure these particles flux should exert as they are reflected off the membrane when the sun is in view.

So far they haven't seen anything unexpected, but new upgrades this winter will make their experiment even more sensitive to both solar chameleons and other exotic cosmic-sprung phenomena.

"The dark energy mystery is the biggest challenge in physics, and nothing we currently understand can explain it," Zioutas says. "We need to look at the exotic of the exotica for possible solutions."

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Nov 2, 2016

See theorist Leonardo Senatore's answers to readers' questions about parallel universes.

Symmetry

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by Symmetry Magazine 2 months ago

#AskSymmetry Twitter Chat with Leonardo Senatore 10/31/16

Your parallel universe questions answered by Leonardo Senatore, Stanford associate professor and theoretical cosmologist at SLAC National Accelerator Laboratory and the Kavli Institute for Particle Astrophysics and Cosmology.

Happy Halloween! What are parallel universes, and why do we think they might exist? symmetrymagazine.org/article/in-sea... #AskSymmetry pic.twitter.com/3I0ASqOtjP

SYMMETRY MAGAZINE @SYMMETRYMAG · 2 MONTHS AGO

Theoretical physicist Leonardo Senatore is taking over our Twitter feed in 30 min to answer questions about parallel universes #AskSymmetry pic.twitter.com/vlUsVBg4Qn

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Leonardo is working to understand how the universe began & evolved to its present form #AskSymmetry physics.stanford.edu/people/faculty...

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Leonardo won @brkthroughprize for "outstanding contributions to theoretical cosmology" #AskSymmetry breakthroughprize.org/Laureates/L160

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What questions do you have about parallel universes? Use the hashtag #AskSymmetry

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Are you ready to explore parallel universes? Leonardo Senatore here, @KIPAC1 @Stanford @SLAClab theoretical cosmologist #AskSymmetry

2 MONTHS AGO

Jamie Mulford
@shiregator

@symmetrymag #AskSymmetry are they connected via black hole wormholes?

2 MONTHS AGO

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Q1 @shiregator: are they connected via black hole wormholes? #AskSymmetry

2 MONTHS AGO

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A1: In principle yes, but we think these kind of connections do not quite exist practically in nature (they are unstable) 1/2 #AskSymmetry

2 MONTHS AGO

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A1: Even more more interesting, there could be huge universes inside horizon of what just looks like a normal black hole 2/2 #AskSymmetry

2 MONTHS AGO

Grant Kluber
@kibiklu

Would two leptons be able to occupy the same quantum state if they were in different universes? Would Pauli's Exclusion P hold? #AskSymmetry

2 MONTHS AGO

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Q2 (1/2) @kibiklu: Would two leptons be able to occupy the same quantum state if they were in different universes? #AskSymmetry

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Q2 (2/2) @kibiklu: Would Pauli's Exclusion P hold? #AskSymmetry

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A2: The space of states is much larger in a multiverse. There can be multiple copies of the same universe 1/3 #AskSymmetry

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A2: So, the same-looking state can be occupied by two different electrons in two universes 2/3 #AskSymmetry

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A2: This does not violate Pauli Exclusion P. In fact, for example, their wavefunctions do not overlap 3/3 #AskSymmetry

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The One
@RBZ_TheOne
@symmetrymag Is there a possibility we have more than 1 dimension on Earth and each one corresponds to 1 reality in time-space? #AskSymmetry

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Q3 @RBZ_TheOne Is there a possibility we have more than 1 dimension on Earth & each one corresponds to 1 reality in time-space? #AskSymmetry

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A3: If the additional spatial dimensions are curled up so that they are very small, then they could exist 1/2 #AskSymmetry

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A3: . They are real. Indeed, the number of space dimensions has experimental consequences 2/2 #AskSymmetry

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🌠👻🎃Hamide🎃👻🌠
@H__Mikaelson
#AskSymmetry the parallel universes are entangled or they're totally different? @symmetrymag

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symmetry magazine
@symmetrymag
Q4 @H__Mikaelson: the parallel universes are entangled or they're totally different? #AskSymmetry

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A4: Parallel universes can be entangled, because every state in quantum mechanics can be entangled with any other 1/2 #AskSymmetry

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A4: However, often the entanglement in practice is expected to be very small (2/2) #AskSymmetry

2 MONTHS AGO

K SUSHANTH REDDY
@KSUSHANTHREDDY9
#AskSymmetry If the universe is expanding, what is it expanding into?

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In search of a parallel universe (http://www.symmetrymagazine.org/article/in-search-of-a-parallel-universe?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Oct 31, 2016

What are parallel universes, and why do we think they might exist?

Theoretical physicist Leonardo Senatore from the Kavli Institute for Particle Astrophysics and Cosmology explains.

Ask Symmetry - What is a parallel universe?

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).

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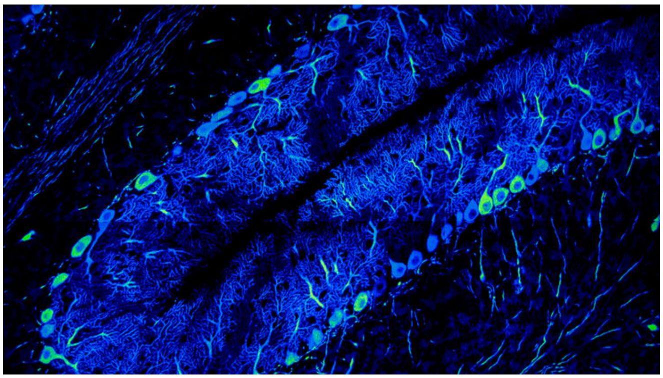
Oct 27, 2016

Can a biochemistry technique win the battle against background for scientists studying the nature of neutrinos?



While we read, think, move or just perceive the world around us, thousands of neurons fire in our brain. Ions, like little messengers, jump from neuron to neuron and create a cascade of information transfer. Using a technique called single-molecule fluorescence imaging, neuroscientists can make these cascades glow.

David Nygren, a physics professor who studies neutrinos at the University of Texas at Arlington, was reading about how neuroscientists watch brain cells think. If Nygren's brain cells had been lit up with fluorescence while he read, they would have looked like glowing trees branching up into the sky. He had an idea.

To conduct single-molecule fluorescence imaging, scientists release a dye into brain cells—they use rat brain cells—and hit them with light. The dye gets excited and starts to glow. This works because the dye attaches only to certain ions—calcium ions, which act as messengers between neurons.

"It hit me," Nygren says, "calcium and barium are not that different."

Just as calcium is important to neuroscientists, barium is important to Nygren. That's because he is part of the Neutrino Experiment with Xenon TPC, also known as NEXT.

NEXT is searching for proof of a theoretical process called neutrinoless double beta decay. During a double-beta decay, two neutrons within one nucleus transform into two protons, two electrons and two neutrinos. For a double-beta decay to be called "neutrinoless," the two neutrinos created would need to annihilate one another.

If this happened, scientists would have the answer to an important question in particle physics: Are neutrinos their own antiparticles? If two neutrinos canceled one another, physicists would know that neutrinos and antineutrinos are one and the same.

NEXT looks for neutrinoless double-beta decay in xenon. If xenon went through the process of neutrinoless double-beta decay, its nucleus would transform into barium. Nygren's neurons were firing because he realized he might be able to use single-molecule fluorescence imaging to search for that new barium nucleus.

Neutrinoless double-beta decay would be an extremely rare process. In a ton of xenon this decay might happen only a few times in a year.

Most radioactive processes happen far more often than neutrinoless double-beta decay. And most materials on Earth include a small amount of naturally occurring radioactive elements. All of this creates a sea of ambient background radiation that scientists must find a way to filter out if they ever want to see evidence of neutrinoless double-beta decay.

Using single-molecule fluorescence imaging could make neutrinoless double-beta decay stand out from the crowd.

"If they succeed in proving the principle of their detector concept, they will eliminate all background except for normal double-beta decay," says Steven Elliot, scientist at the Majorana Demonstrator at Sanford Underground Research Facility. "This would be a great leap for our field and our understanding of the universe."

Nygren took his idea to a group of fellow scientists at Arlington.

"We all had no background in biochemistry," says Nygren's colleague Ben Jones, an assistant professor. "But we dove into the topic to explore and adapt the technique for our needs."

The group at Arlington released a calcium-tagging dye in an aqueous environment and found that it was able to grab barium ions and glow. The next step will be to test the technique in a dry environment; they want to eventually employ the dye in a xenon gas chamber.

"We are still at the beginning, but so far the idea to use this technique for our detector looks less crazy every single day," says Austin McDonald, a

"We are still at the beginning, but so far the idea to use this technique for our detector looks less crazy every single day," says Austin McDonald, a research assistant at the University of Texas at Arlington. "We really hope we can realize this in a large-scale project."

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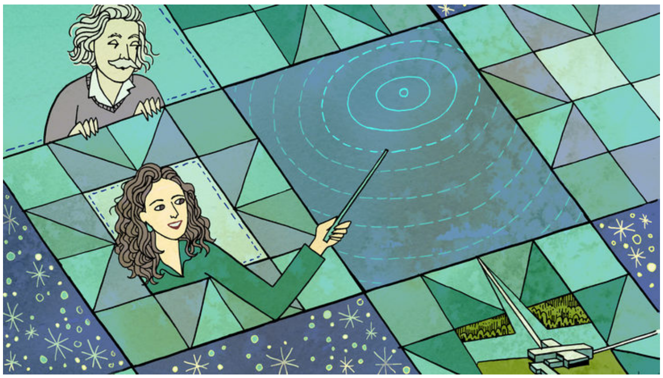
A primer on gravitational-wave detectors (http://www.symmetrymagazine.org/article/a-primer-on-gravitational-wave-detectors?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Oct 25, 2016

Physicists are searching for gravitational waves all across the spectrum.

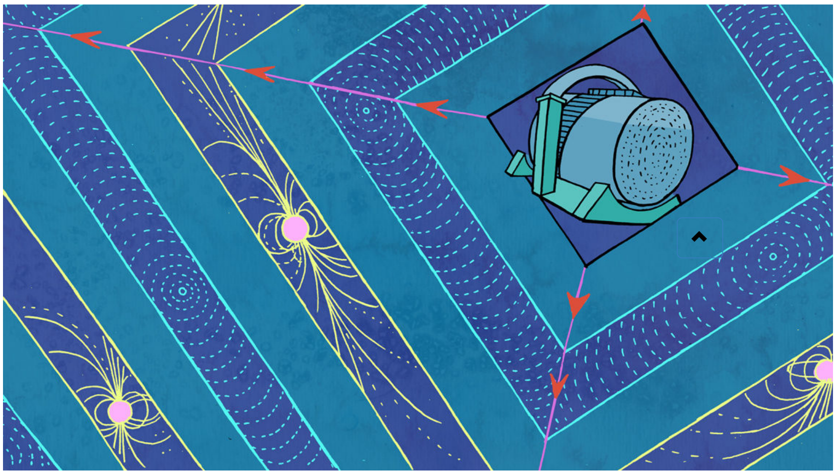


Gravitational waves, or ripples in the fabric of space-time, have captured the imagination of physicists since Albert Einstein first predicted them in 1916. But it wasn't until the 1960s that Joseph Weber, an experimental physicist at the University of Maryland, built the first machine meant to find them.

About 50 years later, scientists finally did it; the Laser Interferometer Gravitational-Wave Observatory detected gravitational waves coming from the merger of two black holes.

The merging black holes LIGO discovered emit gravitational waves at relatively high frequencies. But more massive objects, such as supermassive black holes and merging galaxies, produce waves with longer periods and lower frequencies.

Astronomers are using a wide variety of instruments to seek out gravitational waves at these different frequencies to detect the cosmic events that produce them.



(http://www.symmetrymagazine.org/sites/default/files/images/standard/Inline_4_Gravwave_detectors.jpg)

Illustration by Sandbox Studio, Chicago with Corinne Mucha

Resonant-mass detectors

Weber's first gravitational wave detector was a resonant bar detector, or Weber bar. These detectors are big cylindrical metal bars that vibrate at their resonant frequencies when a gravitational wave passes by, a bit like massive tuning forks.

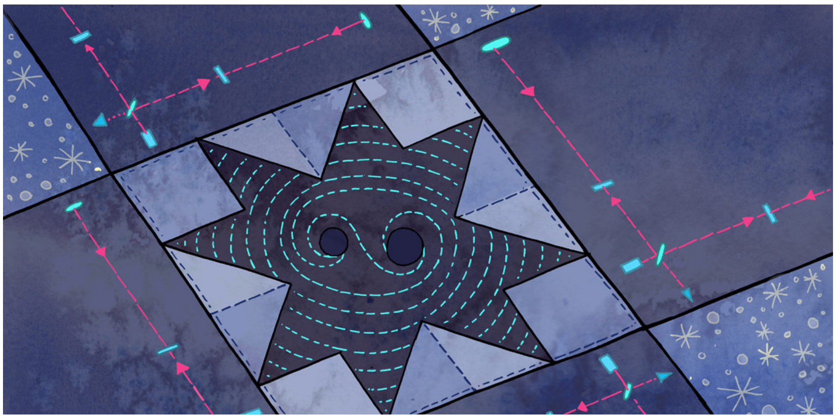
After the many generations of following Weber's first attempts, most resonant-mass detectors are now out of commission. Physicists use them to search for gravitational waves around the 700- to 3000-hertz region, where they expect to find supernovae, merging neutron stars and possibly even mini black holes. The major limitation of these instruments is that they are sensitive to a very small frequency range.

To increase their chances, some physicists decided to switch from a bar-shaped resonant-mass detector to a spherical one that could detect gravitational waves in all directions and with any polarization, not just some.

One of the most recently built spherical detectors is the Mario Schenberg gravitational-wave detector, which is now at the National Institute for Space Research (INPE) in Brazil. The sphere is around 65 centimeters in diameter and weighs around 1150 kilograms.

This project is still active, though its members are now part of the LIGO collaboration and devote most of their time there.

"We keep going, slowly, but our objective is to make these detectors run perhaps five or 10 years from now," says Odylio Denys Aguiar, a physicist at INPE and the leader of the project.



(http://www.symmetrymagazine.org/sites/default/files/images/standard/Inline_1_Gravwave_detectors.jpg)

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Ground-based interferometers

Ground-based interferometers are probably the most well known gravitational-wave detectors, thanks to LIGO's breakthrough. These detectors have two arms that form the shape of an L. In LIGO's case, each arm is 4 kilometers long.

In ground-based interferometers, physicists split a laser beam and send it down each arm. The beam bounces off mirrors at each end, travelling back and forth. A passing gravitational wave changes the relative lengths of the arms slightly and shifts the beam's path, creating a change that physicists can identify.

These observatories can detect short wavelengths, primarily with frequencies in the hundreds of hertz range, making them sensitive to mergers of neutron stars and black holes that are between a few times to tens of times the mass of the sun.

There are a number of ground-based interferometers, both active and under construction. LIGO operates out of twin observatories in Louisiana and Washington state. There are plans to build a third LIGO observatory in India. Virgo and GEO600, which have similar set-ups but shorter arms, are located in Italy and Germany, respectively. KAGRA, an underground interferometer, is under construction in Japan.

These detectors are sensitive to a similar range of frequencies, but there is a key benefit to having many detectors in different parts of the world. Gravitational-wave detectors act like microphones, surveying massive patches of the cosmos from all directions. This increases their chances of finding signs of gravitational waves, but it also makes it difficult to see where exactly they came from. Having more than one detector allows physicists to triangulate a signal to better locate its position on the sky.

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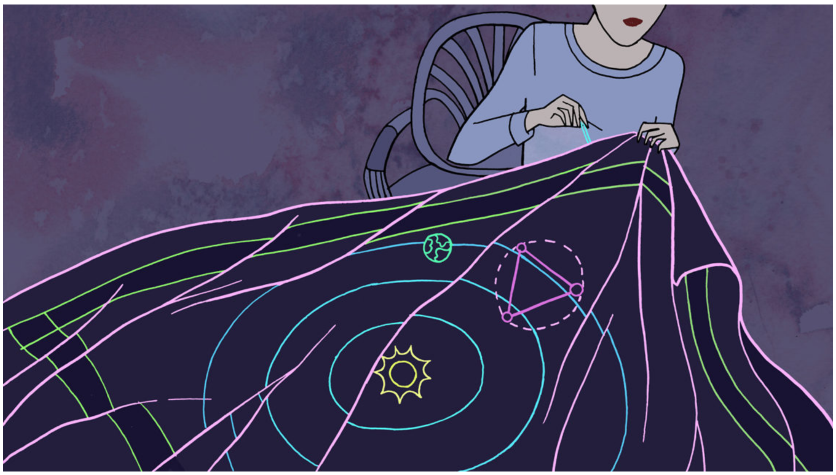

(http://www.symmetrymagazine.org/sites/default/files/images/standard/Inline_2_Gravwave_detectors.jpg)

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Space-based interferometers

Some astronomers plan to bring gravitational-wave astronomy to space. The Laser Interferometer Space Antenna (LISA) has a set-up similar to LIGO, except with three arms over a million kilometers long. Instead of an L-shape, LISA would form an equilateral triangle orbiting the sun, with a satellite placed at each of the vertices. Like in LIGO, a laser beam would go back and forth along the arms, and physicists could detect changes in the length of the arms as a gravitational wave passed through.

The LISA collaboration hopes to launch a space-based observatory around 2034. So far, they have launched the LISA Pathfinder, a short version of one of the arms of the observatory, to test how well it works.

"With the success of LISA Pathfinder, we already know that we can do large parts of the mission," says Martin Hewitson, a physicist at the Max Planck Institute for Gravitational Physics working on both LISA and LISA Pathfinder. "So there is a lot of scientific and political momentum to make this mission happen earlier."

In space, the detector will be sensitive to much lower frequencies than the ground-based ones—in LISA's case, frequencies in the millihertz range. Here, astronomers expect to see gravitational waves from mergers of the supermassive black holes at the center of galaxies. "By looking at these and how they evolve, there is a hope to trace how these galaxies merged and how these black holes have grown over the whole cosmic time," Hewitson says.

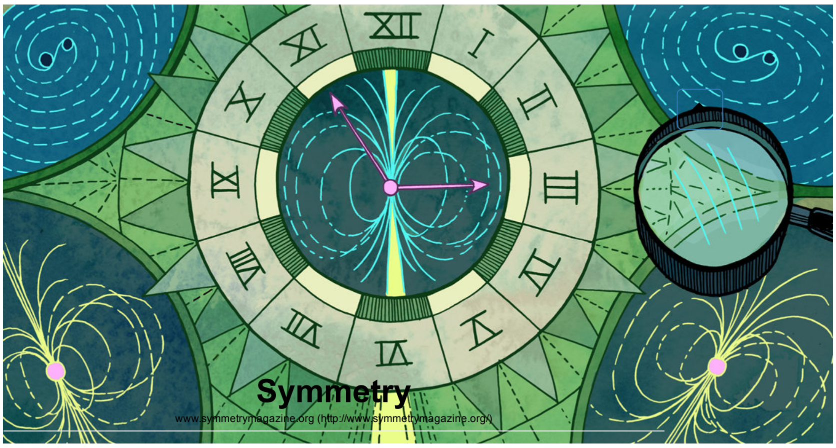

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Illustration by Sandbox Studio, Chicago with Corinne Mucha

Pulsar timing arrays

Pulsars, spinning neutron stars that constantly emit beams of electromagnetic radiation, are natural timekeepers. Of these, millisecond pulsars are the most regular—to the point that astronomers can predict the time they will arrive on Earth with nanosecond precision.

