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Cosmic neutrinos named Physics World 2013 Breakthrough of the Year

Dec 13, 2013 [13 comments](#)

The *Physics World* award for the 2013 Breakthrough of the Year goes to "the [IceCube South Pole Neutrino Observatory](#) for making the first observations of high-energy cosmic neutrinos". Nine other achievements are highly commended and cover topics ranging from nuclear physics to nanotechnology



[Celebrating the completion of IceCube at the South Pole](#)

In seeking to make sense of night skies, astronomers have always had to rely on electromagnetic radiation – from visible and infrared light to X-rays and gamma rays. The team behind the *Physics World* Breakthrough of the Year has, however, ushered in an era of "neutrino astronomy", whereby particles – not radiation – are the tools of the trade.

The researchers did this by building a colossal detector deep under the ice at the South Pole. Despite the many challenges of doing science in such a remote and inhospitable environment, the IceCube South Pole Neutrino Observatory has spotted extremely high-energy neutrinos that originate from far beyond the solar system.

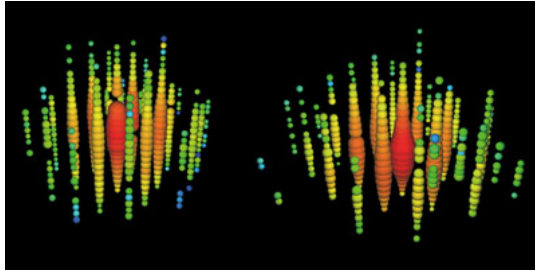
Neutrinos are notoriously difficult to detect and IceCube uses a huge 1 km³ volume of ice as a giant particle detector. IceCube can also determine the direction from which a neutrino came, making it an incredibly useful telescope. Indeed, it could solve an important astrophysical mystery by revealing the origins of cosmic rays. These high-energy charged particles are created in the same locations as cosmic neutrinos but are deflected en route by magnetic fields and cannot be traced back to their origins.

According to IceCube's principal investigator [Francis Halzen](#), by far the greatest challenge in building the detector was drilling the 2.5 km-deep holes in the ice into which the detector components were lowered. In total, 86 holes each 60 cm in diameter were drilled at a rate of about three per week using hot water. The drilling could only be done during the brief polar summer and as a result it took four years to complete the process.

Pleasant surprises

As the detector was being built, the scientists got several pleasant surprises, says Halzen, who is at the University of Wisconsin-Madison in the US. One was that the ice in the region of the detector has much better optical properties than expected. Indeed, it is much clearer than the pristine fluids used in other neutrino detectors.

Clarity is important because IceCube uses strings of photomultiplier tubes to detect the faint Cerenkov light that is given off by fast-moving charged particles that are created when a neutrino collides with a nucleus in the ice. As well as boosting the performance of the detector, the high quality of the ice will make it easier to expand the detector volume, because new holes can now be separated by about 300 m rather than the current 25 m.



Bert and Ernie

The biggest surprise, however, was the measurement of a shower of particles created by an extremely high-energy cosmic neutrino – dubbed Ernie – that was made even before the detector was fully commissioned. What was unexpected about Ernie – and Bert and about 20 other neutrinos – is that a large portion of the energy of the neutrino was deposited in the detector. This allowed the team to determine minimum values of the energies of these neutrinos to within about 15%.

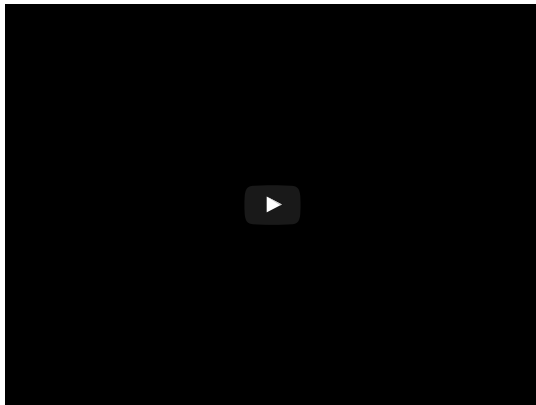
Tracking muon neutrinos

The team had thought that such events would be extremely rare, and had planned on focusing its attention on cosmic muon neutrinos. These particles interact with the detector to produce a muon that can be tracked with great accuracy. This means that the cosmic origin of the neutrino can be pinpointed to better than 0.4 degrees – much better than for Ernie and Bert – but its energy cannot be measured accurately. So now scientists using IceCube have two distinct ways of studying cosmic neutrinos.

