My New Scientist

'Light-speed' neutrinos point to new physical reality

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The speed limit was smashed at Italy's OPERA detector *(Image: Istituto Nazionale di Fisica Nucleare)*

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SUBATOMIC particles have broken the universe's fundamental speed limit, or so it was reported last week. The speed of light is the ultimate limit on travel in the universe, and the basis for Einstein's special theory of relativity, so if the finding stands up to scrutiny, does it spell the end for physics as we know it? The reality is less simplistic and far more interesting.

"People were saying this means Einstein is wrong," says physicist Heinrich Päs of the Technical University of Dortmund in Germany. "But that's not really correct."

Instead, the result could be the first evidence for a reality built out of extra dimensions. Future historians of science may regard it not as the moment we abandoned Einstein and broke physics, but rather as the point at which our view of space vastly expanded, from three dimensions to four, or more.

"This may be a physics revolution," says Thomas Weiler at Vanderbilt University in Nashville, Tennessee, who has devised theories built on extra dimensions. "The famous words 'paradigm shift' are used too often and tritely, but they might be relevant."

The subatomic particles - neutrinos - seem to have zipped faster than light from CERN, near Geneva, Switzerland, to the OPERA detector at the Gran Sasso lab near L'Aquila, Italy. It's a conceptually simple result: neutrinos making the 730-kilometre journey arrived 60 nanoseconds earlier than they would have if they were travelling at light speed. And it relies on three seemingly simple measurements, says Dario Autiero of the Institute of Nuclear Physics in Lyon, France, a member of the OPERA collaboration: the distance between the labs, the time the neutrinos left CERN, and the time they arrived at Gran Sasso.

But actually measuring those times and distances to the accuracy needed to detect nanosecond differences is no easy task. The OPERA collaboration spent three years chasing down every source of error they could imagine (see illustration) before Autiero made the result public in a seminar at CERN on 23 September.

Physicists grilled Autiero for an hour after his talk to ensure the team had considered details like the curvature of the Earth, the tidal effects of the moon and the general relativistic effects of having two clocks at different heights (gravity slows time so a clock closer to Earth's surface runs a tiny bit slower).

They were impressed. "I want to congratulate you on this extremely beautiful experiment," said Nobel laureate Samuel Ting of the Massachusetts Institute of Technology after Autiero's talk. "The experiment is very carefully done, and the systematic error carefully checked."

Most physicists still expect some sort of experimental error to crop up and explain the anomaly, mainly because it contravenes the incredibly successful law of special relativity which holds that the speed of light is a constant that no object can exceed. The theory also leads to the famous equation $E = mc^2$.

Hotly anticipated are results from other neutrino detectors, including T2K in Japan and MINOS at Fermilab in Illinois, which will run similar experiments and confirm the results or rule them out (see "Fermilab stops hunting Higgs, starts neutrino quest").

In 2007, the MINOS experiment searched for faster-than-light neutrinos but didn't see anything statistically significant. The team plans to reanalyse its data and upgrade the detector's stopwatch. "These are the kind of things that we have to follow through, and make sure that our prejudices don't get in the way of discovering something truly fantastic," says Stephen Parke of Fermilab.

In the meantime, suggests Sandip Pakvasa of the University of Hawaii, let's suppose the OPERA result is real. If the experiment is tested and replicated and the only explanation is faster-than-light neutrinos, is $E = mc^2$ done for?

Not necessarily. In 2006, Pakvasa, Päs and Weiler came up with a model that allows certain particles to break the cosmic speed limit while leaving special relativity intact. "One can, if not rescue Einstein, at least leave him valid," Weiler says.

The trick is to send neutrinos on a shortcut through a fourth, thus-far-unobserved dimension of space, reducing the distance they have to travel. Then the neutrinos wouldn't have to outstrip light to reach their destination in the observed time.

In such a universe, the particles and forces we are familiar with are anchored to a four-dimensional membrane, or "brane", with three dimensions of space and one of time. Crucially, the brane floats in a higher dimensional space-time called the bulk, which we are normally completely oblivious to.