Physicists use pulsar timing arrays to search for gravitational waves. When a gravitational wave passes, space-time warps between the pulsar and earth. This changes the time of arrival of the pulses, which physicists can then detect with radio telescopes.

“With LIGO, they are trying to detect a deformation much smaller than the diameter of a proton across an instrument that is many kilometers in length—an incredibly tiny signature,” explains Shami Chatterjee, an astronomer at Cornell University working on the North American Nanohertz Observatory for Gravitational Waves (NANOGrav). “For pulsar timing arrays, it's the same scaling—our arms are hundreds or thousands of light years long, but we're trying to measure the same kind of fractional change.”

This technique is sensitive to even lower frequencies than LISA, in the nanohertz range. Here, scientists expect to see a stochastic background of merging supermassive black holes (the sum of all the mergers), binary supermassive black holes, as well as more exotic sources such as cosmic strings and memory bursts, the permanent imprint on space-time left behind by merging supermassive black holes.

There are three major pulsar timing array experiments in operation: NANOGrav, the European Pulsar Timing Array, and the Parkes Pulsar Timing Array in Australia.

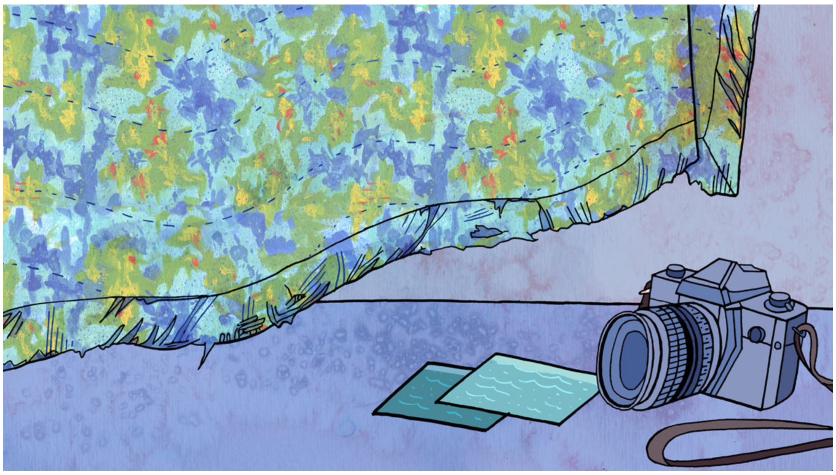

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Illustration by Sandbox Studio, Chicago with Corinne Mucha

Cosmic microwave background detectors

Finally, astronomers are also looking for primordial gravitational waves. These are waves created in the chaos of the very early universe.

One of the ways astronomers do this is quite different from the techniques described above. Rather than watching moving light originating from a laser or a pulsar, they look at a still image of light left over from the time just after the Big Bang—the cosmic microwave background—and try to see evidence of gravitational waves imprinted in it.

“It’s the difference between finding something bobbing up and down in the ocean and taking a snapshot of the ocean and seeing the crests and troughs,” Chatterjee says.

This is extremely difficult because there are many sources of noise, making the feat a bit like finding a specific small ripple in a pool while people are splashing around in it.

Interferometers and pulsar timing arrays are searching for these ancient waves as well. “The primordial gravitational wave background can, in principle, be observed in a very broad range of frequencies, from very low to very high ones,” says Pablo Rosado, an astrophysicist at Monash University studying gravitational wave detection. But according to Rosado, detectors like LIGO might not be able to see this signal because there may be too many binary black holes masking it.

LIGO's discovery was just the beginning. Just as the electromagnetic spectrum spans everything from long radio waves to short gamma rays, the gravitational wave spectrum extends across a huge range of frequencies that require very different instruments to find. Astronomers hope that together, these detectors will find the invisible signals that will help them understand the universe in a whole new light.

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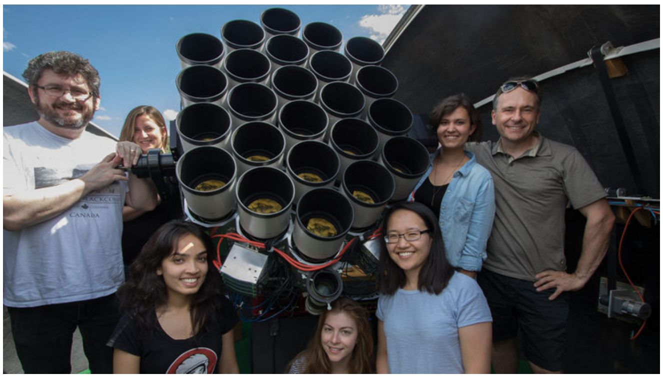
🕒 Oct 20, 2016

With a small side project, astronomers discover a new type of galaxy.



In 2011, astronomers Pieter van Dokkum and Roberto “Bob” Abraham found themselves in a restaurant in Toronto nursing something of a mid-life crisis. Abraham, a professor at the University of Toronto, and van Dokkum, at Yale, had become successful scientists, but they discovered that often meant doing less and less science and more and more managing large, complex projects.

“They’re important and they’re great and you feel this tremendous obligation once you’ve reached a certain age to serve on these committees because you have to set things up for the next generation,” Abraham says. “At the same time, it was no longer very much fun.”

The two friends fantasized about finding a small, manageable project that might still have some impact. By the time a few hours had passed, they picked an idea: using new camera lenses to find objects in the sky that emit very little light.

They had no way of knowing then that within the next five years, they’d discover an entirely new class of galactic object.

From the handmade telescopes of Galileo to spacefaring technological marvels like Hubble, all telescopes are designed for one basic task:

gathering light. Telescope technology has advanced far enough that Hubble can pick up light from stars that were burning just 400 million years after the universe first popped into existence.

But telescopes often miss objects with light that's spread out, or diffuse, which astronomers describe as having low surface brightness. Telescopes like Hubble have large mirrors that scatter light from bright objects in the sky, masking anything more diffuse. "There's this bit of the universe that's really quite unexplored because our telescope designs are not good at detecting these things," Abraham says.

When van Dokkum and Abraham sat down at that bar, they decided to try their hands at studying these cosmic castaways. The key turned out to be van Dokkum's hobby as an amateur insect photographer. He had heard of new camera lenses developed by Canon that were coated with nanoparticles designed to prevent light scattering. Although they were intended for high-contrast photography—say, snapping a photo of a boat in a sunny bay—van Dokkum thought these lenses might be able to spot diffuse objects in the sky.

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

Amateur insect photographer van Dokkum has a collection of dragonfly photos.

Pieter van Dokkum

Abraham was skeptical at first: "Yeah, I'm sure the Canon corporation has come up with a magical optical coating," he recalls thinking. But when the pair took one to a parking lot in a dark sky preserve in Quebec, they were sold on its capabilities. They acquired more and more lenses—not an easy task, at $12,000 a pop—eventually gathering 48 of them, and arranged them in an ever-growing honeycomb shape to form what can rightly be called a telescope. They named it Dragonfly.

In 2014, both van Dokkum and Abraham were at a conference in Oxford when van Dokkum examined an image that had come in from Dragonfly. (At the time, it had just eight lenses.) It was an image of the Coma Cluster, one of the most photographed galaxy clusters in the universe, and it was dotted with faint smudges that didn't match any objects in Coma Cluster catalogs.

Van Dokkum realized these smudges were galaxies, and that they were huge, despite their hazy light. They repeated their observations using the Keck telescope, which enabled them to calculate the velocities of the stars inside their mysterious galaxies. One was measured at 50 kilometers per second, 10 times the speed the galaxy should be moving based on the mass of its stars alone.

"We realized that for these extremely tenuous objects to survive as galaxies and not be ripped apart by their movement through space and interactions with other galaxies, there must be much more than meets the eye," van Dokkum says.

The galaxy, dubbed Dragonfly 44, has less than 1 percent as many stars as the Milky Way, and yet it has to be just as massive. That means that the vast majority of its matter is not the matter that makes up stars and planets and people—everything we can see—but dark matter, which seems to interact with regular matter through gravity alone.

Astronomers have known for decades that galaxies can be made almost entirely of dark matter. But those galaxies were always small, a class known as dwarf galaxies, which have between 100 million and a few billion stars. A dark-matter-dominated galaxy as large as the Milky Way, with its 200 billion or more stars, needed an entirely new category. Van Dokkum and Abraham coined a term for them: ultradiffuse.

"You look at a galaxy and you see this beautiful spiral structure and they're gorgeous. I love galaxies," Abraham says. "But what you see is really just kind of the frosting on the cake. The cake is the dark matter."

No one knows how many of these galaxies might exist, or whether they can have an even larger percentage of dark matter than Dragonfly 44. Perhaps there are galaxies that have no luminous matter at all, simply massive dark blobs hurtling through empty space. Though such galaxies have thus far evaded observation, evidence of their existence may be lurking in unexamined data from the past.

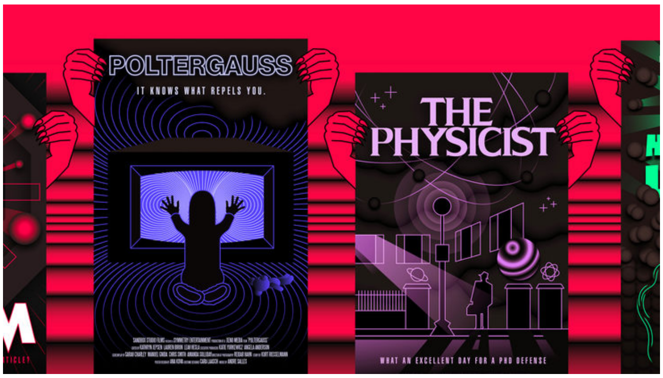
And Dragonfly could be the key for finding them. "When people knew they were real and that these things could exist and could be part of these galaxy clusters, suddenly they turned up in large numbers," van Dokkum says. "They just escaped attention for all these decades."

Read More... (http://www.symmetrymagazine.org/article/99-percent-invisible?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

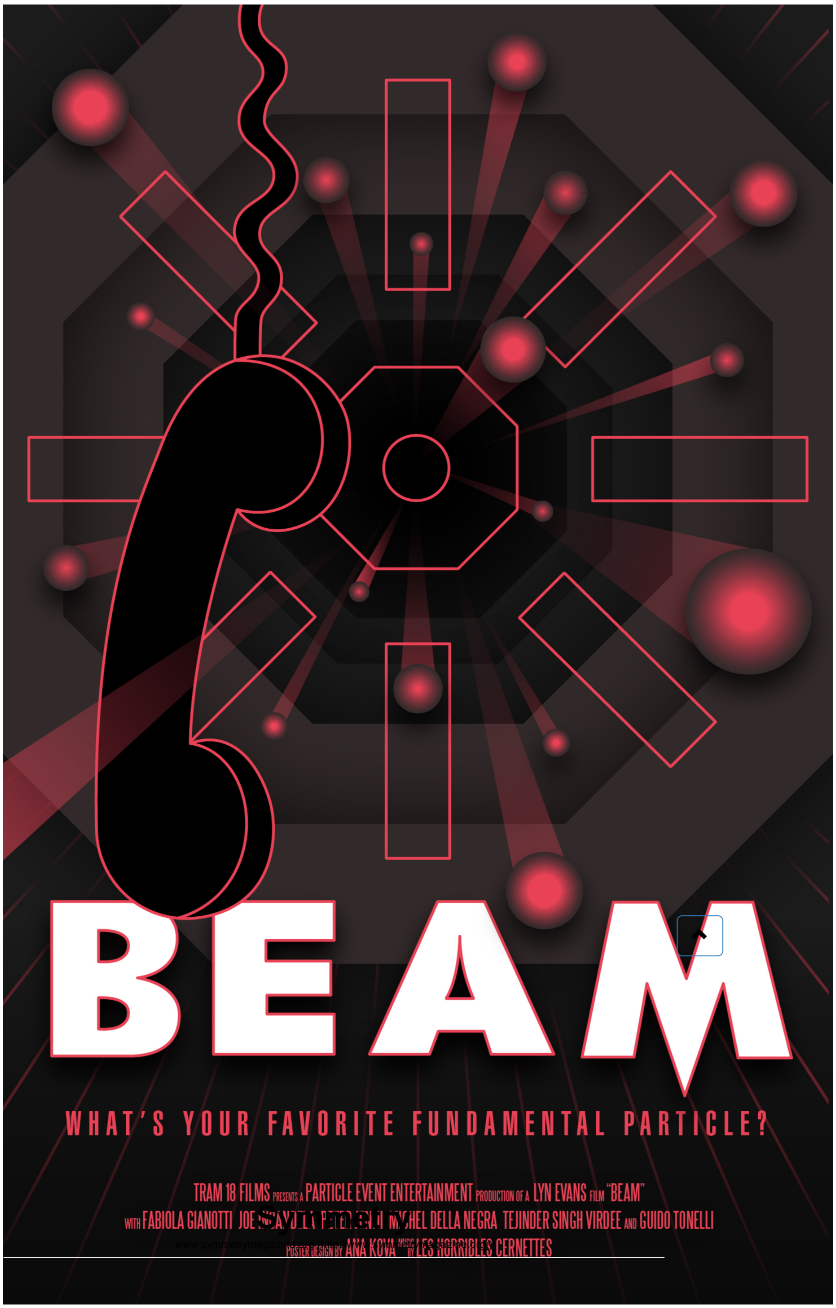
It came from the physics lab (http://www.symmetrymagazine.org/article/it-came-from-the-physics-lab?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Oct 18, 2016

Settle in for a physics-themed Halloween movie marathon.



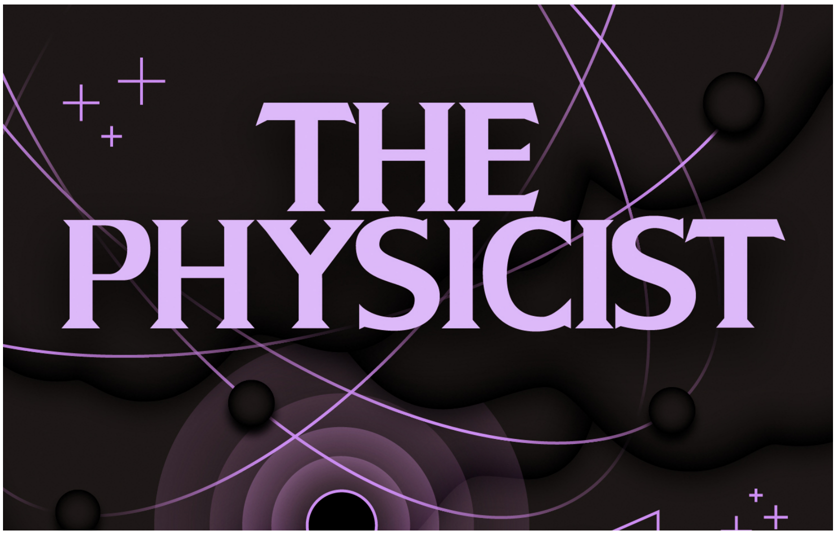
Looking for a way to celebrate Halloween? Has 2016 got you too spooked to go outside? Pop some corn and sample *Symmetry*'s little-known series of physics horror films instead. (Actual movies not included.)



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

Download PDF (/sites/default/files/images/hi-res/Symmetry_Halloween_Beam.pdf)
Artwork by Sandbox Studio, Chicago with Ana Kova

Someone's taken their love of the Higgs boson one step too far!



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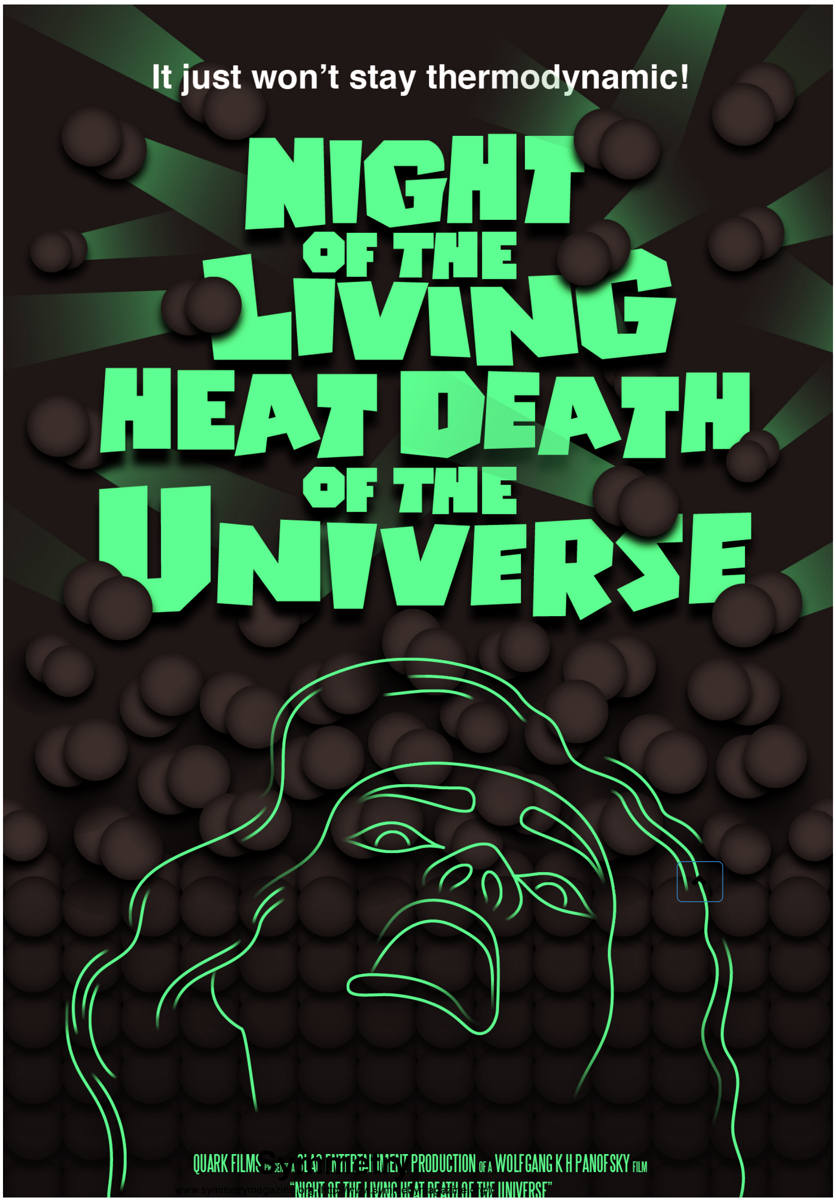
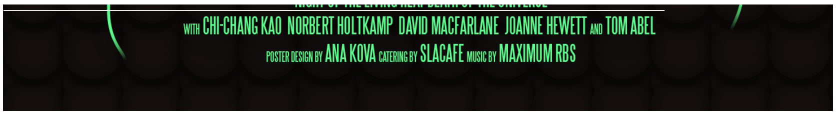
I need an old theorist and a young theorist.