IceCube is expected to run for 20 years, and in addition to supporting research in neutrino physics and neutrino astronomy it has also joined the hunt for dark matter. It will also be used to study the interior of the Earth by the neutrinos it emits.

"The success of IceCube builds on the efforts of hundreds of collaborators around the world – from the design, the deployment in a harsh environment and the AMANDA prototype to data harvesting and physics analysis. The Breakthrough of the Year award is a superb way to ultimately honour these efforts," says [Olga Botner](#) at Uppsala University, who is an IceCube spokesperson.

Physics World reported on IceCube's observations on 21 November: "[IceCube finds cosmic neutrinos at the South Pole](#)".



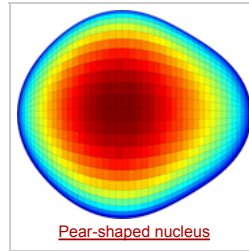
Now for the rest of our picks for the top-10 breakthroughs of 2013. They are listed below in no particular order. The top 10 were chosen by a panel of six *Physics World* editors and reporters, and the criteria for judging the top-10 breakthroughs included

- fundamental importance of research;
- significant advance in knowledge;
- strong connection between theory and experiment; and
- general interest to all physicists.

Nuclear physics goes pear-shaped

"To the international team of nuclear physicists that used the REX-ISOLDE and MINIBALL facilities at CERN to create and study the first pear-shaped nucleus."

Since the 1990s, physicists had suspected that some nuclei have lopsided shapes that are driven by subtle underlying "octupole" interactions between their constituent protons and neutrons. That prediction was confirmed this year for radon-220 and radium-224. As well as shedding further light on the difficult problem of calculating the properties of large nuclei, pear-shaped nuclei could also offer a way of measuring the permanent electric dipole moment of an atom, which is forbidden by the Standard Model of particle physics.



Pear-shaped nucleus

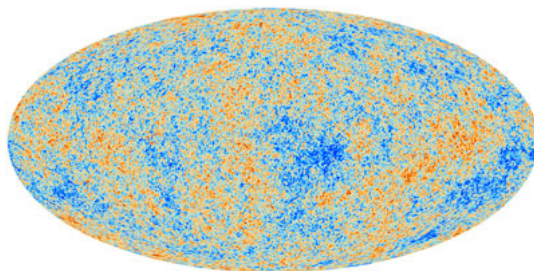
Creating 'molecules' of light

"To Mikhail Lukin at Harvard University and Vlatan Vuletić at the Massachusetts Institute of Technology and colleagues, who are the first to create 'molecules' of light."

Photons normally pass through each other without interacting – so the idea of a molecule made of light seems bizarre. But a photon does interact with the media that it passes through, which can affect how the media responds to subsequent photons. By carefully engineering this interaction in an ultracold atomic gas, Lukin, Vuletić and colleagues have caused pairs of photons to draw together as they pass through the medium. The result is a two-photon molecule of light that could find application in optical communications and computing systems.

Planck reveals 'almost perfect' universe

"To scientists working on the European Space Agency's Planck space telescope for making the most precise measurement ever of the cosmic microwave background (CMB) radiation."



The universe as seen by Planck

Our basic understanding of the universe underwent an important revision this year thanks to the scientists working on Planck, which was launched by the European Space Agency in 2009. We now know that the proportion of the universe made up of dark energy is slightly less than previously thought, but there is more dark matter and ordinary matter than previous studies of the cosmic microwave background radiation (CMB) had suggested. Planck also concluded that the universe is about 80 million years older than previously thought. In addition, the Planck data contain tantalizing hints of anomalies in the temperature of the CMB in different parts of the universe, which could point towards new physics.

'Quantum microscope' peers into the hydrogen atom

"To Aneta Stodolna of the FOM Institute for Atomic and Molecular Physics in the Netherlands, Marc Vrakking at the Max-Born-Institute in Germany and colleagues for taking the first direct images of atomic orbitals."

Anyone who has studied science has seen representations of atomic orbitals, but until this year no-one had ever managed to actually take a direct image of an orbital. Stodolna and Vrakking took the atomic snapshot with their new "quantum microscope", which detects electrons that are ejected from helium atoms by laser light. When the atoms are put into a Rydberg state with an extremely large atomic orbital, the result is a clear image of the orbital's nodal structure.

