The Case of the Speedy Neutrinos: An Afterword to *Relativity for the Questioning Mind*

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6 February 2012; note added 22 February 2012

On Friday, 23 September 2011, a momentous seminar was delivered in the main auditorium at one of the world's most distinguished and celebrated research establishments, CERN, the European Organization for Nuclear Research.[1] At this seminar Dario Autiero, of the *Institut de Physique Nucléaire de Lyon* in France, announced that he and his 178 collaborators had measured particles called neutrinos traveling faster than light.

A stunning claim, because (as explained in chapter 10 of *Relativity for the Questioning Mind*) according to relativity and the principle of causality, no causal signal can travel faster than the speed of light in any inertial frame. Within moments, the worldwide media were abuzz with the story. Did Autiero and his coworkers find a flaw in relativity? Or a flaw in causality? Or both?

Before jumping to conclusions, let's examine the experiment. Neutrinos are subatomic particles, each about one-millionth the mass of an electron, that interact very weakly with any other matter. For example, if a neutron is injected into solid lead, it will travel about one-tenth of a millimeter before its path is deflected by a lead atom.[2] But if a neutrino is injected into solid lead, it will travel about 10^{16} meters before its path is deflected by a lead atom. This is almost the distance from the Sun to the next star! As a consequence, neutrino detectors have to be enormous, and they are located far underground to prevent stray signals from cosmic rays.

For example, the neutrino detector used in Autiero's experiment, called OPERA (Oscillation Project with Emulsion-tRacking Apparatus), is almost a mile underground (1400 meters). It is part of the *Laboratori Nazionali del Gran*

[1] The acronym derives from the laboratory's former French-language name *Conseil Européen pour la Recherche Nucléaire*.

[2] This can be calculated from the cross section of 11.34 barn published in *Neutron News*, **3**:3 (1992) 29–37.

Sasso located between the towns of L'Aquila and Teramo in Italy.[3] The OPERA detector is a cube about 45 feet on a side that weighs about 1300 tons. Even so, most of the neutrinos that enter OPERA pass right through undetected.

In the experiment in question neutrinos were produced at CERN in Geneva, Switzerland, and traveled underground 450 miles (730 kilometers) to reach OPERA. If those neutrinos were traveling at the speed of light, their journey would have required 2,400,000 nanoseconds. But the measured time of transit was about 60 nanoseconds *less* than this time.[4] If the measurement is accurate, then those neutrinos were traveling 0.003% *faster* than the speed of light.

It's instantly apparent that this is a difficult experiment: To begin with *all* experiments involving neutrinos are difficult, and on top of that Autiero and his coworkers were measuring a tiny effect. This exact same effect would result if the OPERA detector were located 60 feet closer to the CERN source than the scientists had measured. (Remember, 60 feet out of 450 miles.) Autiero and colleagues developed elaborate schemes for measuring distance and time precisely (in fact, they claim to have measured this distance with a precision of 20 centimeters) but there are innumerable ways that their schemes could fail to deliver the requisite accuracy.

I can think of three possible reactions to the 23 September 2011 announcement. The first is that somewhere within this sprawling 179-person collaboration, somebody slipped up. The neutrinos are not actually traveling faster than light, there was just some mistake in the experiment. This possibility was recognized by James Gillies, CERN spokesman, when he said that in making their announcement, the researchers "are inviting the broader physics community to look at what they've done and really scrutinize it in great detail"[5].

> Note added 22 September 2012: The "Science Insider" blog announced today an unconfirmed report that this reaction is indeed the issue: "the 60 nanoseconds discrepancy appears to come from a bad connection between a fiber optic cable that connects to the GPS receiver used to correct the timing of the neutrinos' flight and an electronic card in a computer. After tightening the connection and then measuring the time it takes data to travel the length of the fiber," the discrepancy vanished. See Edwin Cartlidge, "BREAKING NEWS: Error Undoes Faster-Than-Light Neutrino Results".

[3] In 1984 Italy was building a tunnel to carry the A24 highway under the Apennine Mountains, and they decided that while they were building an underground highway they would build an underground laboratory as well. If you have the good fortune to visit the Gran Sasso Laboratory, be sure to check out not only the impressive apparatus but also the stunning mountain scenery.

[4] The precise value is 57.8 ± 7.8 ns less.

[5] The Associated Press, "CERN physics labs in Switzerland says it discovered neutrinos that travel faster than speed of light", *New York Daily News*, 22 September 2011. (The fact that the announcement made in Geneva on 23 September was reported in New York on 22 September reflects time zones rather than causality disruption.)

The second reaction comes from realizing that the scientists got their timing information from the Global Positioning System. The GPS relies on a collection of 32 satellites in Earth orbit moving from west to east at a speed of about $V = 4000$ m/s. Because the clocks on these satellites are synchronized in their own frame, they are *not* synchronized in the Earth's frame. Now CERN is located a distance $L_0 = 730\,000$ m west of OPERA, so, in Earth's frame, the GPS satellite above CERN is set ahead of the GPS satellite above OPERA by the amount

$$\frac{L_0 V}{c^2} = \frac{(730\,000 \text{ m})(4000 \text{ m/s})}{(3 \times 10^8 \text{ m/s})^2} = 32 \text{ nanoseconds.}$$

This would account for 32 ns worth of the 60 ns discrepancy. This reaction came from Ronald A.J. van Elburg of the University of Groningen in the Netherlands on 12 October 2011. It inspired Jacques Martino, director of France's National Institute of Nuclear and Particle Physics to suggest "a synchronization of the time reference at CERN and Gran Sasso independently from the GPS, using possibly a fiber"[6].

The third reaction is that the experimenters made no errors, the effect is real, and that somehow the science presented in *Relativity for the Questioning Mind* applies to all other matter but not to neutrinos. This would not mean that you wasted your time in learning relativity as it was understood in 2010, because this relativity would still apply to almost all matter. And before we can accept this reaction we have to realize that there are plenty of other experiments showing that the speed limit c *does* apply to neutrinos. (For example, on 24 February 1987 the light and neutrinos from an exploding star in the Large Magellanic Cloud were detected here on Earth. Analysis of this event, called Supernova 1987A, suggests strongly that neutrinos from that source *did* travel at the speed of light.[7])

What is the difference between ordinary matter and neutrinos? What is the difference between Supernova 1987A neutrinos and Gran Sasso neutrinos? If the CERN/OPERA results are confirmed, these exciting questions will have to be probed in detail.

There are two messages to take away from these developments. The first concerns the character of science. I sometimes encounter opinion pieces claiming that scientists don't like change, that they suppress new ideas by social convention, that "scientific heretics [are] persecuted for their radical ideas"[8]. This is clear nonsense. Not one of the 179 scientists who worked on the CERN/OPERA experiment has been persecuted. Their claims have not been and should not be accepted without critical scrutiny, but no one is trying to suppress their claims.

[6] Italian Institute for Nuclear Physics (INFN), press release, "New tests confirm the results of OPERA on the neutrino velocity, but it is not yet the final conformation", 18 November 2011.

[7] M.J. Longo, "Tests of relativity from SN1987A", Physical Review D, **36** (1987) 3276–3277.

[8] Matt Ridley, "Is that scientific heretic a genius — or a loon?", *Wall Street Journal*, 12–13 November 2011, page C4.

The second message concerns the character of the universe that scientists study. Every time we think we have the universe understood, tamed, and confined in a bottle, the universe slips out. Our universe is entrancing, surprising, subtle, and wonderful. We are fortunate to live in such a delightful place, and we are fortunate indeed to be members of a species that has discovered and appreciated so much about our universe.