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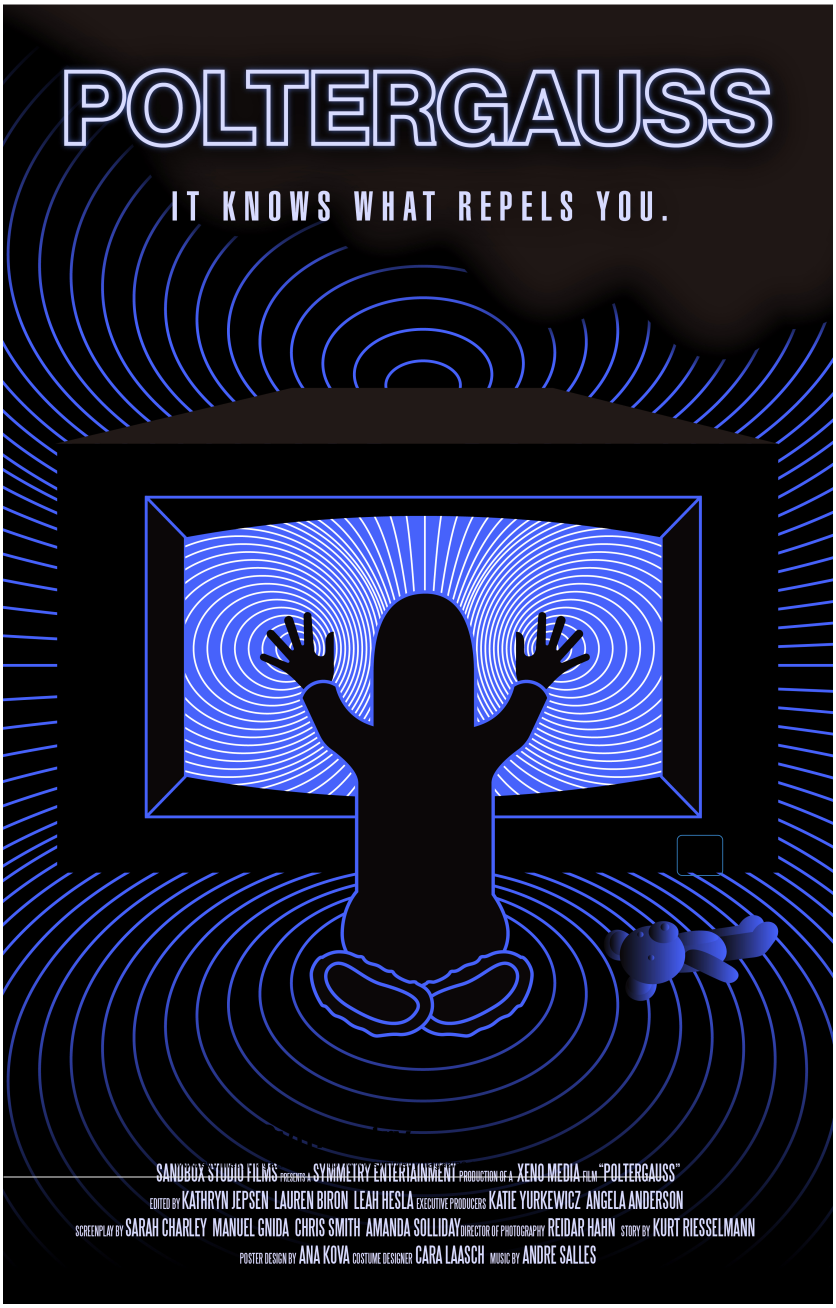
Entropy's coming to get you, Barbara!



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He's heeere.

Read More... (http://www.symmetrymagazine.org/article/it-came-from-the-physics-lab?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Citizen scientists join search for gravitational waves (http://www.symmetrymagazine.org/article/citizen-scientists-join-search-for-gravitational-waves?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Oct 12, 2016

A new project pairs volunteers and machine learning to sort through data from LIGO.

Barbara Téglás was looking to try something different while on a break from her biotechnology work.

So she joined Zooniverse, a website dedicated to citizen science projects, and began to hunt pulsars and classify cyclones from her home computer.

“It’s a great thing that scientists share data and others can analyze it and participate,” Téglás says. “The project helps me stay connected with science in other fields, from anywhere.”

In April, at her home in the Caribbean Islands, Téglás saw a request for volunteers to help with a new gravitational-wave project called Gravity Spy (https://www.zooniverse.org/projects/zooniverse/gravity-spy). Inspired by the discovery of gravitational waves by the Laser Interferometer Gravitational-wave Observatory, or LIGO, she signed up the same day.

“To be a complete outsider and have the opportunity to contribute to an astrophysics project such as LIGO, it’s extraordinary,” Téglás says.

Tuning out the noise

It took a century after Albert Einstein predicted the existence of gravitational waves—or ripples in space-time—for scientists to build an instrument sophisticated enough to see them. LIGO observed these ripples for the first (http://www.symmetrymagazine.org/article/ligo-sees-gravitational-waves) (and second (http://www.symmetrymagazine.org/article/second-gravitational-wave-detection-announced)) time, using two L-shaped detectors called interferometers designed to measure infinitesimal changes in distance. These changes were generated by two black holes that collided a billion years in the past, giving off gravitational waves that eventually passed through Earth. As they traveled through our planet, these gravitational waves stretched and shrank the 4-kilometer arms of the detectors.

The LIGO detectors can measure a change in distance about 10,000 times smaller than the diameter of a proton. Because the instruments are so sensitive, this also makes them prone to capturing other vibrations, such as earthquakes or heavy vehicles driving near the detectors. Equipment fluctuations can also create noise.

The noise, also called a glitch, can move the arms of the detector and potentially mimic an astrophysical signal.

The two detectors are located nearly 2000 miles apart, one in Louisiana and the other in Washington state. Gravitational waves from astrophysical events will hit both detectors at nearly the same time, since gravitational waves travel straight through Earth at the speed of light. However, the distance between the two makes it unlikely that other types of vibrations will be felt simultaneously.

“But that’s really not enough,” says Mike Zevin, a physics and astronomy graduate student at Northwestern University and a member of the Gravity Spy science team. “Glitches happen often enough that similar vibrations can appear in both detectors at nearly the same time. The glitches can tarnish the data and make it unusable.”

Gravity Spy enlists the help of volunteers to analyze noise that appears in LIGO detectors.

This information is converted to an image called spectrogram, and the patterns show the time and frequencies of the noise. Shifts in blue, green and yellow indicate the loudness of the glitch, or how much the noise moved the arms of the detector. The glitches show up frequently in the large amount of information generated by the detectors.

“Some of these glitches in the spectrograms are easily identified by computers, while others aren’t,” Zevin says. “Humans are actually better at spotting new patterns in the images.”

The Gravity Spy volunteers are tasked with labeling these hard-to-identify categories of glitches. In addition, the information is used to create training sets for computer algorithms.

As the training sets grow larger, the computers become better at classifying glitches. That can help scientists eliminate the noise from the detectors or find ways to account for glitches as they look at the data.

“One of our goals is to create a new way of doing citizen science that scales with the big-data era we live in now,” Zevin says.

Gravity Spy is a collaboration between Adler Planetarium, California State University-Fullerton, Northwestern University, Syracuse University, University of Alabama at Huntsville, and Zooniverse. The project is supported by an interdisciplinary grant (https://www.nsf.gov/pubs/2016/nsf16023/nsf16023.pdf) from the National Science Foundation.

About 1400 people volunteered for initial tests of Gravity Spy. Once the beta testing of Gravity Spy is complete, the volunteers will look at new images created when LIGO begins to collect data during its second observing run.

(http://www.symmetrymagazine.org/sites/default/files/images/standard/FINAL_Inline_Gravity_spy_092916_0.png)
Artwork by Sandbox Studio, Chicago with Ana Kova

A human endeavor

The project also provides an avenue for human-computer interaction research.

Another goal for Gravity Spy is to learn the best ways to keep citizen scientists motivated while looking at immense data sets, says Carsten Oesterlund, information studies professor at Syracuse University and member of the Gravity Spy research team.

“What is really exciting from our perspective is that we can look at how human learning and machine learning can go hand-in-hand,” Oesterlund says. “While the humans are training the machines, how can we organize the task to also facilitate human learning? We don’t want them simply looking at image after image. We want developmental opportunities for the volunteers.”

The researchers are examining how to encourage the citizen scientists to collaborate as a team. They also want to support new discoveries, or make it easier for people to find unique sets of glitches.

One test involves incentives—in an earlier study, the computing researchers found if a volunteer knows that they are the first to classify an image, they go on to classify more images.

“We’ve found that the sense of novelty is actually quite motivating,” says Kevin Crowston, a member of the Gravity Spy science team and associate dean for research at Syracuse University’s School of Information Studies.

Almost every day, Téglás works on the Gravity Spy project. When she has spare time, she sits down at her computer and looks at glitches. Since April, she’s classified nearly 15,000 glitches and assisted other volunteers with hundreds of additional images through talk forums on Zooniverse.

She’s pleased that her professional skills developed while inspecting genetics data can also help many citizen science projects.

On her first day with Gravity Spy, Téglás helped identify a new type of glitch. Later, she classified another unique glitch called “paired doves” after its repeating, chirp-like patterns, which closely mimic the signal created by binary black holes. She’s also found several new variations of known glitches. Her work is recognized in LIGO’s log (https://alog.ligo-wa.caltech.edu/aLOG/index.php?callRep=27138), and the newly found glitches are now part of the official workflow for the experiment.

Different experiences, backgrounds and ways of thinking can make citizen science projects stronger, she says.

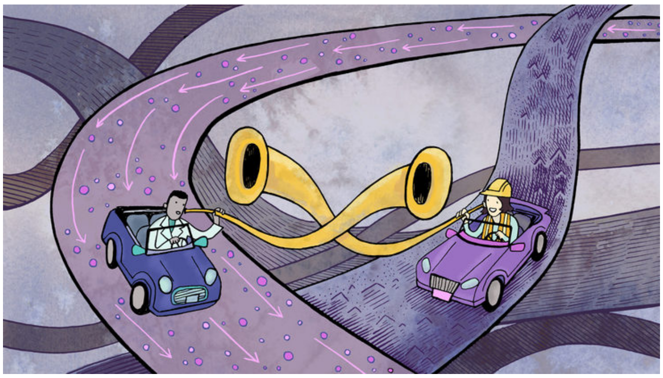
“For this project, you’re not only using your eyes,” Téglás says. “It’s also an opportunity to understand an important experiment in modern science.”

Read More... (http://www.symmetrymagazine.org/article/citizen-scientists-join-search-for-gravitational-waves?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Recruiting team geoneutrino (http://www.symmetrymagazine.org/article/recruiting-team-geoneutrino?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Oct 11, 2016

Physicists and geologists are forming a new partnership to study particles from inside the planet.



The Earth is like a hybrid car.

Deep under its surface, it has two major fuel tanks. One is powered by dissipating primordial energy left over from the planet's formation. The other is powered by the heat that comes from radioactive decay.

We have only a shaky understanding of these heat sources, says William McDonough, a geologist at the University of Maryland. "We don't have a fuel gauge on either one of them. So we're trying to unravel that."

One way to do it is to study geoneutrinos, a byproduct of the process that burns Earth's fuel. Neutrinos rarely interact with other matter, so these particles can travel straight from within the Earth to its surface and beyond.

Geoneutrinos hold clues as to how much radioactive material the Earth contains. Knowing that could lead to insights about how our planet formed and its modern-day dynamics. In addition, the heat from radioactive decay plays a key role in driving plate tectonics. Understanding the composition of the planet and the motion of the plates could help geologists model seismic activity.

To effectively study geoneutrinos, scientists need knowledge both of elementary particles and of the Earth itself. The problem, McDonough says, is that very few geologists understand particle physics, and very few particle physicists understand geology. That's why physicists and geologists have begun coming together to build an interdisciplinary community.

"There's really a need for a beyond-superficial understanding of the physics for the geologists and likewise a nonsuperficial understanding of the Earth by the physicists," McDonough says, "and the more that we talk to each other, the better off we are."

There are hurdles to overcome in order to get to that conversation, says Livia Ludhova, a neutrino physicist and geologist affiliated with Forschungzentrum Jülich and RWTH Aachen University in Germany. "I think the biggest challenge is to make a common dictionary and common understanding—to get a common language. At the basic level, there are questions on each side which can appear very naïve."

In July, McDonough and Gianpaolo Bellini, emeritus scientist of the Italian National Institute of Nuclear Physics and retired physics professor at the University of Milan, led a summer institute (https://agenda.infn.it/conferenceDisplay.py?confId=10519) for geology and physics graduate students to bridge the divide.

"In general, geology is more descriptive," Bellini says. "Physics is more structured."

This can be especially troublesome when it comes to numerical results, since most geologists are not used to working with the defined errors that are so important in particle physics.

At the summer institute, students began with a sort of remedial "preschool," in which geologists were taught how to interpret physical uncertainty and the basics of elementary particles and physicists were taught about Earth's interior. Once they gained basic knowledge of one another's fields, the scientists could begin to work together.

This is far from the first interdisciplinary community within science or even particle physics. Ludhova likens it to the field of radiology: There is one expert to take an X-ray and another to determine a plan of action once all the information is clear. Similarly, particle physicists know how to take the necessary measurements, and geologists know what kinds of questions they could answer about our planet.

Right now, only two major experiments are looking for geoneutrinos: KamLAND (http://kamland.stanford.edu/) at the Kamioka Observatory in Japan and Borexino (http://borex.lngs.infn.it/) at the Gran Sasso National Laboratory in Italy. Between the two of them, these observatories detect fewer than 20 geoneutrinos a year.

Because of the limited results, geoneutrino physics is by necessity a small discipline: According to McDonough, there are only about 25 active neutrino researchers with a deep knowledge of both geology and physics.

Over the next decade, though, several more neutrino detectors are anticipated, some of which will be much larger than KamLAND or Borexino. The Jiangmen Underground Neutrino Observatory (JUNO (http://english.ihep.cas.cn/rs/fs/juno0815/)) in China, for example, should be ready in 2020. Whereas Borexino's detector is made up of 300 tons of active material, and KamLAND's contains 1000, JUNO's will have 20,000 tons.

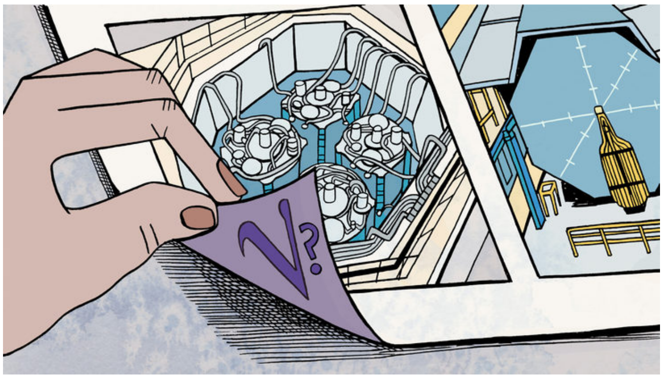
The influx of data over the next decade will allow the community to emerge into the larger scientific scene, Bellini says. "There are some people who say 'now this is a new era of science'—I think that is exaggerated. But I do think that we have opened a new chapter of science in which we use the methods of particle physics to study the Earth."

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

Hunting the nearly un-huntable (http://www.symmetrymagazine.org/article/hunting-the-nearly-un-huntable?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Oct 7, 2016

The MINOS and Daya Bay experiments weigh in on the search for sterile neutrinos.



In the 1990s, the Liquid Scintillator Neutrino Detector (LSND) experiment at Los Alamos National Laboratory saw intriguing hints of an undiscovered type of particle, one that (as of yet) cannot be detected. In 2007, the MiniBooNE experiment at the US Department of Energy's Fermi

National Accelerator Laboratory followed up and found a similar anomaly.

Today scientists on two more neutrino experiments—the MINOS experiment at Fermilab and the Daya Bay experiment in China—entered the discussion, presenting results that limit the places where these particles, called sterile neutrinos, might be hiding.

“This combined result was a two-year effort between our collaborations,” says MINOS scientist Justin Evans of the University of Manchester. “Together we’ve set what we believe is a very strong limit on a very intriguing possibility.”

In three separate papers—two published individually by MINOS (http://journals.aps.org/prl/abstract/10.1103/PhysRevLett.117.151803) and Daya Bay (http://journals.aps.org/prl/abstract/10.1103/PhysRevLett.117.151802) and one jointly (http://journals.aps.org/prl/abstract/10.1103/PhysRevLett.117.151801), all in *Physical Review Letters*—scientists on the two experiments detail the results of their hunt for sterile neutrinos.

Both experiments are designed to see evidence of neutrinos changing, or oscillating, from one type to another. Scientists have so far observed three types of neutrinos, and have detected them changing between those three types, a discovery that was awarded the 2015 Nobel Prize (http://www.symmetrymagazine.org/article/nobel-prize-awarded-for-discovery-of-neutrino-oscillations) in physics.

What the LSND and MiniBooNE experiments saw—an excess of electron neutrino-like signals—could be explained by a two-step change: muon neutrinos morphing into sterile neutrinos, then into electron neutrinos. MINOS and Daya Bay measured the rate of these steps using different techniques.

MINOS, which is fed by Fermilab’s neutrino beam—the most powerful in the world—looks for the disappearance of muon neutrinos. MINOS can also calculate how often muon neutrinos should transform into the other two known types and can infer from that how often they could be changing into a fourth type that can’t be observed by the MINOS detector.

Daya Bay performed a similar observation with electron anti-neutrinos (assumed, for the purposes of this study, to behave in the same way as electron neutrinos).

The combination of the two experiments’ data (and calculations based thereon) cannot account for the apparent excess of neutrino-like signals observed by LSND. That along with a reanalysis of results from Bugey, an older experiment in France, leaves only a very small region where sterile neutrinos related to the LSND anomaly could be hiding, according to scientists on both projects.

“There’s a very small parameter space left that the LSND signal could correspond to,” says Alex Sousa of the University of Cincinnati, one of the MINOS scientists who worked on this result. “We can’t say that these light sterile neutrinos don’t exist, but the space where we might find them oscillating into the neutrinos we know is getting narrower.”

Both Daya Bay and MINOS’ successor experiment, MINOS+, have already taken more data than was used in the analysis here. MINOS+ has completely analyzed only half of its collected data to date, and Daya Bay plans to quadruple its current data set. The potential reach of the final joint effort, says Kam-Biu Luk, co-spokesperson of the Daya Bay experiment, “could be pretty definitive.”