Quantum state endures for 39 minutes at room temperature

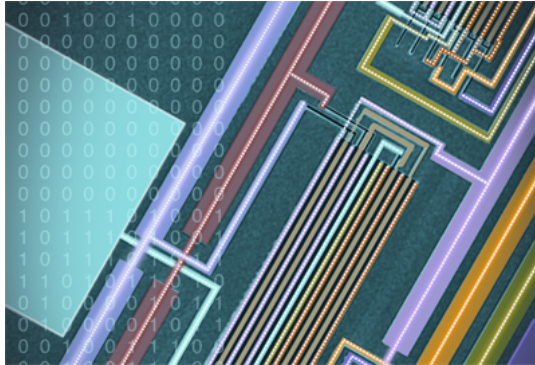
"To Mike Thewalt of Simon Fraser University and colleagues for storing quantum information for up to 39 minutes in a solid-state device at room temperature."

Quantum-information systems rely on quantum states that endure for long enough for information to be processed. Unfortunately, noise, heat and other environmental factors cause most quantum states to decay long before they are useful. What Thewalt and colleagues have done is to find a way to ensure that nuclear spins in a piece of silicon retain

their quantum nature for an astonishing 39 minutes. This shatters the previous room-temperature record of 2 s and could bring us one step closer to "quantum money" that would be impossible to counterfeit.

The first carbon-nanotube computer

"To Max Shulaker and colleagues at Stanford University for making the first carbon-nanotube computer."



Up close with the first carbon-nanotube-based computer

Carbon nanotubes are tiny tubes of carbon with walls as thin as just one atom. They have a range of desirable electronic properties, which in principle could be used to make faster and more energy-efficient electronic devices. While other researchers have created transistors and other individual devices, Shulaker and colleagues developed a suite of new fabrication techniques that allowed them to integrate 178 carbon-nanotube-based transistors to create a computer that can store and execute a program.

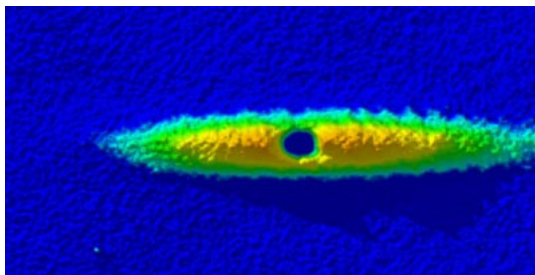
B-mode polarization spotted in cosmic microwave background

"To astronomers working on the South Pole Telescope for being the first to measure B-mode polarization in the cosmic microwave background (CMB) radiation."

The IceCube collaboration may have bagged the *Physics World* 2013 Breakthrough of the Year award, but another discovery from the South Pole also makes it into our top-10 list. It is for the first detection of a subtle twist in light from the cosmic microwave background (CMB), known as B-mode polarization. This twist has long been predicted and its detection paves the way for a definitive test of inflation – a key theory in the Big Bang model of the universe.

The first laser-cooled Bose–Einstein condensate

"To Florian Schreck and colleagues at the Institute for Quantum Optics and Quantum Information in Innsbruck for creating the first Bose–Einstein condensate to be cooled using just lasers."



A laser-cooled Bose–Einstein condensate

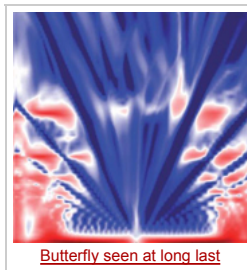
The traditional way to making Bose–Einstein condensates (BECs), which are essentially macroscopic quantum states, involves cooling a gas of atoms using lasers to a temperature of near to absolute zero and then allowing the remaining hot atoms to escape via "evaporative cooling". This process is, however, time-consuming and discards most of the original atoms. Now, a team led by Florian Schreck is the first to cool a BEC using lasers alone, which is a much more efficient technique and could allow BECs to be used in a wider range of practical applications, including atom lasers.

Hofstadter's butterfly spotted in graphene

"To three groups that have independently made the first measurement of Hofstadter's butterfly in a solid-state system. One group is led by Philip Kim of Columbia University,

another is led by Roman Gorbachev of the University of Manchester and another by Pablo Jarillo-Herrero and Ray Ashoori at the Massachusetts Institute of Technology."

