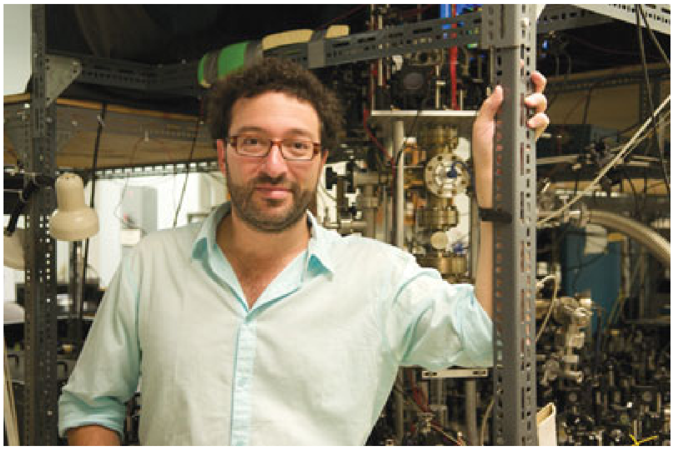
Physics World reveals its top 5 breakthroughs for 2011

Dec 16, 2011 13 comments



Aephraim Steinberg wants you to throw off your quantum biases

The two physics stories that dominated the news in 2011 were questions rather than solid scientific results, namely "Do neutrinos travel faster than light?" and "Has the Higgs boson been found?". However, there have also been some fantastic bona fide research discoveries over the last 12 months, which made it difficult to decide on the *Physics World* 2011 Breakthrough of the Year.

But after much debate among the *Physics World* editorial team, this year's honour goes to Aephraim Steinberg and colleagues from the University of Toronto in Canada for their experimental work on the fundamentals of quantum mechanics. Using an emerging technique called "weak measurement", the team is the first to track the average paths of single photons passing through a Young's double-slit experiment – something that Steinberg says physicists had been "brainwashed" into thinking is impossible.

We have also awarded nine runners-up (see below). The choice between first and second place was particularly close this year because the number-two finding also involves weak measurement – this time to map the wavefunction of a bunch of photons. But we felt that Steinberg's finding edged it. Other breakthroughs in the list include the first "space–time" cloak, a laser made from a living cell and a new way to measure cosmic distances.

1st place: Shifting the morals of quantum measurement

Steinberg's work stood out because it challenges the widely held notion that quantum mechanics forbids us any knowledge of the paths taken by individual photons as they travel through two closely spaced slits to create an interference pattern.

This interference is exactly what one would expect if we think of light as an electromagnetic wave. But quantum mechanics also allows us to think of the light as photons – although with the weird consequence that if we determine which slit individual photons travel through, then the interference pattern vanishes. By using weak measurements Steinberg and his team have been able to gain some information about the paths taken by the photons without destroying the pattern.

In the experiment, the double slit is replaced by a beamsplitter and a pair of optical fibres. A single photon strikes the beamsplitter and travels along either the right or the left fibre. After emerging from the closely spaced ends of the parallel fibres, it creates an interference pattern on a detector screen.

How to ask a 'forbidden question'

Aephraim Steinberg explains how his team tracked photons in a double-slit experiment and what the result means for quantum mechanics

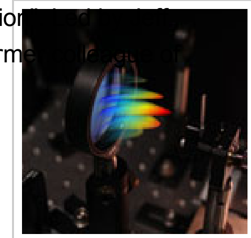
The weak measurement is performed by passing the emerging photons through a piece of calcite, which imparts a tiny rotation in the polarization of the photon. The amount of rotation depends on the direction of travel of the photon – in other words, its momentum. The photons are then "post-selected" according to where they strike the screen, which allows the researchers to determine the average direction of travel of photons that arrive there.

The experiment reveals, for example, that a photon detected on the right-hand side of the diffraction pattern is more likely to have emerged from the optical fibre on the right than from the optical fibre on the left. While this knowledge is not forbidden by quantum mechanics, Steinberg says that physicists have been taught that "asking where a photon is before it is detected is somehow immoral".

"Little by little, people are asking forbidden questions," says Steinberg, who adds that his team's experiment will "push [physicists] to change how they think about things".

2nd place: Measuring the wavefunction

Second place goes to another group that has asked a "forbidden question". Led by Jeff Lundeen at the National Research Council of Canada in Ottawa – a former colleague of Steinberg – a team has used weak measurement to map out the wavefunction of an ensemble of identical photons without actually destroying any of them. Quantum tomography, in contrast, maps out the wavefunction at the expense of destroying the state. As well as boosting our understanding of the fundamentals of quantum mechanics, the technique could prove useful in cases where tomography cannot be used.