The IceCube collaboration, which measures atmospheric neutrinos with a detector deep under the Antarctic ice, recently conducted a similar search (http://www.symmetrymagazine.org/article/sterile-neutrinos-in-trouble) for sterile neutrinos and also came up empty.

All of this might seem like bad news for fans of sterile neutrinos, but according to theorist André de Gouvea of Northwestern University, the hypothesis is still alive.

Sterile neutrinos are “still the best new physics explanation for the LSND anomaly that we can probe, even though that explanation doesn’t work very well,” de Gouvea says. “The important thing to remember is that these results from MINOS, Daya Bay, Ice Cube and others don’t rule out the concept of sterile neutrinos, as they may be found elsewhere.”

Theorists have predicted the existence of sterile neutrinos based on anomalous results from several different experiments. The results from MINOS and Daya Bay address the sterile neutrinos predicted based on the LSND and MiniBooNE anomalies. Theorists predict other types of sterile neutrinos to explain anomalies in reactor experiments and in experiments using the chemical gallium. Much more massive types of sterile neutrinos would help explain why the neutrinos we know are so very light and how the universe came to be filled with more matter than antimatter.

Searches for sterile neutrinos have focused on the LSND neutrino excess, de Gouvea says, because it provides a place to look. If that particular anomaly is ruled out as a key to finding these nigh-undetectable particles, then they could be hiding almost anywhere, leaving no clues. “Even if sterile neutrinos do not explain the LSND anomaly, their existence is still a logical possibility, and looking for them is always interesting,” de Gouvea says.

Scientists around the world are preparing to search for sterile neutrinos in different ways.

Fermilab is preparing a three-detector suite of short-baseline experiments dedicated to nailing down the cause of both the LSND anomaly and an excess of electrons seen in the MiniBooNE experiment. These liquid-argon detectors will search for the appearance of electron neutrinos, a method de Gouvea says is a more direct way of addressing the LSND anomaly. One of those detetors, MicroBooNE, is specifically chasing down the MiniBooNE excess.

Scientists at Oak Ridge National Laboratory are preparing the Precision Oscillation and Spectrum Experiment (PROSPECT), which will search for sterile neutrinos generated by a nuclear reactor. CERN’s SHiP experiment, which stands for Search for Hidden Particles, is expected to look for sterile neutrinos with much higher predicted masses.

Obtaining a definitive answer to the sterile neutrino question is important, Evans says, because the existence (or non-existence) of these particles might impact how scientists interpret the data collected in other neutrino experiments, including Japan’s T2K, the United States’ NOvA, the forthcoming DUNE, and other future projects. DUNE in particular will be able to look for sterile neutrinos across a broad spectrum, and evidence of a fourth kind of neutrino would enhance its already rich scientific program.

“It’s absolutely vital that we get this question resolved,” Evans says. “Whichever way it goes, it will be a crucial part of neutrino experiments in the future.”

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Creating the universe in a computer (http://www.symmetrymagazine.org/article/creating-the-universe-in-a-computer?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Oct 4, 2016

Computer simulations help cosmologists unlock the mystery of how the universe evolved.

Astronomers face a unique problem. While scientists from most fields can conduct experiments—particle physicists build massive particle colliders to test their theories of subatomic material, and microbiologists probe the properties of microbes on petri dishes—astronomers cannot conduct experiments with the stars and planets. Even the most advanced telescopes can provide only snapshots of the cosmos, and very little changes during our lifetimes.

Yet many questions remain, such as how the Milky Way formed, what dark matter is and the role of supermassive black holes at the center of galaxies. In an attempt to edge closer to answering these unsolved mysteries, some scientists have embarked on ambitious projects: creating virtual universes.

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

The EAGLE simulation shows how supermassive black holes help shape galaxies.

Courtesy of EAGLE

Evolving the cosmos

The earliest observational evidence of the universe come from the cosmic microwave background, the afterglow created by the Big Bang. Computational cosmologists use this data to model the conditions at this time, when the universe was around a few hundred thousand years old.

Then they add the basic ingredients: baryonic (or ordinary) matter, from which the stars and planets form; dark matter, which enables galactic structures to grow; and dark energy, the mysterious force behind cosmic acceleration. These are coded into a simulation along with equations that describe various physical processes such as supernova explosions and black holes. Cosmologists then wait as the simulation evolves: The virtual universe expands, gas condenses into small structures and eventually form into stars and galaxies.

“The exciting thing is that if you do this, the universe that develops in a computer looks remarkably like the real universe,” says Joop Schaye of Leiden University and the principal investigator of the EAGLE (Evolution and Assembly of GaLaxies and their Environments) Project. “You get galaxies of all kinds of sizes and morphologies that look a lot like the real galaxies.”

A number of groups around the world are working on these simulations. In 2014, both the EAGLE Project and the Illustris Project, led by theoretical astrophysicist Mark Vogelsberger from MIT, made major steps forward with their groundbreaking, realistic universes. Both simulations are massive, covering a cubic space of around 300 million light years on each side. They also require a hefty amount of computing power—just one complete run requires large supercomputers to run for months at a time.

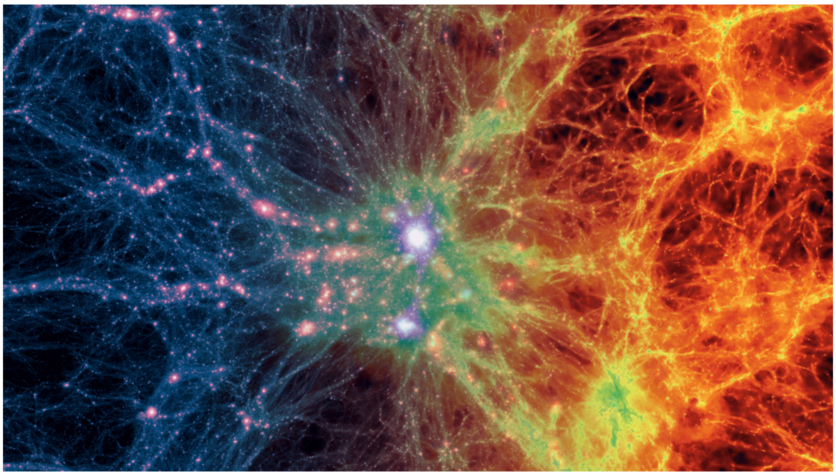
“What we ended up doing is running the big simulation once, but we want to understand why the universe behaved as it did,” says Richard Bower, a cosmologist at Durham University and member of the EAGLE Project. “So we’ve been running lots of other simulations where we change things a little bit.”

These simulations have already revealed some interesting properties of evolving galaxies. Bower and his colleagues, for instance, discovered that the number and size of galaxies is dependent on a fine balance between supernovae and black holes.

Using their simulation, they found that without supernovae, the universe created far too many galaxies. This is because without supernovae exploding, many small galaxies were not being blown apart.

On the other hand, they found that including only supernovae made galaxies grow too massive—10 times the mass of the Milky Way. To manage the size of those galaxies, they needed to also include black holes.

“The supernovae and the black holes are both kind of competing to use up the material that's supplied to the galaxy,” explains Bower. “Once the supernovae begin to wane, the black hole takes over, and it's the end of forming stars and the beginning of forming bigger and bigger black holes.”



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

Dark matter density (left) transitions to gas density (right).

Courtesy of Illustris

Zooming in

There are two type of simulations in this field of study—representative volume simulations, which model huge volumes of the observable universe, and zoom simulations, which focus on individual galaxies or galaxy clusters.

As astronomers collect more and more detailed snapshots of the universe, cosmologists such as Andrew Pontzen at the University College London are using zoom simulations to try to investigate the properties of individual galaxies at the same level of specificity. “We're trying to push forward on understanding the individual galaxies in enough detail that we can make meaningful comparisons to this really cutting-edge data,” Pontzen says.

To do so, Pontzen and his colleagues have developed a technique called genetic modification, which involves creating many different versions of galaxies. “It almost becomes like an experiment,” says Pontzen. “You have your control over how a particular object forms, and then you can say if it forms in this particular way, then the galaxy that comes out at the end looks like this.” For example, they can change the way that mass arrives in galaxies over time and see how it affects the galaxy that emerges.

In a similar way, cosmologists working on larger-scale simulations can “turn the knobs” by changing certain variables—the laws of gravity or the properties of dark matter, for example—and see what the universe that emerges looks like. “I think what's very interesting is to try to constrain the properties of dark matter and dark energy through these simulations,” says Vogelsberger. “We don't know what they are, but by tweaking minor parameters of these models we can try to constrain the properties of dark matter or dark energy in more detail.”

These scientists also work closely with observers to compare how the simulations stack up against what is actually out there in the universe. “That's the critical part,” says Pontzen. “We want to be able to link all of these things together.”

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

LHC smashes old collision records (http://www.symmetrymagazine.org/article/lhc-smashes-old-collision-records?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Sep 29, 2016

The Large Hadron Collider is now producing about a billion proton-proton collisions per second.

The LHC is colliding protons at a faster rate than ever before, approximately 1 billion times per second. Those collisions are adding up: This year alone the LHC has produced roughly the same number of collisions as it did during all of the previous years of operation together.

This faster collision rate enables scientists to learn more about rare processes and particles such as Higgs bosons, which the LHC produces about once every billion collisions.

“Every time the protons collide, it's like the spin of a roulette wheel with several billion possible outcomes,” says Jim Olsen, a professor of physics at Princeton University working on the CMS experiment. “From all these possible outcomes, only a few will teach us something new about the subatomic world. A high rate of collisions per second gives us a much better chance of seeing something rare or unexpected.”

Since April, the LHC has produced roughly 2.4 quadrillion particle collisions in both the ATLAS and CMS experiments. The unprecedented performance this year is the result of both the incremental increases in collision rate and the sheer amount of time the LHC is up and running.

“This year the LHC is stable and reliable,” says Jorg Wenninger, the head of LHC operations. “It is working like clockwork. We don't have much downtime.”

Scientists predicted that the LHC would produce collisions around 30 percent of the time during its operation period. They expected to use the rest of the time for maintenance, rebooting, refilling and ramping the proton beams up to their collision energy. However, these numbers have flipped; the LHC is actually colliding protons 70 percent of the time.

“The LHC is like a juggernaut,” says Paul Laycock, a physicist from the University of Liverpool working on the ATLAS experiment. “We took around a factor of 10 more data compared to last year, and in total we already have more data in Run 2 than we took in the whole of Run 1. Of course the biggest difference between Run 1 and Run 2 is that the data is at twice the energy now, and that's really important for our physics program.”

This unexpected performance comes after a slow start-up in 2015, when scientists and engineers still needed to learn how to operate the machine at that higher energy.

“With more energy, the machine is much more sensitive,” says Wenninger. “We decided not to push it too much in 2015 so that we could learn about the machine and how to operate at 13 [trillion electronvolts]. Last year we had good performance and no real show-stoppers, so now we are focusing on pushing up the luminosity.”

The increase in collision rate doesn't come without its difficulties for the experiments.

“The number of hard drives that we buy and store the data on is determined years before we take the data, and it's based on the projected LHC uptime and luminosity,” Olsen says. “Because the LHC is outperforming all estimates and even the best rosy scenarios, we started to run out of disk space. We had to quickly consolidate the old simulations and data to make room for the new collisions.”

The increased collision rate also increased the importance of vigilant detector monitoring and adjustments of experimental parameters in real time. All the LHC experiments are planning to update and upgrade their experimental infrastructure in winter 2017.

“Even though we were kept very busy by the deluge of data, we still managed to improve on the quality of that data,” says Laycock. “I think the challenges that arose thanks to the fantastic performance of the LHC really brought the best out of ATLAS, and we're already looking forward to next year.”

Astonishingly, 2.4 quadrillion collisions represent just 1 percent of the total amount planned during the lifetime of the LHC research program. The LHC is scheduled to run through 2037 and will undergo several rounds of upgrades to further increase the collision rate.

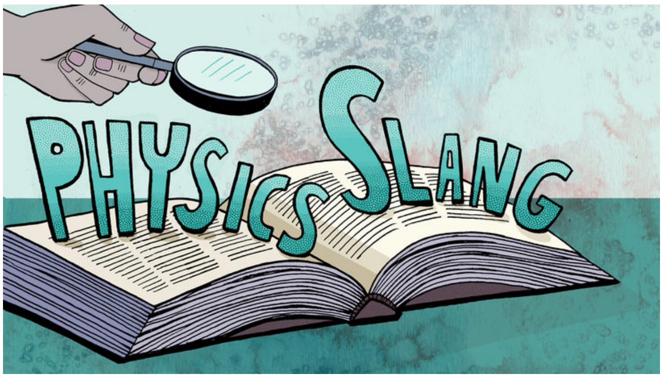
“Do we know what we will find? Absolutely not,” Olsen says. “What we do know is that we have a scientific instrument that is unprecedented in human history, and if new particles are produced at the LHC, we will find them.”

Read More... (http://www.symmetrymagazine.org/article/lhc-smashes-old-collision-records?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

You keep using that physics word (http://www.symmetrymagazine.org/article/you-keep-using-that-physics-word?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Sep 27, 2016

I do not think it means what you think it means.



Physics can often seem inconceivable. It's a field of strange concepts and special terms. Language often fails to capture what's really going on within the math and theories. And to make things even more complicated, physics has repurposed a number of familiar English words.

Much like Americans in England, folks from beyond the realm of physics may enter to find themselves in a dream within a dream, surrounded by a sea of words that sound familiar but are still somehow completely foreign.

Not to worry! *Symmetry* is here to help guide you with this list of words that acquire a new meaning when spoken by physicists.

(http://www.symmetrymagazine.org/sites/default/files/images/standard/Inline_1_Physics_Slang_Quench.jpg)

Illustration by Sandbox Studio, Chicago with Corinne Mucha

Quench

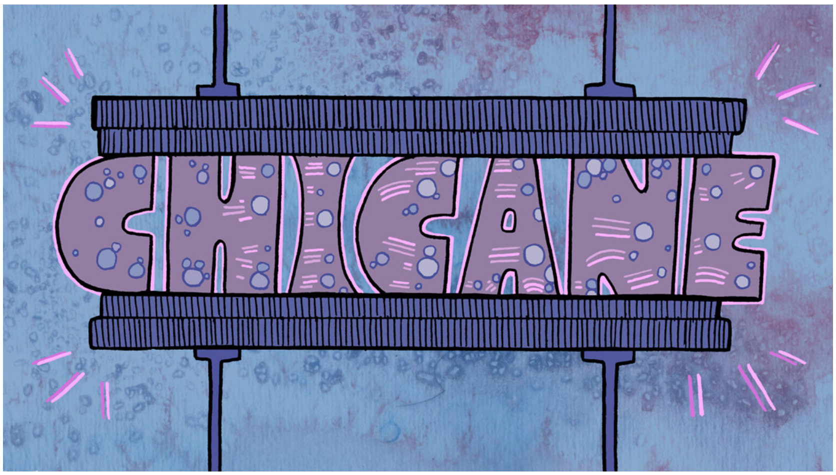
The physics version of quench has nothing to do with Gatorade products or slaking thirst. Instead, a quench is what happens when superconducting materials lose their ability to superconduct (or carry electricity with no resistance). During a quench, the electric current heats up the superconducting wire and the liquid coolant meant to keep the wire at its cool, superconducting temperature warms and turns into a gas that escapes through vents. Quenches are fairly common and an important part of training magnets that will focus and guide beams through particle accelerators. They also take place in superconducting accelerating cavities.

(http://www.symmetrymagazine.org/sites/default/files/images/standard/Inline_2_Physics_Slang_Cannibalism.jpg)

Illustration by Sandbox Studio, Chicago with Corinne Mucha

Cannibalism, strangulation and suffocation

These gruesome words take on a new, slightly kinder meaning in astrophysics lingo. They are different ways that a galaxy's shape or star formation rate can be changed when it is in a crowded environment such as a galaxy cluster. Galactic cannibalism, for example, is what happens when a large galaxy merges with a companion galaxy through gravity, resulting in a larger galaxy.

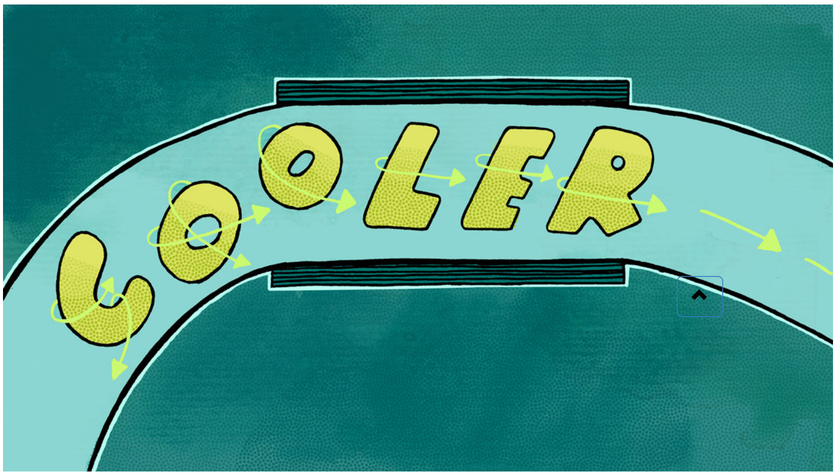


(http://www.symmetrymagazine.org/sites/default/files/images/standard/Inline_3_Physics_Slang_Chicane.jpg)

Illustration by Sandbox Studio, Chicago with Corinne Mucha

Chicane

Depending on how much you know about racecars and driving terms, you may or may not have heard of a chicane. In the driving world, a chicane is an extra turn or two in the road, designed to force vehicles to slow down. This isn't so different from chicanes in accelerator physics, where collections of four dipole magnets compress a particle beam to cluster the particles together. It squeezes the bunch of particles together so that those in the head (the high-momentum particles at the front of the group) are closer to the tail (the particles in the rear).

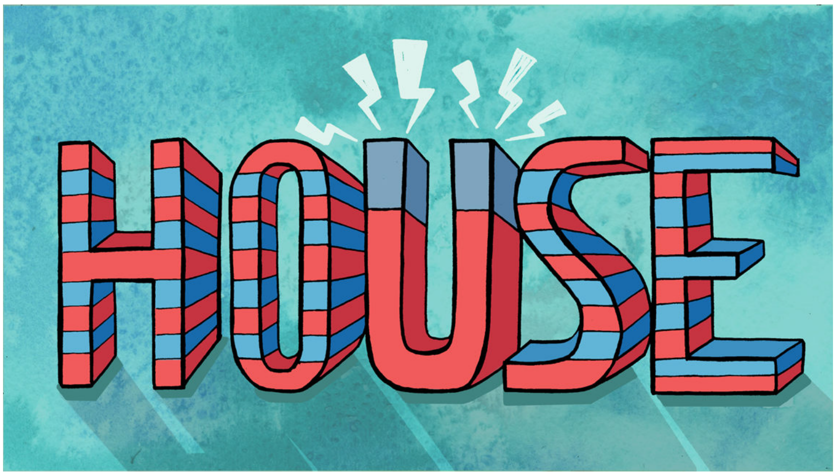


(http://www.symmetrymagazine.org/sites/default/files/images/standard/Inline_4_Physics_Slang_Cooler.jpg)

Illustration by Sandbox Studio, Chicago with Corinne Mucha

Cooler

A beam cooler won't be of much use at your next picnic. Beam cooling makes particle accelerators more efficient by keeping the particles in a beam all headed the same direction. Most beams have a tendency to spread out as they travel (something related to the random motion, or "heat," of the particles), so beam cooling helps kick rogue particles back onto the right path—staying on the ideal trajectory as they race through the accelerator.



