Not so fast

Nearly six months on from the faster-than-light neutrino sensation we are still no nearer to understanding what is going on, says **Robert Garisto**

ACCORDING to Einstein's special theory of relativity, nothing can travel faster than light. It was thus a shock when a team of physicists reported in September that particles called neutrinos seem to have broken the light barrier.

The results caused a sensation. Theoretical physicists wrote dozens of papers attempting to explain the results, many of which found their way to me. As an editor at the journal *Physical Review Letters*, my job is to consult experts in the field and ultimately decide which manuscripts to publish. So I am in a good position to judge where we stand nearly six months on.

First, a quick refresher. The result came from the OPERA neutrino detector based at the Gran Sasso laboratory near L'Aquila, Italy. OPERA detected neutrinos fired from CERN, about 730 kilometres away in Geneva, Switzerland, and found they arrived 60 nanoseconds earlier than expected, implying they zipped along at one part in 40,000 faster than the speed of light.

This is as reassuring to a physicist as telling a mathematician, "I added 2 and 2 and got slightly more than 4". Physicist Jim Al-Khalili publicly offered to eat his boxer shorts if the results are proved correct.

The experiment was not conceptually difficult. It calculated the neutrinos' speed as you would do for any moving object: distance divided by time. However, the researchers had to precisely measure the neutrinos' path through the Earth and synchronise the clocks at each end to an accuracy of a few parts per million. It is possible that the result arises from some as yet unknown systematic error in these. Independent measurements being made at Fermilab in Batavia, Illinois, should help us decide whether that is the case.

Another possibility is that the result is a statistical fluke. Data are sometimes described as "statistically significant" if they reach the 95 per cent confidence level. This is a disquietingly lax standard. It doesn't mean that there is a 95 per cent chance there is an effect. It means "supposing there is no effect, you will still get data showing one 5 per cent of the time". Do hundreds of trials and you will see many spurious effects, even at the 99 per cent confidence level. Quite a number of experiments have disagreed with the standard model of particle physics at the 99 per cent confidence level but have fizzled out after more data was taken.

However, the OPERA team claim a confidence level greater than 99.9999999 per cent. In other words you would have to do billions of trials in order to expect to get this result by chance.

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So why are physicists underwear-eating-sure that there's a mundane explanation? Because, when it comes to data that conflicts with established theory, we tend to be Bayesians – we take our prior confidence in the established theory into account. As Andrew Pontzen of the University of Cambridge and Hiranya Peiris of University College London wrote in *New Scientist* in 2010: "Bayesian statistics shows us that the anomalies in the data are insufficient on their own to motivate drastic revision." We also need a plausible theory.

Sure enough, the theories soon started rolling in. In the first few weeks after the announcement, physicists produced more than a paper a day on the subject. Many put forward new models explaining how neutrinos could travel faster than light. The rest either tried to find flaws in the experimental techniques or pointed out constraints which rule out most of the new models.

Many of these papers were submitted to *Physical Review Letters*. Thus far we have received over 50 papers and published just three, all in the last category (*Physical Review Letters*, vol 107, p 181803, p 241802 and p 251801).

All reach the same conclusion: models which explain the result by breaking relativity are ruled out. It doesn't matter how you do it, if you break relativity, your idea is a goner.

How so? The paper by Andrew Cohen of Boston University and his Nobel laureate colleague Sheldon Glashow (vol 107, p 181803) is the easiest to explain. Imagine an aeroplane going faster than the speed of sound. It creates a shockwave of air which you hear as a sonic boom, and which carries energy away. An analogous thing happens to a particle going faster than the speed of light: it loses energy via a shockwave of particles. And yet the OPERA neutrinos arrived with no energy lost. So there was no shockwave and thus no faster-than-light travel.

Whenever a paper proposing a new model arrived on my desk, I would ask the authors to explain how they circumvented this constraint. None did so convincingly. Even so, it surprised me how many authors responded that, although they agreed that other such models were ruled out, theirs was not, even though it was. Some were not even convinced by detailed comments from anonymous referees.

Are there any ways around this theory-slayer? You may have heard of tachyons, hypothetical particles which always travel faster than light. They don't actually break relativity, and so the constraints wouldn't apply. Classically, such particles are allowed. But a quantum theory with tachyons is unstable. Such a theory always gives way to a new, stable theory without tachyons. So they are not the answer.

The last resort is to somehow bend relativity without breaking it. It's not clear whether this vague idea can be fleshed out, but if the OPERA results are convincingly confirmed, it's one avenue which doesn't seem to be ruled out.

Thus we are left with seemingly strong evidence challenging firmly established theory. But after months of trying, physicists have not yet come up with any plausible explanation for all the data. So for now, boxer-betting Bayesians can breathe easy. ■

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