Experimental set-up

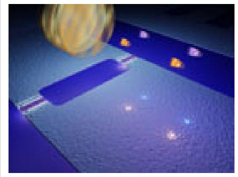
3rd place: Cloaking in space and time

Coming in at third place are two teams – one at Cornell University in the US led by Alexander Gaeta, and the other at Imperial College London headed by Martin McCall. In early 2011 McCall's team published a theoretical analysis of how an event in space and time could be cloaked, which he later described in a special *Physics World* feature. A few months later, Gaeta and colleagues built a device that uses two "split time lenses" to do just that. As well as changing our ideas about what can and cannot be cloaked, space–time cloaking could also be used in the perfect bank heist – at least in theory.

4th place: Measuring the universe using black holes

Fourth spot on the list goes to Darach Watson and colleagues at the University of Copenhagen, Denmark, and the University of Queensland, Australia, who have worked out a way of using supermassive black holes – which power active galactic nuclei (AGNs) – as "standard candles" for making accurate measurements of cosmic distances. The work is important because AGNs can be found just about everywhere in the universe, and unlike the supernovae currently used as standard candles, the light from AGNs endures for long periods of time.

5th place: Turning darkness into light



Something from nothing

Christopher Wilson and colleagues of Chalmers University of Technology in Sweden together with physicists in Japan, Australia and the US have bagged fifth place because they are the first to see the dynamical Casimir effect in the lab. The effect arises when a mirror is moving so quickly through a vacuum that pairs of virtual photons – which are always appearing and then annihilating – are pulled apart to create real photons that can then be detected. As well as shedding new light on the Casimir effect, the team's use of a superconducting quantum interference device (SQUID) as the mirror make this an extremely clever experiment.

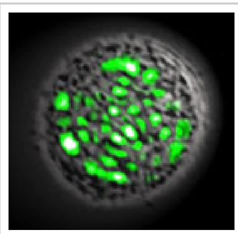
6th place: Taking the temperature of the early universe

Just after the Big Bang, the universe was a complicated soup of free quarks and gluons that eventually condensed to form the protons and neutrons we see today. Sixth place in our top 10 goes to a team of physicists in the US, India and China that has made the best calculation yet of this condensation temperature: two trillion degrees Kelvin. As well as providing important insights into the early universe, the work also advances our understanding of quantum chromodynamics, which describes the properties of neutrons, protons and other hadrons.

7th place: Catching the flavour of a neutrino oscillation

Seventh place is awarded to the international team of physicists working on the Tokai-to-Kamioka (T2K) experiment in Japan. The researchers fired a beam of muon neutrinos 300 km underground to a detector, where they found that six neutrinos had changed, or "oscillated", into electron neutrinos. While the measurement is not good enough to claim the discovery of the muon-to-electron neutrino oscillation, it is the best evidence yet that one "flavour" of neutrino can oscillate into another.

8th place: Living laser brought to life

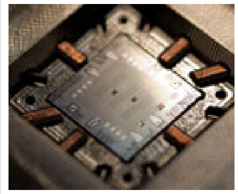


Living laser lights up life

In a fascinating bit of biophysics, Malte Gather and Seok Hyun Yun at Harvard Medical School in the US share eighth place for being the first to make a laser from a living biological cell. By shining intense blue light onto green fluorescent protein molecules inside an embryonic kidney cell, the molecules generate light that is intense, monochromatic and directional. The cells survive the ordeal and this amazing phenomenon could potentially be used to distinguish cancerous cells from healthy ones.

9th place: Complete quantum computer made on a single chip

Ninth place goes to Matteo Mariantoni and colleagues at the University of California, Santa Barbara for being the first to implement a quantum version of the "Von Neumann" architecture found in PCs. Based on superconducting circuits and integrated on a single chip, the new device has been used to perform two important quantum-computing algorithms. Its development moves us closer to the creation of practical quantum computers that solve real-life problems.


Quantum bus

10th place: Seeing pure relics from the Big Bang

Michele Fumagalli and Xavier Prochaska of the University of California, Santa Cruz and John O'Meara of Saint Michael's College in Vermont take 10th spot for being the first to catch sight of clouds of gas that are pure relics of the Big Bang. Unlike other clouds in the distant universe – which appear to contain elements created by stars – these clouds contain just the hydrogen, helium and lithium created by the Big Bang. As well as confirming predictions of the Big Bang theory, the clouds provide a unique insight into the materials from which the first stars and galaxies were born.

Happy with our choices? Annoyed at something we missed? Or do you just want to congratulate the winners? Tell us what you think of our top 5 breakthroughs by commenting below

About the author

Hamish Johnston is editor of *physicsworld.com*

13 comments

Comments on this article are now closed.

1 **Jarek Duda**
Dec 16, 2011 7:33 AM
Cracow, Poland

Removing the blindfold...

I completely agree with the first two choices - while orthodox quantum mechanics forbids even thinking of it, they are successfully doing such measurements ... The real sociological problem is that while it is generally known that quantum mechanics is not a complete description, Bell inequalities 'made it forbidden' to even think of underlying objective deterministic physics - maybe these experiments will help removing this blindfold ...

I've just briefly looked through news from this year and choose three most interesting from excluded here: More surprises for the Voyager mission at the edge of the solar system - how underappreciated are reconnections of magnetic flux ropes, Physicists create 'anti-laser' - time reversal analogue of laser and surprising zero-index materials: Light propagates as if 'space is missing'.