(http://www.symmetrymagazine.org/sites/default/files/images/standard/Inline_5_Physics_Slang_Holuse.jpg)

Illustration by Sandbox Studio, Chicago with Corinne Mucha

House

In particle physics, a house is a place for magnets to reside in a particle accelerator. House is also used as a collective noun for a group of magnets. Fermilab's Tevatron particle accelerator, for example, had six sectors, each of which had four houses of magnets.

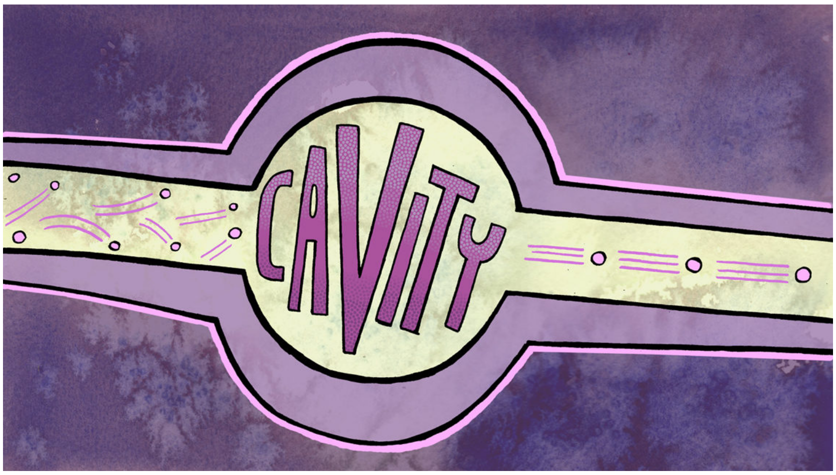
(http://www.symmetrymagazine.org/sites/default/files/images/standard/Inline_6_Physics_Slang_Barn.jpg)

Illustration by Sandbox Studio, Chicago with Corinne Mucha

Barn

A barn is a unit of measurement used in nuclear and particle physics that indicates the target area ("cross section") a particle represents. The meaning of the science term was originally classified, owing to the secretive nature of efforts to better understand the atomic nucleus in the 1940s. Now you can know: One barn is equal to [illegible]^{24} cm^{2}. In the subatomic world, a particle with that size is quite large—and hitting it with another

Now you can know: One barn is equal to [illegible] world, a particle with that size is quite large – and hitting it with another particle is practically like hitting the broad side of a barn.

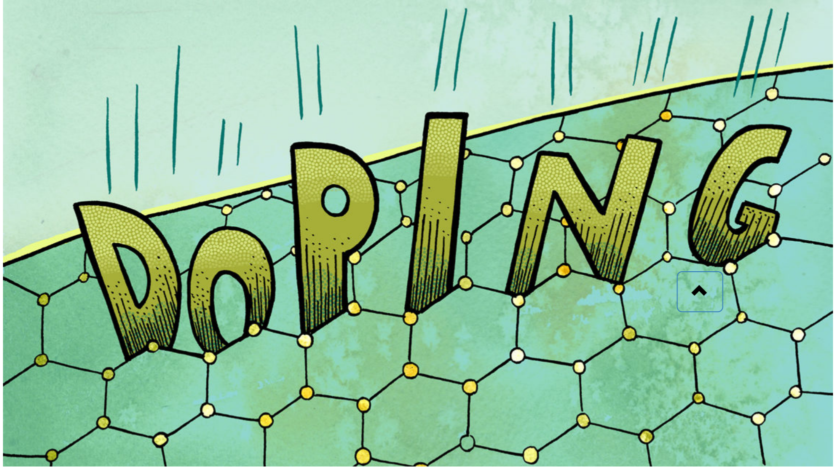


(http://www.symmetrymagazine.org/sites/default/files/images/standard/Inline_7_Physics_Slang_Cavity.jpg)

Illustration by Sandbox Studio, Chicago with Corinne Mucha

Cavity

Most people dread cavities, but not in particle physics. A cavity is the name for a common accelerator part. These metal chambers shape the accelerator's electric field and propel particles, pushing them closer to the speed of light. The electromagnetic field within a radio-frequency cavity changes back and forth rapidly, kicking the particles along. The cavities also keep the particles bunched together in tight groups, increasing the beam's intensity.

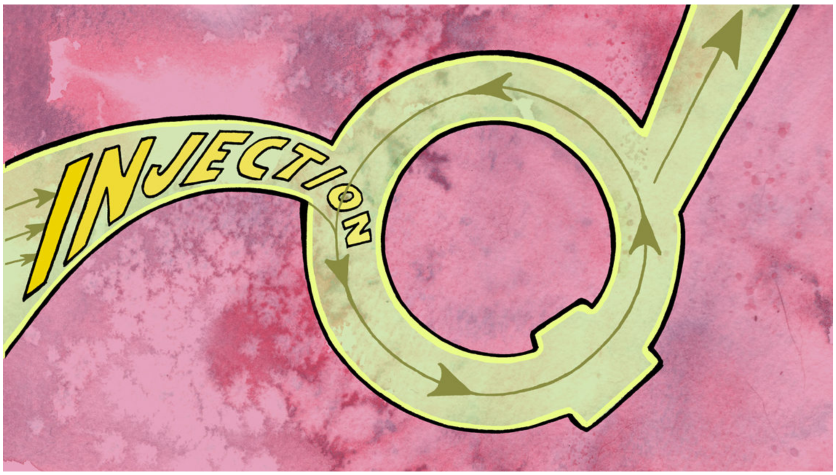


(http://www.symmetrymagazine.org/sites/default/files/images/standard/Inline_8_Physics_Slang_Doping.jpg)

Illustration by Sandbox Studio, Chicago with Corinne Mucha

Doping

Most people associate doping with drug use and sports. But doping can be so much more! It's a process to introduce additional materials (often considered impurities) into a metal to change its conducting properties. Doped superconductors can be far more efficient than their pure counterparts. Some accelerator cavities made of niobium are doped with atoms of argon or nitrogen. This is being investigated for use in designing superconducting magnets as well.



(http://www.symmetrymagazine.org/sites/default/files/images/standard/Inline_9_Physics_Slang_Injection.jpg)

Illustration by Sandbox Studio, Chicago with Corinne Mucha

Injection

In particle physics, injections don't deliver a vaccine through a needle into your arm. Instead, injections are a way to transfer particle beams from one accelerator into another. Particle beams can be injected from a linear accelerator into a circular accelerator, or from a smaller circular accelerator (a booster) into a larger one.

(http://www.symmetrymagazine.org/sites/default/files/images/standard/Inline_10_Physics_Slang_Decay.jpg)

Illustration by Sandbox Studio, Chicago with Corinne Mucha

Decay

Most people associate decay with things that are rotting. But a particle decay is the process through which one particle changes into other particles. Most particles in the Standard Model are unstable, which means that they decay almost immediately after coming into being. When a particle decays, its energy is divided into less massive particles, which may then decay as well.

Read More... (http://www.symmetrymagazine.org/article/you-keep-using-that-physics-word?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Small cat, big science (http://www.symmetrymagazine.org/article/small-cat-big-science?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Sep 21, 2016

The proposed International Linear Collider has a fuzzy new ally.

Hello Kitty is known throughout Japan as the poster girl (poster cat?) of *kawaii*, a segment of pop culture built around all things cute.

But recently she took on a new job: representing the proposed International Linear Collider.

At the August International Conference on High Energy Physics in Chicago, ILC boosters passed out folders featuring the white kitty wearing a pair of glasses, a shirt with pens in the pocket and a bow with an L for "Lagrangian (http://www.symmetrymagazine.org/article/the-deconstructed-standard-model-equation)," the name of the long equation in the background. Some picture the iconic cat sitting on an ILC cryomodule.

Hello Kitty has previously tried activities such as cooking, photography and even scuba diving. This may be her first foray into international research.

Japan is considering hosting the ILC, a proposed accelerator that could mass-produce Higgs bosons and other fundamental particles. Japan's Advanced Accelerator Association partnered with the company Sanrio to create the special *kawaii* gear in the hopes of drawing attention to the large-scale project.

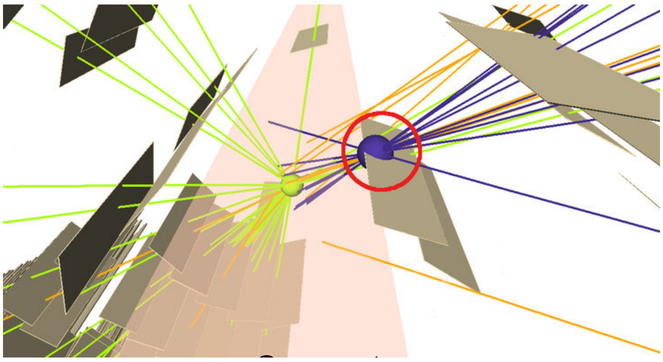
The ILC: Science you'll want to snuggle.

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

The secret lives of long-lived particles (http://www.symmetrymagazine.org/article/the-secret-lives-of-long-lived-particles?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Sep 16, 2016

A theoretical species of particle might answer nearly every question about our cosmos—if scientists can find it.



The universe is unbalanced.

Gravity is tremendously weak. But the weak force, which allows particles to interact and transform, is enormously strong. The mass of the Higgs boson is suspiciously petite. And the catalog of the makeup of the cosmos? Ninety-six percent incomplete.

Almost every observation of the subatomic universe can be explained by the Standard Model of particle physics—a robust theoretical framework bursting with verifiable predictions. But because of these unsolved puzzles, the math is awkward, incomplete and filled with restrictions.

A few more particles would solve almost all of these frustrations. Supersymmetry (nicknamed SUSY for short) is a colossal model that introduces new particles into the Standard Model's equations. It rounds out the math and ties up loose ends. The only problem is that after decades of searching, physicists have found none of these new friends.

But maybe the reason physicists haven't found SUSY (or other physics beyond the Standard Model) is because they've been looking through the wrong lens.

“Beautiful sets of models keep getting ruled out,” says Jessie Shelton, a theorist at the University of Illinois, “so we've had to take a step back and consider a whole new dimension in our searches, which is the lifetime of these particles.”

In the past, physicists assumed that new particles produced in particle collisions would decay immediately, almost precisely at their points of origin. Scientists can catch particles that behave this way—for example, Higgs bosons—in particle detectors built around particle collision points. But what if new particles had long lifetimes and traveled centimeters—even kilometers—before transforming into something physicists could detect?

This is not unprecedented. Bottom quarks, for instance, can travel a few tenths of a millimeter before decaying into more stable particles. And muons can travel several kilometers (with the help of special relativity) before transforming into electrons and neutrinos. Many theorists are now predicting that there may be clandestine species of particles that behave in a similar fashion. The only catch is that these long-lived particles must rarely interact with ordinary matter, thus explaining why they've escaped detection for so long. One possible explanation for this aloof behavior is that long live particles dwell in a hidden sector of physics.

“Hidden-sector particles are separated from ordinary matter by a quantum mechanical energy barrier—like two villages separated by a mountain range,” says Henry Lubatti from the University of Washington. “They can be right next to each other, but without a huge boost in energy to get over the peak, they'll never be able to interact with each other.”

High-energy collisions generated by the Large Hadron Collider could kick these hidden-sector particles over this energy barrier into our own regime. And if the LHC can produce them, scientists should be able to see the fingerprints of long-lived particles imprinted in their data.

Long-lived particles jolted into our world by the LHC would most likely fly at close to the speed of light for between a few micrometers and a few hundred thousand kilometers before transforming into ordinary and measurable matter. This incredibly generous range makes it difficult for scientists to pin down where and how to look for them.

But the lifetime of a subatomic particle is much like that of any living creature. Each type of particle has an average lifespan, but the exact lifetime of an individual particle varies. If these long-lived particles can travel thousands of kilometers before decaying, scientists are hoping that they'll still be able to catch a few of the unlucky early-transformers before they leave the detector. Lubatti and his collaborators have also proposed (http://arxiv.org/abs/1606.06298) a new LHC surface detector, which would extend their search range by many orders of magnitude.

Because these long-lived particles themselves don't interact with the detector, their signal would look like a stream of ordinary matter spontaneously appearing out of nowhere.

“For instance, if a long lived particle decayed into quarks while inside the muon detector, it would mimic the appearance of several muons closely clustered together,” Lubatti says. “We are triggering on events like this in the ATLAS experiment.” After recording the events, scientists use custom algorithms to reconstruct the origins of these clustered particles to see if they could be the offspring of an invisible long-lived parent.

If discovered, this new breed of matter could help answer several lingering questions in physics.

“Long-lived particles are not a prediction of a single new theory, but rather a phenomenon that could fit into almost all of our frameworks for beyond-the-Standard-Model physics,” Shelton says.

In addition to rounding out the Standard Model's mathematics, inert long-lived particles could be cousins of dark matter—an invisible form of matter that only interacts with the visible cosmos through gravity. They could also help explain the origin of matter after the Big Bang.

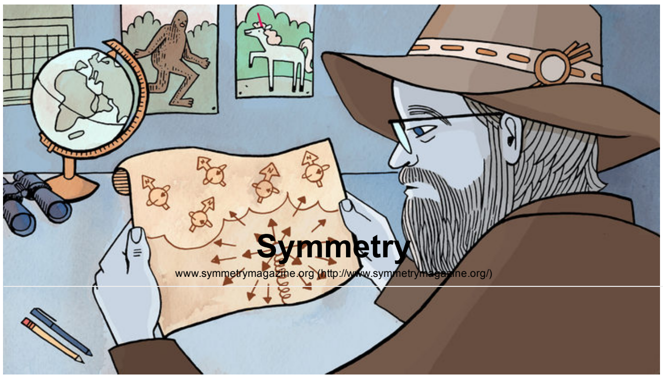
“So many of us have spent a lifetime studying such a tiny fraction of the universe,” Lubatti says. “We've understood a lot, but there's still a lot we don't understand—an enormous amount we don't understand. This gives me and my colleagues pause.”

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

The hunt for the truest north (http://www.symmetrymagazine.org/article/the-hunt-for-the-truest-north?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Sep 13, 2016

Many theories predict the existence of magnetic monopoles, but experiments have yet to see them.

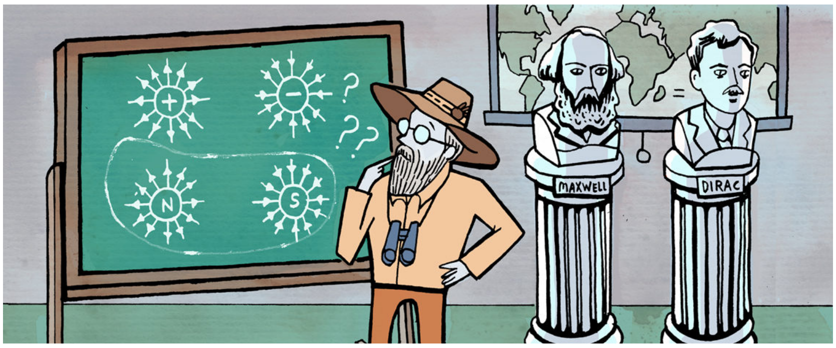


If you chop a magnet in half, you end up with two smaller magnets. Both the original and the new magnets have “north” and “south” poles.

But what if single north and south poles exist, just like positive and negative electric charges? These hypothetical beasts, known as “magnetic monopoles,” are an important prediction in several theories.

Like an electron, a magnetic monopole would be a fundamental particle. Nobody has seen one yet, but many—maybe even most—physicists would say monopoles probably exist.

“The electric and magnetic forces are exactly the same force,” says Wendy Taylor of Canada's York University. “Everything would be totally symmetric if there existed a magnetic monopole. There is a strong motivation by the beauty of the symmetry to expect that this particle exists.”



(http://www.symmetrymagazine.org/sites/default/files/images/standard/Inline_1_Magnetic_monopoles.jpg)
Illustration by Sandbox Studio, Chicago with Corinne Mucha

Dirac to the future

Combining the work of many others, nineteenth-century physicist James Clerk Maxwell showed that electricity and magnetism were two aspects of a single thing: the electromagnetic interaction.

But in Maxwell's equations, the electric and magnetic forces weren't quite the same. The electrical force had individual positive and negative charges. The magnetic force didn't. Without single poles—monopoles—Maxwell's theory looked asymmetrical, which bugged him. Maxwell thought and wrote a lot about the problem of the missing magnetic charge, but he left it out of the final version of his equations.

Quantum pioneer Paul Dirac picked up the monopole mantle in the early 20th century. By Dirac's time, physicists had discovered electrons and determined they were indivisible particles, carrying a fundamental unit of electric charge.

Dirac calculated the behavior of an electron in the magnetic field of a monopole. He used the rules of quantum physics, which say an electron or any particle (http://www.symmetrymagazine.org/article/what-is-a-particle) also behaves like a wave. For an electron sitting near another particle—including a monopole—those rules say the electron's wave must go through one or more full cycles wrapping around the other particle. In other words, the wave must have at least one crest and one trough: no half crests or quarter-troughs.

For an electron in the presence of a proton, this quantum wave rule explains the colors of light emitted and absorbed by a hydrogen atom, which is made of one electron and one proton. But Dirac found the electron could only have the right wave behavior if the product of the monopole magnetic charge and the fundamental electric charge carried by an electron were a whole number. That means monopoles, like electrons, carry a fundamental, indivisible charge. Any other particle carrying the fundamental electric charge—protons, positrons, muons, and so forth—will follow the same rule.

Interestingly, the logic runs the other way too. Dirac's result says if a single type of monopole exists, even if that type is very rare, it explains a very important property of matter: why electrically charged particles carry multiples of the fundamental electric charge. (Quarks carry a fraction—one-third or two-thirds—of the fundamental charge, but they always combine to make whole-number multiples of the same charge.) And if more than one type of monopole exists, it must carry a whole-number multiple of the fundamental magnetic charge.