Nearly 40 years ago, Douglas Hofstadter calculated the energy levels of electrons exposed to a magnetic field in a 2D solid and expressed the results in a stunning fractal pattern that looks like a butterfly. While the butterfly has been spotted in experiments that are analogous to 2D solids, it had never been seen in a real solid material. But this year three independent groups saw the butterfly in graphene systems, publishing their results over the course of two days this year. As you can see from the image above, it was worth the wait.



About the author

[Hamish Johnston](#) is editor of *physicsworld.com*

13 comments

Comments on this article are now closed.

1 bhanuregmi

Dec 13, 2013 3:45 PM

Nice collection of achievements of the year 2013 in physics

2 M. Asghar

Dec 13, 2013 6:35 PM

Ice- Cube, something like LHC at CERN.

Yes, the Ice-Cube in the Antarctic is a gigantic project comparable to the LHC machine at CERN. It has detected the very high energy: $\sim 10^{15}$ eV, directional cosmic neutrinos giving hope that that this may lead to identify the emitting spatial active centres for them and the charged cosmic-rays. However, one one has to be aware that even the very small magnetic moment of the uncharged neutrinos as fermions, should couple to the spatial magnetic fields as the cosmic-rays and make this identification process complicated.

3 James T. Dwyer

Dec 15, 2013 3:56 PM

"In seeking to make sense of night skies, astronomers have always had to rely on electromagnetic radiation – from visible and infrared light to X-rays and gamma rays. The team behind the Physics World Breakthrough of the Year has, however, ushered in an era of "neutrino astronomy", whereby particles – not radiation – are the tools of the trade."

Ice Cube is a breakthrough development for many reasons, but its detection of particles rather than EMR is not unique - see [en.wikipedia.org...Neutrino astronomy](http://en.wikipedia.org...Neutrino_astronomy)
Ice Cube may well usher in a *new* era in neutrino astronomy...

Edited by James T. Dwyer on Dec 15, 2013 3:58 PM.

4 reader01

Dec 16, 2013 10:28 AM

Bert and Ernie

Are they similar collisions (that means neutrino with hydrogen nuclei or oxygen nuclei)both? Or they are different first neutrino with hydrogen nuclei and second neutrino with oxygen nuclei? So are Bert and Ernie similar?

5 Hamish Johnston

Dec 16, 2013 1:23 PM

Bristol, United Kingdom

Quote:

Originally posted by James T. Dwyer

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Ice Cube may well usher in a *new* era in neutrino astronomy...

Thanks for the comment James. You are right in saying that neutrinos from beyond the Earth have been seen in the past. The serendipitous detection of neutrinos from the 1987A supernova being an example. And of course physicists have been studying solar neutrinos for some time now. However, I think it's safe to say that IceCube is the first true neutrino telescope that is designed to look beyond the solar system – which to us is a good definition of astronomy.

6 reader01

Dec 16, 2013 3:41 PM

if it is not collision of neutrino and gluons

we can say we can speak about wave function of oxygen nuclei (the collision of nuclei and neutrino) and also hydrogen nuclei...

7 John Duffield

Dec 16, 2013 4:44 PM

United Kingdom

I think there's some nice work here. I think IceCube is great stuff, and Planck, and the "quantum microscope", and the BEC, and the polarization, and the others. I'm not a big fan of prizes or ranking, but if pressed my choice would be the "molecules of light". That's because IMHO the really big breakthrough is that light interacts with light. Take a look at [two photon physics](#) on Wikipedia. It gives what you'd call the official explanation, and it says this:

"A photon can, within the bounds of the uncertainty principle, fluctuate into a charged fermion-antifermion pair, to either of which the other photon can couple".

That's saying pair production occurs because pair production occurs. And that a 511keV photon spends its time spontaneously morphing into a 511keV electron and a 511keV positron, which then magically morph back into a single 511keV photon, which nevertheless manages to keep on going at the speed of light. That's "what QED says", and it breaks every rule in the book. Because it's wrong! It's gamma-gamma pair production. Light interacts with light. Google on "tying light in knots". When the penny drops with all this, sheesh, you'll know about it. It will be mega.

8 pbarya

Dec 17, 2013 6:54 AM

First cosmic ray neutrino was found much earlier

Welcoming the observation.

" making the first observations of high-energy cosmic neutrinos" is something creates a doubt about the neutrino observational history. I want to point out that the first neutrino observation in cosmic ray was done much earlier in India (1965). A collaboration of particle physicists from Tata Institute of Fundamental Research (India), Osaka City University (Japan) and Durham University (UK) recorded the first cosmic ray neutrino interaction in an underground laboratory in Kolar Gold Fields in India in 1965.