The fantastic success of special relativity up to now, plus other cosmological observations, have led physicists to think that the brane might be flat, like a sheet of paper. Quantum fluctuations could make it ripple and roll like the surface of the ocean, Weiler says. Then, if neutrinos can break free of the brane, they might get from one point on it to another by dashing through the bulk, like a flying fish taking a shortcut between the waves (see illustration).

This model is attractive because it offers a way out of one of the biggest theoretical problems posed by the OPERA result: busting the apparent speed limit set by neutrinos detected pouring from a supernova in 1987.

As stars explode in a supernova, most of their energy streams out as neutrinos. These particles hardly ever interact with matter (see "Neutrinos: Everything you need to know"). That means they should escape the star almost immediately, while photons of light will take about 3 hours. In 1987, trillions of neutrinos arrived at Earth 3 hours before the dying star's light caught up. If the neutrinos were travelling as fast as those going from CERN to OPERA, they should have arrived in 1982.

OPERA's neutrinos were about 1000 times as energetic as the supernova's neutrinos, though. And Pakvasa and colleagues' model calls for neutrinos with a specific energy that makes them prefer tunnelling through the bulk to travelling along the brane. If that energy is around 20 gigaelectronvolts - and the team don't yet know that it is - "then you expect large effects in the OPERA region, and small effects at the supernova energies," Pakvasa says. He and Päs are meeting next week to work out the details.

The flying fish shortcut isn't available to all particles. In the language of string theory, a mathematical model some physicists hope will lead to a comprehensive "theory of everything", most particles are represented by tiny vibrating strings whose ends are permanently stuck to the brane. One of the only exceptions is the theoretical "sterile neutrino", represented by a closed loop of string. These are also the only type of neutrino thought capable of escaping the brane.

Neutrinos are known to switch back and forth between their three observed types (electron, muon and tau neutrinos), and OPERA was originally designed to detect these shifts. In Pakvasa's model, the muon neutrinos produced at CERN could have transformed to sterile neutrinos mid-flight, made a short hop through the bulk, and then switched back to muon before reappearing on the brane.

So if OPERA's results hold up, they could provide support for the existence of sterile neutrinos, extra dimensions and perhaps string theory. Such theories could also explain why gravity is so weak compared with the other fundamental forces. The theoretical particles that mediate gravity, known as gravitons, may also be closed loops of string that leak off into the bulk. "If, in the end, nobody sees anything wrong and other people reproduce OPERA's results, then I think it's evidence for string theory, in that string theory is what makes extra dimensions credible in the first place," Weiler says.

Meanwhile, alternative theories are likely to abound. Weiler expects papers to appear in a matter of days or weeks.

Even if relativity is pushed aside, Einstein has worked so well for so long that he will never really go away. At worst, relativity will turn out to work for most of the universe but not all, just as Newton's mechanics work until things get extremely large or small. "The fact that Einstein has worked for 106 years means he'll always be there, either as the right answer or a low-energy effective theory," Weiler says.

A neutrino walks into a bar...

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"...We don't allow faster-than-light neutrinos in here," says the barman. A neutrino walks into a bar...

As reports spread of subatomic particles moving faster than light and potentially travelling through time, such gags were born. But this apparently hasty motion is not the only strange thing about neutrinos.

With a neutral charge and nearly zero mass, neutrinos are the shadiest of particles, rarely interacting with ordinary matter and slipping through our bodies, buildings and the Earth at a rate of trillions per second. Every so often, they crash into an atom to produce a signal that allows us to detect them.

Their stealth, however, belies their potential importance.

Take extra dimensions. Most particles come in two varieties: ones that spin clockwise and ones that spin anticlockwise. Neutrinos are the only ones that seem to just spin anticlockwise. Some theorists say this is evidence for extra dimensions, which could host the "missing", right-handed neutrinos.

Unseen right-handed neutrinos may also account for dark matter - the 80 per cent of all matter needed to stop galaxies from flying apart. The idea is that this variety is much heavier than the other, so could provide the requisite gravity.

Another strange thing about neutrinos is that they can change their "flavour". Recent experiments suggest there may be differences between the way that antineutrinos and neutrinos flip, which might in turn explain how an imbalance of matter and antimatter arose in the early universe. **Chelsea Whyte**

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