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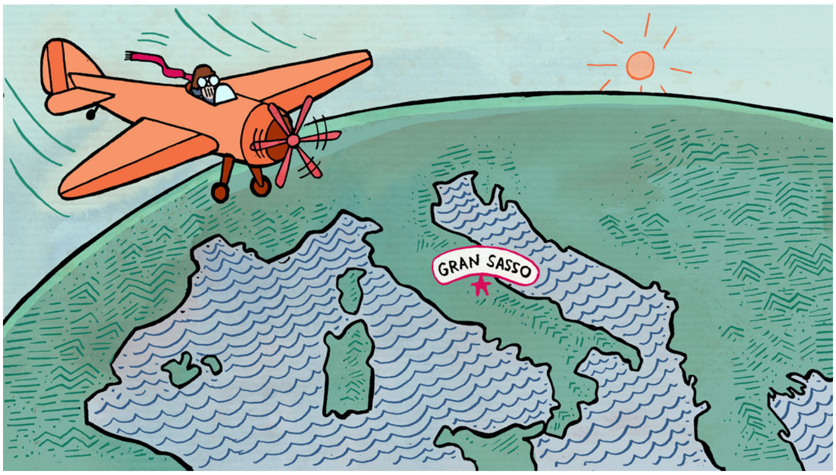


(http://www.symmetrymagazine.org/sites/default/files/images/standard/Inline_2_Magnetic_monopoles.jpg)
Illustration by Sandbox Studio, Chicago with Corinne Mucha

The magnetic unicorn

Dirac's discovery was really a plausibility argument: If monopoles existed, they would explain a lot, but nothing would crumble if they didn't.

Since Dirac's day, many theories have made predictions about the properties of magnetic monopoles. Grand unified theories (http://www.symmetrymagazine.org/article/a-gut-feeling-about-physics) predict monopoles that would be over 10 quadrillion times more massive than protons.

Producing such particles would require more energy than Earthly accelerators can reach, "but it's the energy that was certainly available at the beginning of the universe," says Laura Patrizii of the Italian National Institute for Nuclear Physics.

Cosmic ray detectors around the world are looking for signs of these monopoles, which would still be around today, interacting with molecules in the air. The MACRO experiment at Gran Sasso in Italy also looked for primordial monopoles, and provided the best constraints we have at present.

Luckily for scientists like Patrizii and Taylor, grand unified theories aren't the only ones to predict monopoles. Other theories predict magnetic monopoles of lower masses that could feasibly be created in the Large Hadron Collider, and of course Dirac's original model didn't place any mass constraints on monopoles at all. That means physicists have to be open to discovering particles that aren't part of any existing theory.

Both of them look for monopoles created at the Large Hadron Collider, Patrizii using the MoEDAL detector and Taylor using ATLAS.

"I think personally there's lots of reasons to believe that monopoles are out there, and we just have to keep looking," Taylor says.

"Magnetic monopoles are probably my favorite particle. If we discovered the magnetic monopole, [the discovery would be] on the same scale as the Higgs particle."

Read More... (http://www.symmetrymagazine.org/article/the-hunt-for-the-truest-north?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

A tale of two black holes (http://www.symmetrymagazine.org/article/a-tale-of-two-black-holes?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

🕒 Sep 9, 2016

What can the surprisingly huge mass of the black holes detected by LIGO tell us about dark matter and the early universe?

The historic detection of gravitational waves announced earlier this year breathed new life into a theory that's been around for decades: that black holes created in the first second of the universe might make up dark matter. It also inspired a new idea: that those so-called primordial black holes could be contributing to a diffuse background light.

The connection between these perhaps seemingly disparate areas of astronomy were tied together neatly in a theory from Alexander Kashlinsky, an astrophysicist at NASA's Goddard Spaceflight Center. And while it's an unusual idea, as he says, it could be proven true in only a few years.

Mapping the glow

Kashlinsky's focus has been on a residual infrared glow in the universe, the accumulated light of the earliest stars. Unfortunately, all the stars, galaxies and other bright objects in the sky—the known sources of light—oversaturate this diffuse glow. That means that Kashlinsky and his colleagues have to subtract them out of infrared images to find the light that's left behind.

They've been doing precisely that since 2005, using data from the Spitzer space telescope to arrive at the residual infrared glow: the cosmic infrared background (CIB).

Other astronomers followed a similar process using Chandra X-ray Observatory data to map the cosmic X-ray background (CXB), the diffuse glow of hotter cosmic material and more energetic sources.

In 2013, Kashlinsky and colleagues compared the CIB and CXB and found correlations between the patchy patterns in the two datasets, indicating that something is contributing to both types of background light. So what might be the culprit for both types of light?

"The only sources that could be coherent across this wide range of wavelengths are black holes," he says.

To explain the correlation they found, roughly 1 in 5 of the sources had to be black holes that lived in the first few hundred million years of our universe. But that ratio is oddly large.

"For comparison," Kashlinsky says, "in the present populations, we have 1 in 1000 of the emitting sources that are black holes. At the peak of star formation, it's 1 in 100."

He wasn't sure how the universe could have ever had enough black holes to produce the patterns his team saw in the CIB and CXB. Then the Laser Interferometric Gravitational-wave Observatory (LIGO) discovered a pair of strange beasts: two roughly-30-solar-mass black holes merging and emitting gravitational waves.

A few months later, Kashlinsky saw a study led by Simeon Bird analyzing the possibility that the black holes LIGO had detected were primordial—formed in the universe's first second. "And it just all came together," Kashlinsky says.

Gravitational secrets

The crucial ripples in space-time picked up by the LIGO detector on September 14, 2015, came from the last dance of two black holes orbiting each other and colliding. One black hole was 36 times the sun's mass, the other 29 times. Those black-hole weights aren't easy to make.

The majority of the universe's black holes are less than about 15 solar masses and form as massive stars collapse at the end of their lives. A black hole weighing 30 solar masses would have to start from a star closer to 100 times our sun's mass—and nature seems to have a hard time making stars that enormous. To compound the strangeness of the situation, the LIGO detection is from *a pair* of those black holes. Scientists weren't expecting such a system, but the universe has a tendency to surprise us.

Bird and his colleagues from Johns Hopkins University next looked at the possibility that those black holes formed not from massive stars but instead during the universe's first fractions of a second. Astronomers haven't yet seen what the cosmos looked like at that time, so they have to rely on theoretical models.

In all of these models, the early universe exists with density variations. If there were regions of very high-contrasting density, those could have collapsed into black holes in the universe's first second. If those black holes were at least as heavy as mountains when they formed, they'd stick around until today, dark and seemingly invisible and acting through the gravitational force. And because these primordial black holes formed from density perturbations, they wouldn't be comprised of protons and neutrons, the particles that make up you, me, stars and, thus, the material that leads to normal black holes.

All of those characteristics make primordial black holes a tempting candidate for the universe's mysterious dark matter, which we believe makes up some 25 percent of the universe and reveals itself only through the gravitational force. This possible connection has been around since the 1970s, and astronomers have looked for hints of primordial black holes since. Even though they've slowly narrowed down the possibilities, there are a few remaining hiding spots—including the region where the black holes that LIGO detected fall, between about 20 and 1000 solar masses.

Astronomers have been looking for explanations of what dark matter is for decades. The leading theory is that it's a new type of particle, but searches keep coming up empty. On the other hand, we know black holes exist; they stem naturally from the theory of gravity.

"They're an aesthetically pleasing candidate because they don't need any new physics," Bird says.

A glowing contribution

Kashlinsky's newest analysis (http://dx.doi.org/10.3847/2041-8205/823/2/L25) took the idea of primordial black holes the size that LIGO detected and looked at what that population would do to the diffuse infrared light of the universe. He evolved a model of the early universe, looking at how the first black holes would congregate and grow into clumps. These black holes matched the residual glow of the CIB and, he found, "would be just right to explain the patchiness of infrared background by sources that we measured in the first couple hundred million years of the universe."

This theory fits nicely together, but it's just one analysis of one possible model that came out of an observation of one astrophysical system. Researchers need several more pieces of evidence to say whether primordial black holes are in fact the dark matter. The good news is LIGO will soon begin another observing run that will be able to see black hole collisions even farther away from Earth and thus further back in time. The European gravitational wave observatory VIRGO will also come online in January, providing more data and working in tandem with LIGO.

More cases of gravitational waves from black holes around this 30-solar-masses range could add evidence that there is a population of primordial black holes. Bird and his colleague Ilias Cholis suggest looking for a more unique signal, though, in future gravitational-wave data. For two primordial black holes to become locked in a binary system and merge, they would likely be gravitationally captured during a glancing interaction, which could result in a signal with multiple frequencies or tones at any one moment.

"This is a rare event, but it would be very characteristic of our scenario," Cholis says. "In the next 5 to 10 years, we might see one."

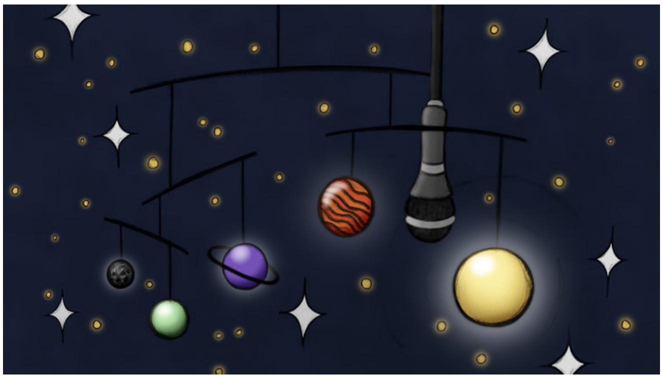
This smoking-gun signature, as they call it, would be a strong piece of evidence that primordial black holes exist. And if such objects are floating around our universe, it might not be such a stretch to connect them to dark matter.

Read More... (http://www.symmetrymagazine.org/article/a-tale-of-two-black-holes?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Turning on the cosmic microphone (http://www.symmetrymagazine.org/article/turning-on-the-cosmic-microphone?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Sep 6, 2016

A new tool lets astronomers listen to the universe for the first time.



When Galileo first introduced the telescope in the 1600s, astronomers gained the ability to view parts of the universe that were invisible to the naked eye. This led to centuries of discovery—as telescopes advanced, they exposed new planets, galaxies and even a glimpse of the very early universe.

Last September, scientists gained yet another invaluable tool: the ability to hear the cosmos through gravitational waves.

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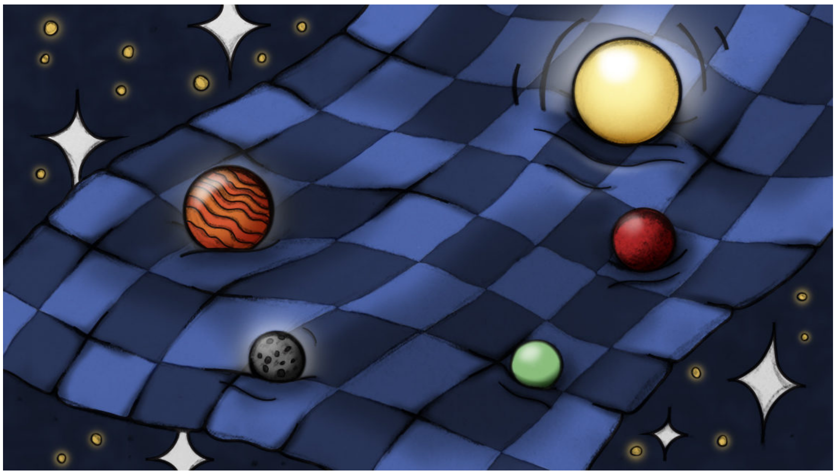


(http://www.symmetrymagazine.org/sites/default/files/images/standard/Inline_1_Gravitational_wave_astronomy.jpg)
Illustration by Sandbox Studio, Chicago with Lexi Fodor

Ripples in space-time

Newton described gravity as a force. Thinking about gravity this way can explain most of the phenomena that happens here on Earth. For example, the force of gravity acting on an apple makes it fall from a tree onto an unsuspecting person sitting below it. However, to understand gravity on a cosmic scale, we need to turn to Einstein, who described gravity as the bending of space-time itself.

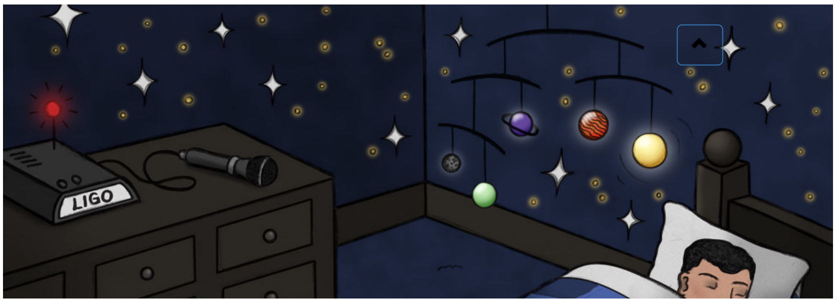
Some physicists describe this process using a bowling ball and a blanket. Imagine space-time as a blanket. A bowling ball placed at the center of the blanket bends the fabric around it. The heavier an object is, the further it sinks. As you move the ball along the fabric, it produces ripples, much like a boat travelling through water.

“The curvature is what makes the Earth orbit the sun—the sun is a bowling ball in a fabric and it's that bending in the fabric that makes the Earth go around,” explains Gabriela González, the spokesperson for the Laser Interferometer Gravitational-Wave Observatory (LIGO) collaboration.

Everything with mass—planets, stars and people—pulls on the fabric of space-time and produces gravitational waves as they move through space. These are passing through us all time, but they are much too weak to detect.

To find these elusive signals, physicists built LIGO, twin observatories in Louisiana and Washington. At each L-shaped detector, a laser beam is split and sent down two four-kilometer arms. The beams reflect off the mirrors at each end and travel back to reunite. A passing gravitational wave slightly alters the relative lengths of the arms, shifting the path of the laser beam, creating a change that physicists can detect.

Unlike telescopes, which are pointed toward very specific parts of the sky, detectors like LIGO scan a much larger area of the universe and hear sources from all directions. “Gravitational waves detectors are like microphones,” says Laura Nuttall, a postdoctoral researcher at Syracuse University.



(http://www.symmetrymagazine.org/sites/default/files/images/standard/Inline_2_Gravitational_wave_astronomy.jpg)
Illustration by Sandbox Studio, Chicago with Lexi Fodor

First detections

On the morning of September 14, 2015, a gravitational wave from two black holes that collided 1.3 billion years ago passed through the two LIGO detectors, and an automatic alert system pinged LIGO scientists around the world. “It took us a good part of the day to convince ourselves that this was not a drill,” González says.

Because LIGO was still preparing for an observing run—researchers were still running tests and diagnostics during the day—they needed to conduct a large number of checks and analyses to make sure the signal was real.

Months later, once researchers had meticulously checked the data for errors or noise (such as lightning or earthquakes) the LIGO collaboration announced to the world that they had finally reached a long-anticipated goal: Almost 100 years after Einstein first predicted their existence, scientists had detected gravitational waves.

A few months after the first signal arrived, LIGO detected yet another black hole collision. “Finding a second one proves that there's a population of sources that will produce detectible gravitational waves,” Nuttall says. “We are actually an observatory now.”

(http://www.symmetrymagazine.org/sites/default/files/images/standard/Inline_3_Gravitational_wave_astronomy.jpg)
Illustration by Sandbox Studio, Chicago with Lexi Fodor

Cosmic microphones

Many have dubbed the detection of gravitational waves as the dawn of the age of gravitational wave astronomy. Scientists expect to see hundreds, maybe even thousands, of these binary black holes in the years to come. Gravitational-wave detectors will also allow astronomers to look much more closely at other astronomical phenomena, such as neutron stars, supernovae and even the Big Bang.

One important next step is to detect the optical counterparts—such as light from the surrounding matter or gamma ray bursts—of the sources of gravitational waves. To do this, astronomers need to point their telescopes to the area of the sky where the gravitational waves came from to find any detectable light.

Currently, this feat is like finding a needle in a haystack. Because the field of view of gravitational wave detectors is much, much larger than telescopes, it is extremely difficult to connect the two. “Connecting gravitational waves with light for the first time will be such an important discovery that it's definitely worth the effort,” says Edo Berger, an astronomy professor at Harvard University.

LIGO is also one of several gravitational wave observatories. Other ground-based observatories, such as Virgo in Italy, KAGRA in Japan and the future LIGO India have similar sensitivities to LIGO. There are also other approaches that scientists are using—and plan to use in the future—to detect gravitational waves at completely different frequencies.

The evolved Laser Interferometer Space Antenna (eLISA), for example, is a gravitational wave detector that physicists plan to build in space. Once complete, eLISA will be composed of three spacecraft that are over a million kilometers apart, making it sensitive to much lower gravitational wave frequencies, where scientists expect to detect supermassive black holes.

Pulsar array timing is a completely different method of detection. Pulsars are natural timekeepers, regularly emitting beams of electromagnetic radiation. Astronomers carefully measure the arrival time of the pulses to find discrepancies, because when a gravitational wave passes by, space-time warps, changing the distance between us and the pulsar, causing the pulses to arrive slightly earlier or later. This method is sensitive to even lower frequencies than eLISA.

These and many other observatories will reveal a new view of the universe, helping scientists to study phenomena such as merging black holes, to test theories of gravity and possibly even to discover something completely unexpected, says Daniel Holz, a professor of physics and astronomy at the University of Chicago. “Usually in science you're just pushing the boundaries a little bit, but in this case, we're opening up a whole new frontier.”

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CUORE almost ready for first cool-down (http://www.symmetrymagazine.org/article/cuore-almost-ready-for-first-cool-down?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Sep 2, 2016

The refrigerator that will become the coldest cubic meter in the universe is fully loaded and ready to go.

Deep within a mountain in Italy, scientists have finished the assembly of an experiment more than one decade in the making. The detector of CUORE, short for Cryogenic Underground Observatory for Rare Events, is ready to be cooled down to its operating temperature for the first time.

Ettore Fiorini, the founder of the collaboration, proposed the use of low temperature detectors to search for rare events in 1984 and started creating the first prototypes with his group in Milano. What began as a personal project involving a tiny crystal and a small commercial cooler has grown to a collaboration of 165 scientists loading almost one ton of crystals and several tons of refrigerator and shields.

The CUORE experiment is looking for a rare process that would be evidence that almost massless particles called neutrinos are their own antiparticles, something that would give scientists a clue as to how our universe came to be.

Oliviero Cremonesi, current spokesperson of the CUORE collaboration, joined the quest in 1988 and helped write the first proposal for the experiment. At first, funding agencies in Italy and the United States approved a smaller version: Cuoricino.

“We had five exciting years of measurements from 2003 to 2008 on this machine, but we knew that we wanted to go bigger. So we kept working on CUORE,” Cremonesi says.

In 2005 the collaboration got approval for the big detector, which they called CUORE. That started them on a whole new journey involving growing crystals in China, bringing them to Italy by boat, and negotiating with archeologists for the right to use 2000-year-old Roman lead as shielding material.

“I imagine climbing Mount Everest is a little bit like this,” says Lindley Winslow, a professor at the Massachusetts Institute of Technology and group leader of the MIT activities on CUORE. “We can already see the top, but this last part is the hardest. The excitement is high, but also the fear that something goes wrong.”

The CUORE detector, assembled between 2012 and 2014, consists of 19 fragile copper towers that each host 52 tellurium oxide crystals connected by wires and sensors to measure their temperature.

For this final stage, scientists built a custom refrigerator from extremely pure materials. They shielded and housed it inside of a mountain at Gran Sasso, Italy. At the end of July, scientists began moving the detector to its new home. After a brief pause to ensure the site had not been affected by the 6.2-magnitude earthquake that hit central Italy on August 24, they finished the job on August 26.