As far as I know this was of course observed in a cosmic ray shower and not as a direct high energy neutrino observation.

9 theonh55

Dec 20, 2013 8:56 PM

Answer to the quantum measurement problem

An intriguing step forward in 2013 that went basically unnoticed is an answer to the celebrated measurement problem in quantum mechanics: Why do we get individual outcomes in experiments, while QM is a probabilistic theory (wave theory)? In classical physics the connection of probabilities with individual events is obvious, but in QM it could not be convincingly established. The problem is that a mixed density matrix can be decomposed on any basis, while in measurement one desires to select the measurement basis. Now an answer to this question has been given (arXiv:1107.2138v4 p1-201 or Physics Reports 525 (2013) 1-166): A special type of relaxation inside the apparatus occurs near the end of the measurement. Under realistic conditions, an instability occurs, which singles out the measurement basis as the stable and thus physical basis. This explanation within ordinary quantum statistical mechanics should rid us of the many worlds interpretation and the role of the observer, in favor of physical forces and influences of one system (the apparatus) on the other (the tested system). In the cited paper, other aspects of ideal measurements, such as truncation, registration and reduction are elucidated too, so that the measurement postulates are *derived* within a model for quantum measurement. Claimer: this comment is submitted by one of the authors.

Edited by theonh55 on Dec 20, 2013 9:32 PM.

10 M. Asghar

Dec 22, 2013 12:40 PM

Expected value

theonh, yes, the QM is a probabilistic theory, but when one makes a measurement, one is supposed to get the "expected value" (EV) of the required observable which is independent of basis chosen to expand the wavefunction. This EV results from a series of measurements that scan all the basis functions. If for some reason, one is limited to one basis function, then the results corresponds to only this chosen function and not to the EV for the observable.

Quote:

Originally posted by theonh55 ►

An intriguing step forward in 2013 that went basically unnoticed is an answer to the celebrated measurement problem in quantum mechanics: Why do we get individual outcomes in experiments, while QM is a probabilistic theory (wave theory)? In classical physics the connection of probabilities with individual events is obvious, but in QM it could not be convincingly established. The problem is that a mixed density matrix can be decomposed on any basis, while in measurement one desires to select the measurement basis. Now an answer to this question has been given (arXiv:1107.2138v4 p1-201 or Physics Reports 525 (2013) 1-166): A special type of relaxation inside the apparatus occurs near the end of the measurement. Under realistic conditions, an instability occurs, which singles out the measurement basis as the stable and thus physical basis. This explanation within ordinary quantum statistical mechanics should rid us of the many worlds interpretation and the role of the observer, in favor of physical forces and influences of one system (the apparatus) on the other (the tested system).

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Claimer: this comment is submitted by one of the authors.

11 theonh55

Dec 22, 2013 3:10 PM

Quote:

Originally posted by M. Asghar ▶

when one makes a measurement, one is supposed to get the "expected value" (EV) of the required observable

No, when one does an ideal measurement, one observes a pointer indication corresponding to an eigenvalue of the observed operator. The issue at stake was to explain this from a theoretical framework. It was achieved just within statistical quantum mechanics.

12 M. Asghar

Dec 23, 2013 7:27 PM

Request

Theonh, thank you for the input, but I have not yet seen the text of your paper. If you have a short writeup of your paper, I would appreciate, if you could pass it to me on: masgharfr@yahoo.fr. All the best and a good new year to you and your family and colleagues.

Quote:

Originally posted by theonh55 ▶

Quote:

Originally posted by M. Asghar ▶

when one makes a measurement, one is supposed to get the "expected value" (EV) of the required observable

No, when one does an ideal measurement, one observes a pointer indication corresponding to an eigenvalue of the observed operator. The issue at stake was to explain this from a theoretical framework. It was achieved just within statistical quantum mechanics.

13 John Duffield

Dec 28, 2013 1:46 PM

United Kingdom

Quote:

Originally posted by M. Asghar ▶

...Theonh, thank you for the input, but I have not yet seen the text of your paper. If you have a short writeup of your paper...

M, see [arXiv](#).

Theo: interesting stuff. Sadly "quantum mysticism" tends to attract more publicity than the empirical physics that dispels mystery.