Edited by Jarek Duda on Dec 16, 2011 7:36 AM.

2 **Hamish Johnston**
Dec 16, 2011 9:47 AM
Bristol, United Kingdom

Hi Jarek
I had the last two of your suggestions in my short list, but they didn't make the final cut. As for Voyager, great suggestion, indeed the missions should probably get a "lifetime achievement award" for all their contributions to science!
Hamish

Edited by Matin Durrani on Dec 16, 2011 7:32 PM.

3 **M. Asghar**
Dec 16, 2011 6:39 PM

A dent in the complementary principle.(CP)

Your first choice was also mine, because it pushes and dents a bit the CP of QM and renders the boundary between the wave-nature and particle-nature of a photon a little bit less clear on the average. I hopoe that they would push it a bit farther.

Edited by Matin Durrani on Dec 16, 2011 7:31 PM.

---

4 **newyorker**
Dec 16, 2011 9:02 PM

"two-slit experiment"

"In the experiment, the double slit is replaced by a beamsplitter and a pair of optical fibres" writes the commentator, which is correct. This is not a "two-slit" experiment as claimed by the authors of the paper and thus, it does not affect the postulates of orthodox quantum mechanics.

It could be argued that the claims in this Science paper are inflated, and that would not be a first for Science.

---

5 **M. Asghar**
Dec 17, 2011 1:57 PM

Two slit and coherent beams.

Here the two optics fibres act as the two slits and he beam-splitter ensures that the beams reaching them are coherent.

Quote:

> *Originally posted by **newyorker***
> "In the experiment, the double slit is replaced by a beamsplitter and a pair of optical fibres" writes the commentator, which is correct. This is not a "two-slit" experiment as claimed by the authors of the paper and thus, it does not affect the postulates of orthodox quantum mechanics.
>
> It could be argued that the claims in this Science paper are inflated, and that would not be a first for Science.

---

6 **patmustard**
Dec 18, 2011 6:01 PM
nottingham, United Kingdom

Congratulations!

All I can say, is, Congratulations! To all the winners, I am more than positive there were many more worthy candidates.
As a non academic I find the majority of subjects on here, absolutely amazing. The idea,s and images I see, imagining the strangeness of our existence, is fantastic! I wouldn't insult anybody by putting an idea forward, but would like to thank the publishers and all the people, who put forward their idea's and comments, you have all made my understanding so much greater.
Thank you.
Merry Christmas to you all.

---

7 **John Duffield**
Dec 19, 2011 11:11 AM
United Kingdom
I think it's a pretty good list. I agree that seeing the reality of wavefunction is crucial, and I like the quantum optics leaning. One thing I'm not keen on however is the quantum computing entry. I think QC is merely analogue computing, and that the displacement-current circuitry that featured in last year's print-edition physicsworld is more fundamental, and will turn out to be more important.

---

8 **apturley**
Dec 20, 2011 1:31 PM
So much great physics in a year! I should have been a physicist...

---

9 **Shivpal**

I must have been sleeping

...Great article, i missed most of them on the timeline, thanx for updating...

10 **M. Asghar**
Dec 20, 2011 4:57 PM

QC versus AC

The QC is a powerful technique for solving complex problems, but it suffers from the bane of decoherence phenomenon, where the progress has been slow and meagre. I doubt that an AC system can stand up to an operational QC system in its capacity and versatility.

be Quote:

> *Originally posted by* ***John Duffield***
> I think it's a pretty good list. I agree that seeing the reality of wavefunction is crucial, and I like the quantum optics leaning. One thing I'm not keen on however is the quantum computing entry. I think QC is merely analogue computing, and that the displacement-current circuitry that featured in last year's print-edition physicsworld is more fundamental, and will turn out to be more important.

11 **jwcamery**
Dec 22, 2011 1:00 AM
Mililani, United States

An Omission in the List

The list leaves out all the myriad of breakthroughs that could actually help all the millions without clean drinking water, food, education for their children and energy.

12 **ASIWEL**
Dec 22, 2011 5:05 AM
Kalamazoo, United States
Quote:

> *Originally posted by* ***jwcamery***
> The list leaves out all the myriad of breakthroughs that could actually help all the millions without clean drinking water, food, education for their children and energy.

Well, yes, I suppose it does .. although #5 and #8 eventually may have substantial impact on these important issues. But part of the purpose for and benefit from solutions to basic human necessities is time to enjoy the wonders of creation being explored by all 10 of these fantastically good studies and so many other similar ones.

Besides, individuals and groups can do many things at once and over lifetimes and it is good that we now have so many people studying and working toward so many solutions, goals, and interesting inquiries. To me, the future seems potentially brighter.

13 **aafaque_universe**
Dec 22, 2011 8:10 AM

Brilliant work

Yes indeed!! these are the top ten!! great job physics world team!! And Congratulations to the teams for extending our understanding of the world around us to new realms!!