The towers now reside in the largest refrigerator used for a scientific purpose. By the end of October, they will be cooled below 10 millikelvin (negative 460 Fahrenheit), colder than outer space.

Everything has to be this cold because the scientists are searching for minuscule temperature changes caused by an ultra-rare process. It is predicted to occur only once every trillion trillion years and is called neutrinoless double beta decay.

During a normal beta decay, one atom changes from one chemical element into its *daughter* element and sends out one electron and one antineutrino. For the neutrinoless double beta decay, this would be different: The element would change into its *granddaughter*. Instead of one electron and one neutrino sharing the energy of the decay, only two electrons would leave, and an observer would see no neutrinos at all.

This would only happen if neutrinos were their own antiparticles. In that case, the two neutrinos would cancel each other out, and it would seem like they never existed in the first place.

If scientists measure this decay, it would change the current scientific thinking about the neutrino and give scientists clues about why there is so much more matter than anti-matter in the universe.

“We are excited to start the cool-down, and if everything works according to plan, we can start measuring at the beginning of next year,” Winslow says.

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Universe steps on the gas (http://www.symmetrymagazine.org/article/universe-steps-on-the-gas?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Sep 1, 2016

A puzzling mismatch is forcing astronomers to re-think how well they understand the expansion of the universe.

Astronomers think the universe might be expanding faster than expected.

If true, it could reveal an extra wrinkle in our understanding of the universe, says Nobel Laureate Adam Riess of the Space Telescope Science Institute and Johns Hopkins University. That wrinkle might point toward new particles or suggest that the strength of dark energy, the mysterious force accelerating the expansion of the universe, actually changes over time.

The result appears in a study published in *The Astrophysical Journal* this July, in which Riess’s team measured the current expansion rate of the universe, also known as the Hubble constant, better than ever before.

In theory, determining this expansion is relatively simple, as long as you know the distance to a galaxy and the rate at which it is moving away from us. But distance measurements are tricky in practice and require using objects of known brightness, so-called standard candles, to gauge their distances.

The use of Type Ia supernovae—exploding stars that shine with the same intrinsic luminosity—as standard candles led to the discovery that the universe was accelerating in the first place and earned Riess, as well as Saul Perlmutter and Brian Schmidt, a Nobel Prize in 2011.

The latest measurement builds on that work and indicates that the universe is expanding by 73.2 kilometers per second per megaparsec (a unit that equals 3.3 million light-years). Think about dividing the universe into grids that are each a megaparsec long. Every time you reach a new grid, the universe is expanding 73.2 kilometers per second faster than the grid before.

Although the analysis pegs the Hubble constant to within experimental errors of just 2.4 percent, the latest result doesn’t match the expansion rate predicted from the universe’s trajectory. Here, astronomers measure the expansion rate from the radiation released 380,000 years after the Big Bang and then run that expansion forward in order to calculate what today’s expansion rate should be.

It’s similar to throwing a ball in the air, Riess says. If you understand the state of the ball (how fast it's traveling and where it is) and the physics (gravity and drag), then you should be able to precisely predict how fast that ball is traveling later on.

“So in this case, instead of a ball, it's the whole universe, and we think we should be able to predict how fast it's expanding today,” Riess says. “But the caveat, I would say, is that most of the universe is in a dark form that we don't understand.”

The rates predicted from measurements made on the early universe with the Planck satellite are 9 percent smaller than the rates measured by Riess’ team—a puzzling mismatch that suggests the universe could be expanding faster than physicists think it should.

David Kaplan, a theorist at Johns Hopkins University who was not involved with the study, is intrigued by the discrepancy because it could be easily explained with the addition of a new theory, or even a slight tweak to a current theory.

“Sometimes there's a weird discrepancy or signal and you think 'holy cow, how am I ever going to explain that?'” Kaplan says. “You try to come up with some cockamamie theory. This, on the other hand, is something that lives in a regime where it's really easy to explain it with new degrees of freedom.”

Kaplan’s favorite explanation is that there’s an undiscovered particle, which would affect the expansion rate in the early universe. “If there are super light particles that haven't been taken into account yet and they make up some smallish fraction of the universe, it seems that can explain the discrepancy relatively comfortably,” he says.

But others disagree. “We understand so little about dark energy that it's tempting to point to something there,” says David Spergel, an astronomer from Princeton University who was also not involved in the study. One explanation is that dark energy, the cause of the universe’s accelerating expansion, is growing stronger with time.

“The idea is that if dark energy is constant, clusters of galaxies are moving apart from each other but the clusters of galaxies themselves will remain forever bound,” says Alex Filippenko, an astronomer at the University of California, Berkeley and a co-author on Riess’ paper. But if dark energy is growing in strength over time, then one day—far in the future—even clusters of galaxies will get ripped apart. And the trend doesn’t stop there, he says. Galaxies, clusters of stars, stars, planetary systems, planets, and then even atoms will be torn to shreds one by one.

The implications could—literally—be Earth-shattering. But it's also possible that one of the two measurements is wrong, so both teams are currently working toward even more precise measurements. The latest discrepancy is also relatively minor compared to past disagreements.

"I'm old enough to remember when I was first a student and went to conferences and people argued over whether the Hubble constant was 50 or 100," says Spergel. "We're now in a situation where the low camp is arguing for 67 and the high camp is arguing for 73. So we've made progress! And that's not to belittle this discrepancy. I think it's really interesting. It could be the signature of new physics."

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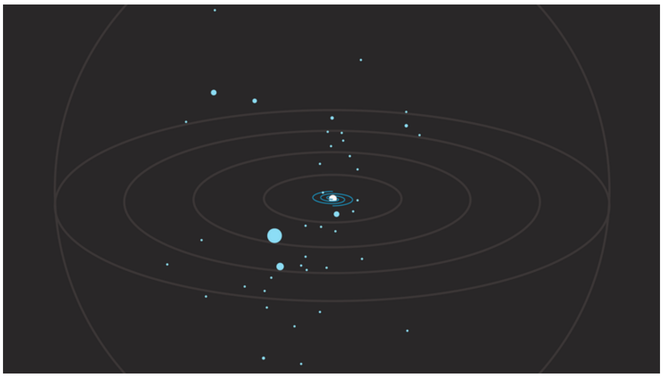
Our galactic neighborhood (http://www.symmetrymagazine.org/article/our-galactic-neighborhood?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Aug 30, 2016

What can our cosmic neighbors tell us about dark matter and the early universe?



Imagine a mansion.

Now picture that mansion at the heart of a neighborhood that stretches irregularly around it, featuring other houses of different sizes—but all considerably smaller. Cloak the neighborhood in darkness, and the houses appear as clusters of lights. Many of the clusters are bright and easy to see from the mansion, but some can just barely be distinguished from the darkness.

This is our galactic neighborhood. The mansion is the Milky Way, our 100,000-light-years-across home in the universe. Stretching roughly a million light years from the center of the Milky Way, our galactic neighborhood is composed of galaxies, star clusters and large roving gas clouds that are gravitationally bound to us.

The largest satellite galaxy, the Large Magellanic Cloud, is also one of the closest. It is visible to the naked eye from areas clear of light pollution in the Southern Hemisphere. If the Large Magellanic Cloud were around the size of the average American home—about 2,500 square feet—then by a conservative estimate the Milky Way mansion would occupy more than a full city block. On that scale, our most diminutive neighbors would occupy the same amount of space as a toaster.

Our cosmic neighbors promise answers to questions about hidden matter and the ancient universe. Scientists are setting out to find them.

What makes a neighbor

If we are the mansion, the neighboring houses are dwarf galaxies. Scientists have identified about 50 possible galaxies orbiting the Milky Way and have confirmed the identities of roughly 30 of them. These galaxies range in size from several billion stars to only a few hundred. For perspective, the Milky Way contains somewhere between 100 billion to a trillion stars.

Dwarf galaxies are the most dark-matter-dense objects known in the universe. In fact, they have far more dark matter than regular matter. Segue 1, our smallest confirmed neighbor, is made of 99.97 percent dark matter.

Dark matter is key to galaxy formation. A galaxy forms when enough regular matter is attracted to a single area by the gravitational pull of a clump of dark matter.

Projects such as the Dark Energy Survey, or DES, find these galaxies by snapping images of a segment of the sky with a powerful telescope camera. Scientists analyze the resulting images, looking for the pattern of color and brightness characteristic of galaxies.

Scientists can find dark matter clumps by measuring the motion and chemical composition of stars. If a smaller galaxy seems to be behaving like a more massive galaxy, observers can conclude a considerable amount of dark matter must anchor the galaxy.

"Essentially, they are nearby clouds of dark matter with just enough stars to detect them," says Keith Bechtol, a postdoctoral researcher at the University of Wisconsin-Madison and a member of the Dark Energy Survey.

Through these methods of identification (and thanks to the new capabilities of digital cameras), the Sloan Digital Sky Survey kicked off the modern hunt for dwarf galaxies in the early 2000s. The survey, which looked at the northern part of the sky, more than doubled the number of known satellite dwarf galaxies from 11 to 26 galaxies between 2005 and 2010. Now DES, along with some other surveys, is leading the search. In the last few years DES and its Dark Energy Camera, which maps the southern part of the sky, brought the total to 50 probable galaxies.

Dark matter mysteries

Dwarf galaxies serve as ideal tools for studying dark matter. While scientists haven't yet directly discovered dark matter, in studying dwarf galaxies they've been able to draw more and more conclusions about how it behaves and, therefore, what it could be.

"Dwarf galaxies tell us about the small-scale structure of how dark matter clumps," says Alex Drlica-Wagner of Fermi National Accelerator Laboratory, one of the leaders of the DES analysis. "They are excellent probes for cosmology at the smallest scales."

Dwarf galaxies also present useful targets for gamma-ray telescopes, which could tell us more about how dark matter particles behave. Some models posit that dark matter is its own antiparticle. If that were so, it could annihilate when it meets other dark matter particles, releasing gamma rays. Scientists are looking for those gamma rays.

But while studying these neighbors provides clues about the nature of dark matter, they also raise more and more questions. The prevailing cosmological theory of dark matter has accurately described much of what scientists observe in the universe. But when scientists looked to our neighbors, some of the predictions didn't hold up.

The number of galaxies appears to be lower than expected from calculations, for example, and those that are around seem to be too small. While some of the solutions to these problems may lie in the capabilities of the telescopes or the simulations themselves, we may also need to reconsider the way we think dark matter interacts.

The elements of the neighborhood

Dwarf galaxies don't just tell us about dark matter: They also present a window into the ancient past. Most dwarf galaxies' stars formed more than 10 billion years ago, not long after the Big Bang. Our current understanding of galaxy formation, according to Bechtol, is that after small galaxies formed, some of them merged over billions of years into larger galaxies.

If we didn't have these ancient neighbors, we'd have to peer all the way across the universe to see far enough back in time to glimpse galaxies that formed soon after the big bang. While the Milky Way and other large galaxies bustle with activity and new star formation, the satellite galaxies remain mostly static—snapshots of galaxies soon after their birth.

"They've mostly been sitting there, waiting for us to study them," says Josh Simon, an astronomer at the Carnegie Institution for Science.

The abundance of certain elements in stars in dwarf galaxies can tell scientists about the conditions and mechanisms that produce them. Scientists can also look to the elements to learn about even older stars.

The first generation of stars are thought to have looked very different than those formed afterward. When they exploded as supernovae, they released new elements that would later appear in stars of the next generation, some of which are found in our neighboring galaxies.

"They do give us the most direct fingerprint we can get as to what those first stars might have been like," Simon says.

Scientists have learned a lot about our satellites in just the past few years, but there's always more to learn. DES will begin its fourth year of data collection in August. Several other surveys are also underway. And the Large Synoptic Survey Telescope, an ambitious international project currently under construction in Chile, will begin operating fully in 2022. LSST will create a more detailed map than any of the previous surveys' combined.

Use this interactive graphic to explore our neighboring galaxies. Click on the abbreviated name of the galaxy to find out more about it.

The size of each galaxy is listed in parsecs, a unit equal to about 3.26 light-years or 19 trillion miles. The distance from the Milky Way is described in kiloparsecs, or 1000 parsecs. The luminosity of each galaxy, L?, is explained in terms of how much energy it emits compared to our sun. Right ascension and declination are astronomical coordinates that specify the galaxy's location as viewed from Earth.

Read extra descriptive text about some of our most notable neighboring galaxies (the abbreviations for which appear in darker red).

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Winners declared in SUSY bet (http://www.symmetrymagazine.org/article/winners-declared-in-susy-bet?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Aug 26, 2016

Physicists exchanged cognac in Copenhagen at the conclusion of a bet about supersymmetry and the LHC.

As a general rule, theorist Nima Arkani-Hamed does not get involved in physics bets.

“Theoretical physicists like to take bets on all kinds of things,” he says. “I’ve always taken the moral high ground… Nature decides. We’re all in pursuit of the truth. We’re all on the same side.”

But sometimes you’re in Copenhagen for a conference, and you’re sitting in a delightfully unusual restaurant—one that sort of reminds you of a cave—and a fellow physicist gives you the opportunity to get in on a decade-old wager (http://www.symmetrymagazine.org/article/june-2014/the-supersymmetric-bet) about supersymmetry and the Large Hadron Collider. Sometimes then, you decide to bend your rule. “It was just such a jovial atmosphere, I figured, why not?”

That’s how Arkani-Hamed found himself back in Copenhagen this week, passing a 1000-Krone bottle of cognac to one of the winners of the bet, Director of the Niels Bohr International Academy Poul Damgaard.

Arkani-Hamed had wagered that experiments at the LHC would find evidence of supersymmetry by the arbitrary date of June 16, 2016. Supersymmetry, SUSY for short, is a theory that predicts the existence of partner particles for the members of the Standard Model of particle physics

The deadline was not met. But in a talk at the Niels Bohr Institute, Arkani-Hamed pointed out that the end of the gamble does not equal the end of the theory.

“I was not a good student in school,” Arkani-Hamed explained. “One of my big problems was not getting homework done on time. It was a constant battle with my teachers… Just give me another week! It’s kind of like the bet.”

He pointed out that so far the LHC has gathered just 1 percent of the total amount of data it aims to collect.

With that data, scientists can indeed rule out the most vanilla form of supersymmetry. But that’s not the version of supersymmetry Arkani-Hamed would expect the LHC to find anyway, he said.

It is still possible LHC experiments will find evidence of other SUSY models—including the one Arkani-Hamed prefers, called split SUSY, which adds superpartners to just half of the Standard Model’s particles. And if LHC scientists don’t find evidence of SUSY, Arkani-Hamed pointed out, the theoretical problems it aimed to solve will remain an exciting challenge for the next generation of theorists to figure out.

“I think Winston Churchill said that in victory you should be magnanimous,” Damgaard said after Arkani-Hamed’s talk. “I know also he said that in defeat you should be defiant. And that’s certainly Nima.”

Arkani-Hamed shrugged. But it turned out he was not the only optimist in the room. Panelist Yonit Hochberg of the University of California, Berkeley conducted an informal poll of attendees. She found that the majority still think that in the next 20 years, as data continues to accumulate, experiments at the LHC will discover something new.

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SUSY Bet 2016

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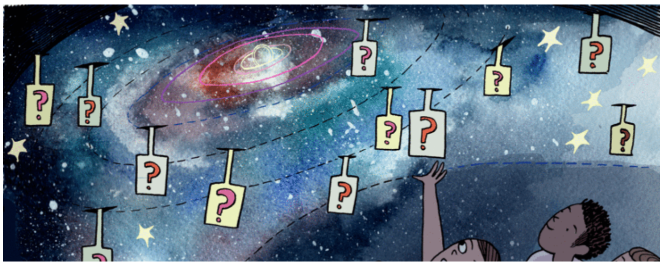
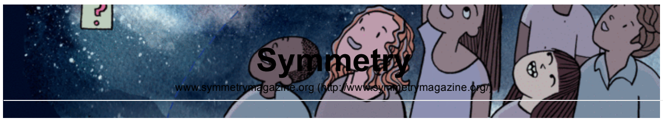
Five facts about the Big Bang (http://www.symmetrymagazine.org/article/five-facts-about-the-big-bang?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Aug 23, 2016

It’s the cornerstone of cosmology, but what is it all about?





Astronomers Edwin Hubble and Milton Humason in the early 20th century discovered that galaxies are moving away from the Milky Way. More to the point: Every galaxy is moving away from every other galaxy on average, which means the whole universe is expanding. In the past, then, the whole cosmos must have been much smaller, hotter and denser.

That description, known as the Big Bang model, has stood up against new discoveries and competing theories for the better part of a century. So what is this "Big Bang" thing all about?

(http://www.symmetrymagazine.org/sites/default/files/images/standard/bb2.gif)

Illustration by Sandbox Studio, Chicago with Corinne Mucha

The Big Bang happened everywhere at once.

The universe has no center or edge, and every part of the cosmos is expanding. That means if we run the clock backward, we can figure out exactly when everything was packed together—13.8 billion years ago. Because every place we can map in the universe today occupied the same place 13.8 billion years ago, there wasn't a location for the Big Bang: Instead, it happened everywhere simultaneously.

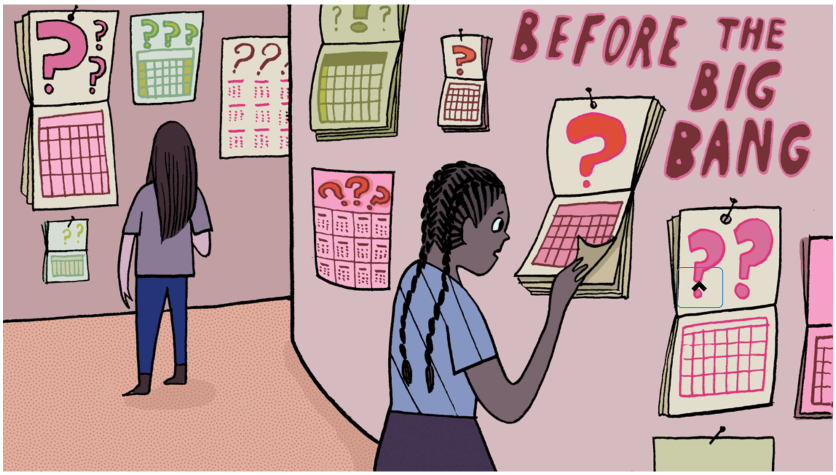


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Illustration by Sandbox Studio, Chicago with Corinne Mucha

The Big Bang may not describe the actual beginning of everything.

"Big Bang" broadly refers to the theory of cosmic expansion and the hot early universe. However, sometimes even scientists will use the term to describe a moment in time—when everything was packed into a single point. The problem is that we don't have either observations or theory that describes that moment, which is properly (if clumsily) called the "initial singularity."

The initial singularity is the starting point for the universe we observe, but there might have been something that came before.

The difficulty is that the very hot early cosmos and the rapid expansion called "inflation" that likely happened right after the singularity wiped out most—if not all—of the information about any history that preceded the Big Bang. Physicists keep thinking of new ways to check for signs of an earlier universe, and though we haven't seen any of them so far, we can't rule it out yet.

(http://www.symmetrymagazine.org/sites/default/files/images/standard/bb4.gif)

Illustration by Sandbox Studio, Chicago with Corinne Mucha

The Big Bang theory explains where all the hydrogen and helium in the universe came from.

In the 1940s, Ralph Alpher and George Gamow calculated that the early universe was hot and dense enough to make virtually all the helium, lithium and deuterium (hydrogen with a neutron attached) present in the cosmos today; later research showed where the primordial hydrogen came from. This is known as “Big Bang nucleosynthesis,” and it stands as one of the most successful predictions of the theory. The heavier elements (such as oxygen, iron and uranium) were formed in stars and supernova explosions.

The best evidence for the Big Bang is in the form of microwaves. Early on, the whole universe was dense enough to be completely opaque. But at a time roughly 380,000 years after the Big Bang, expansion spread everything out enough to make the universe transparent.

The light released from this transition, known as the cosmic microwave background (CMB), still exists. It was first observed in the 1960s by Arno Penzias and Robert Wilson. That discovery cemented the Big Bang theory as the best description of the universe; since then, observatories such WMAP and Planck have used the CMB to tell us a lot about the total structure and content of the cosmos.

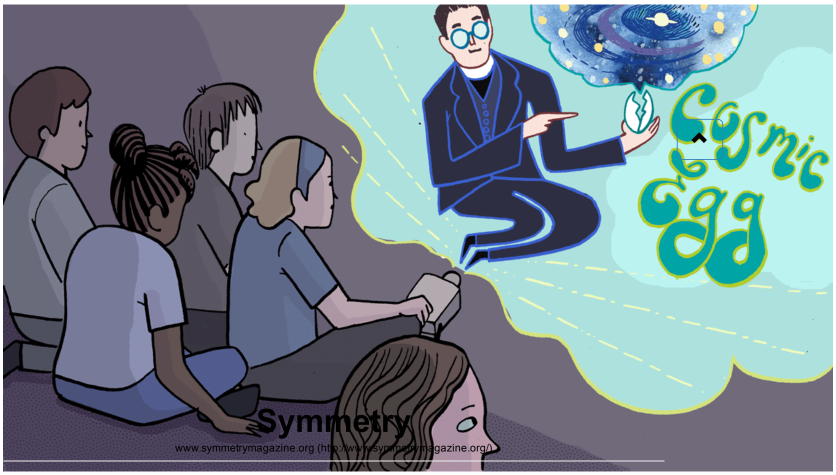

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Illustration by Sandbox Studio, Chicago with Corinne Mucha

One of the first people to think scientifically about the origin of the universe was a Catholic priest.

In addition to his religious training and work, Georges Lemaître was a physicist who studied the general theory of relativity and worked out some of the conditions of the early cosmos in the 1920s and ’30s. His preferred metaphors for the origin of the universe were “cosmic egg” and “primeval atom,” but they never caught on, which is too bad, because …

(http://www.symmetrymagazine.org/sites/default/files/images/standard/bb6.gif)

Illustration by Sandbox Studio, Chicago with Corinne Mucha

It seems nobody likes the name "Big Bang."

Until the 1960s, the idea of a universe with a beginning was controversial among physicists. The name “Big Bang” was actually coined by astronomer Fred Hoyle, who was the leading proponent of an alternative theory, where universe continues forever without a beginning.

His shorthand for the theory caught on, and now we’re kind of stuck with it. Calvin and Hobbes’ attempt to get us to adopt “horrendous space kablooie” (http://www.gocomics.com/calvinandhobbes/1992/06/21) has failed so far.

The Big Bang is the cornerstone of cosmology, but it’s not the whole story. Scientists keep refining the theory of the universe, motivated by our observation of all the weird stuff out there. Dark matter (which holds galaxies together) and dark energy (which makes the expansion of the universe accelerate) are the biggest mysteries that aren't described by the Big Bang theory by itself.

Our view of the universe, like the cosmos itself, keeps evolving as we discover more and more new things. But rather than fading away, our best explanation for why things are the way they are has remained—the fire at the beginning of the universe.

Read More... (http://www.symmetrymagazine.org/article/five-facts-about-the-big-bang?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

The $100 muon detector (http://www.symmetrymagazine.org/article/the-100-muon-detector?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Aug 19, 2016

A doctoral student and his adviser designed a tabletop particle detector they hope to make accessible to budding young engineering physicists.

When Spencer Axani was an undergraduate physics student, his background in engineering led him to a creative pipe dream: a pocket-sized device that could count short-lived particles called muons all day.

Muons, heavier versions of electrons, are around us all the time, a byproduct of the cosmic rays that shoot out from supernovae and other high-energy events in space. When particles from those rays hit Earth's atmosphere, they often decay into muons.

Muons are abundant on the surface of the Earth, but in Axani's University of Alberta underground office, shielded by the floors above, they might be few and far between. A pocket detector would be the perfect gadget for measuring the difference.

Now a doctoral student at Massachusetts Institute of Technology, Axani has nearly made this device a reality. Along with an undergraduate student and Axani's adviser, Janet Conrad, he's developed a detector (http://arxiv.org/abs/1606.01196) that sits on a desk and tallies the muons that pass by. The best part? The whole system can be built by students for under $100.

“Compared to most detectors, it's by far the cheapest and smallest I've found,” Axani says. “If you make 100,000 of these, it starts becoming a very large detector. Instrumenting airplanes and ships would let you start measuring cosmic ray rates around the world.”

Particle physicists deal with cosmic rays all of the time, says Conrad, a physics professor at MIT. “Sometimes we love them, and sometimes we hate them. We love them if we can use them for calibration of our detectors, and we hate them if they provide a background for what it is that we are trying to do.”

Conrad used small muon detectors similar to the one Axani dreamed about when leading a neutrino experiment at Fermi National Accelerator Laboratory called MiniBooNE. When a professor at the University of Alberta proposed adding mini-muon detectors to another neutrino experiment, Axani was ready to pitch in.

The idea was to create muon detectors to add to IceCube, a neutrino detector built into the ice in Antarctica. They would be inserted into IceCube's proposed low-energy upgrade, known as PINGU (Precision IceCube Next Generation Upgrade).

First, they needed a prototype. Axani got to work and quickly devised a rough detector housed in PVC pipe. “It looked pretty lab,” Axani said. It also gave off a terrible smell, the result of using a liquid called toluene as a scintillator, a material that gives off light when hit by a charged particle.

Over the next few months, Axani refined the device, switching to an odorless plastic scintillator and employing silicon photomultipliers (SiPM), which amplify the light from the scintillator into a signal that can be read. Adding some electronics allowed him to build a readout screen that ticks off the amount of energy from muon interactions and registers the time of the event.

Sitting in Axani's office, the counter shows a rate of one muon every few seconds, which is what they expected from the size of the detector. Though it's fairly constant, even minor changes like increased humidity or heavy rain can alter it.

Conrad and Axani have taken the detector down into the Boston subway, using the changes in the muon count to calculate the depth of the train tunnels. They've also brought it into the caverns of Fermilab's neutrino experiments to measure the muon flux more than 300 feet underground.

Axani wants to take it to higher elevations—say, in an airplane at 30,000 feet above sea level—where muon counts should be higher, since the particles have had less time to decay after their creation in the atmosphere.

Fermilab physicist Herman White suggested taking one of the the tiny detectors on a ship to study muon counts at sea. Mapping out the muon rate around the globe at sea has never been achieved. Liquid scintillator can be harmful to marine life, and the high voltage and power consumption of the large devices present a safety hazard.

While awaiting review of the PINGU upgrade, both Conrad and Axani see value in their project as an educational tool. With a low cost and simple instructions, the muon counter they created can be assembled by undergraduates and high school students, who would learn about machining, circuits, and particle physics along the way—no previous experience required.

“The idea was, students building the detectors would develop skills typically taught in undergraduate lab classes,” Spencer says. “In return, they would end up with a device useful for all sorts of physics measurements.”

Conrad has first-hand knowledge of how hands-on experience like this can teach students new skills. As an undergraduate at Swarthmore College, she took a course that taught all the basic abilities needed for a career in experimental physics: using a machine shop, soldering, building circuits. As a final project, she constructed a statue that she's held on to ever since.

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Creating the statue helped Conrad cement the lessons she learned in the class, but the product was abstract, not a functioning tool that could be used to do real science.

“We built a bunch of things that were fun, but they weren't actually useful in any way,” Conrad says. “This [muon detector] takes you through all of the exercises that we did and more, and then produces something at the end that you would then do physics with.”

Axani and Conrad published instructions for building the detector on the open-source physics publishing site arXiv, and have been reworking the project with the aim of making it accessible to high-school students. No math more advanced than division and multiplication is needed, Axani says. And the parts don't need to be new, meaning students could potentially take advantage of leftovers from experiments at places like Fermilab.

“This should be for students to build,” Axani says. “It's a good project for creative people who want to make their own measurements.”

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The physics photographer (http://www.symmetrymagazine.org/article/the-physics-photographer?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Aug 16, 2016

Fermilab's house photographer of almost 30 years, Reidar Hahn, shares four of his most iconic shots.

Science can produce astounding images. Arcs of electricity. Microbial diseases, blown up in full color. The bones of a long-dead beasts. The earth, a hazy blue marble in the distance.

But scientific progress is not always so visually dramatic. In laboratories in certain fields, such as high-energy particle physics, the stuff that excites the scientists might be hidden within the innards of machinery or encrypted as data.

Those labs need visual translators to show to the outside world the beauty and significance of their experiments.

Reidar Hahn specializes in bringing physics to life. As Fermilab's house photographer, he has been responsible for documenting most of what goes on in and around the lab for the past almost 30 years. His photos reveal the inner workings of complicated machinery. They show the grand scale of astronomical studies.

Hahn took up amateur photography in his youth, gaining experience during trips to the mountains out West. He attended Michigan Technological University to earn a degree in forestry and in technical communications. The editor of the school newspaper noticed Hahn's work and recruited him; he eventually became the principal photographer.

After graduating, Hahn landed a job with a group of newspapers in the suburbs of Chicago. He became interested in Fermilab after covering the opening of the Tevatron, Fermilab's now-decommissioned landmark accelerator. He began popping in to the lab to look for things to photograph. Eventually, they asked him to stay.

Reidar says he was surprised by what he found at the lab. "I had this misconception that when I came here, there would be all these cool, pristine cleanrooms with guys in white suits and rubber gloves. And there are those things here. But a lot of it is concrete buildings with duct tape and cable ties on the floor. Sometimes, the best thing you can do for a photo is sweep the floor before you shoot."

Hahn says he has a responsibility, when taking photos for the public, to show the drama of high-energy physics, to impart a sense of excitement for the state of modern science.

Below, he shares the techniques he used to make some of his iconic images for Fermilab.

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Tevatron

Photo by Reidar Hahn, Fermilab

The Tevatron

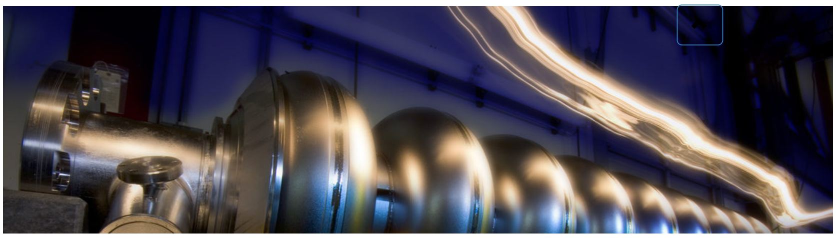
"I knew they were going to be shutting down the Tevatron—our large accelerator—and I wanted to get a striking or different view of it. It was 2011, and it would be big news when the lab shut it down.

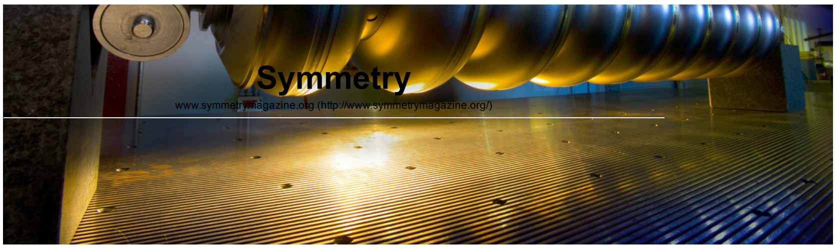
"This was composed of seven different photos. You can't keep the shutter open on a digital camera very long, so I would do a two-minute exposure, then do another two-minute exposure, then another. This shot was done in the dead of winter on a very cold day; It was around zero [degrees]. I was up on the roof probably a good hour.

"It took a little time to prepare and think out. I could have shot it in the daylight, but it wouldn't have had as much drama. So I had fire trucks and security vehicles and my wife driving around in circles with all their lights on for about half an hour. The more lights the better. I was on the 16th floor roof of the high-rise [Fermilab's Wilson Hall]. I had some travelling in other directions, because if they were all going counter-clockwise, you'd just see headlights on the left and taillights on the other end. They were slowly driving around—10, 15 miles an hour—and painting a circle [of light] with their headlights and taillights.

"This image shows a sense of physics on a big scale. And it got a lot of play. It got a full double spread in *Scientific American*. It was in a lot of other publications.

"I think particle physics has some unique opportunities for photography because of these scale differences. We're looking for the smallest constituents of matter using the biggest machines in the world to do it."





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SRF Cavities

Photo by Reidar Hahn, Fermilab

SRF cavities

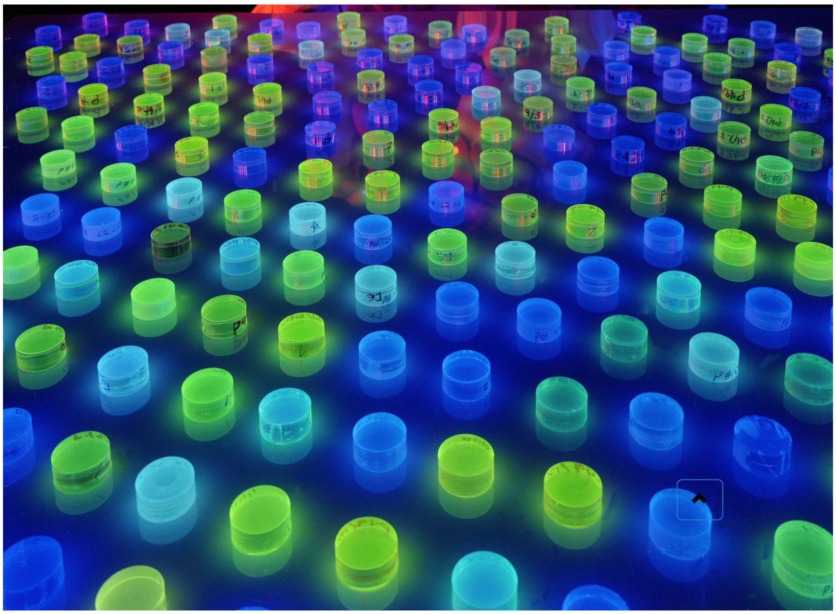
“This was an early prototype superconducting [radio-frequency] cavity, which is used to accelerate particles. Every one of those donuts there forces a particle to go faster and faster. In 2005, these cavities were just becoming a point of interest here at Fermilab.

“This was sitting in a well-lit room with a lot of junk around it. They didn’t want it moved. So I had to think how I could make this interesting. How could I give it some motion, some feel that there’s some energy here?

“So I [turned] all the room lights out. This whole photo was done with a flashlight. You leave the shutter open, and you move the light over the subject and paint the light onto the subject. It’s a way to selectively light certain things. This is about four exposures combined in Photoshop. I had a flashlight with different color gels on it, and I just walked back and forth.

“I wanted something dynamic to the photo. It’s an accelerator cavity; it should look like something that provides movement. So in the end, I took the gels off, and I dragged the flashlight through the scene [to create the streak of light above the cavity]. It could represent a [particle] beam, but it just provides some drama.

“A good photo can help communicate that excitement we all have here about science. Scientists may not use [this photo] as often for technical things, but we’re also trying to make science exciting for the non-scientists. And people can learn that some of these things are beautiful objects. They can see some kind of elegance to the equipment that scientists develop and build for the tools of discovery.”



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Scintillating material

Photo by Reidar Hahn, Fermilab

Scintillating material

“This was taken back in ’93. It was done on film—we bought our first digital camera in 1998.

“This is a chemist here at the lab, and she's worked a lot on different kinds of scintillating compounds. A scintillator is something that takes light in the invisible spectrum and turns it to the visible spectrum. A lot of physics detectors use scintillating material to image particles that you can't normally see.

“[These] are some test samples she had. She needed the photo to illustrate various types of wave-shifting scintillator. I wanted to add her to the photo because—it all goes back to my newspaper days—people make news, not things. But the challenge gets tougher when you have to add a person to the picture. You can’t have someone sit still for three minutes while making an exposure.

“There’s a chemical in this plastic that wave-shifts some type of particle from UV to visible light. So I painted the scintillating plastic with the UV light in the dark and then had Anna come over and sit down at the stool. I had two flashes set up to light her. [The samples] all light internally. That’s the beauty of scintillator materials.

“But it goes to show you how we have to solve a lot of problems to actually make our experiments work.”

(http://www.symmetrymagazine.org/sites/default/files/images/standard/12-0333-21D.hr_.jpg)

Cerro Tololo observatory

Photo by Reidar Hahn, Fermilab

Cerro Tololo Observatory

“This is the Cerro Tololo [Inter-American] Observatory in Chile, taken in October 2012. We have a lot of involvement in the Dark Energy Survey, [a collaboration to map galaxies and supernovae and to study dark energy and the expansion of the universe]. Sometimes we get to go to places to document things the lab’s involved in.

“This one is hundreds of photos stacked together. If you look close, you can see it’s a series of dots. A 30-second exposure followed by a second for the shutter to reset and then another 30-second exposure.

“The Earth spins. When you point a camera around the night sky and happen to get the North Star or Southern Cross—this is the Southern Cross—in the shot, you can see how the Earth rotates: This is what people refer to as star-trails. It’s a good reminder that we live in a vast universe and we’re spinning through it.

“We picked a time when there’s no moon because it’s hard to do this kind of shot when the moon comes up. Up on the top of the mountain, they don’t want a lot of light. We walked around with little squeeze lights or no lights at all because we didn’t want to have anything affect the telescopes. But every once in awhile I would notice a car go down from the top, and as it would go around the corner, they’d tap the brake lights. We learned to use the brake lights to light the building. It gives some drama to the dome.

“You’ve got to improvise. You have to work with some very tight parameters and still come back with the shot.”

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#AskSymmetry Twitter chat with Risa Wechsler (http://www.symmetrymagazine.org/article/asksymmetry-twitter-chat-with-risa-wechsler?utm_source=main_feed_click&utm_medium=rss&utm_campaign=main_feed&utm_content=click)

Aug 10, 2016

See cosmologist Risa Wechsler's answers to readers' questions about dark matter and dark energy.