

Commentary

Superluminal neutrinos? Let's slow down

On 23 September, physicists with the OPERA collaboration went public with the dramatic claim that they had measured the speed of muon neutrinos with average energy of about 17 GeV to be greater than the speed of light.¹ Almost immediately, papers explaining, interpreting, and dismissing the effect began arriving at a rate of several per day on the arXiv preprint server. The smart money (see cartoon, below) says that when the dust settles, OPERA's claim will have been refuted, notwithstanding the assertion that it is a six-sigma effect.

Prominent among the refuters are Andrew Cohen and Sheldon Glashow of Boston University, who show, using conventional kinematics and dynamics, that neutrinos with the speed claimed by OPERA and with energies greater than about 12.5 GeV are unstable to the emission of electron-positron pairs, and they would radiate away their excess energy before reaching the OPERA detector. According to Cohen and Glashow, the absence of any such energy loss in the reported data essentially refutes the interpretation that the neutrinos are indeed moving faster than light. Furthermore, the ICARUS collaboration, located, like OPERA, at Italy's Gran Sasso Laboratory and using the same CERN neutrino beam as OPERA, has searched explicitly for the electron-positron pairs predicted by Cohen and Glashow and reports that they are not there.²

However, the OPERA result is so surprising, and fits so poorly with accepted wisdom, that some authors

have been willing to abandon conventional kinematics and dynamics; others have suggested that the Cohen-Glashow analysis does not apply to what has actually been detected.³

The OPERA experiment itself is conceptually very simple.¹ The neutrinos are produced at CERN and are detected at the Gran Sasso underground facility about 730 km away. The distance is measured very accurately, to 20 cm, using GPS data, which are also used to synchronize the clocks at the two laboratories. Dividing the distance by the time between production and detection gives the speed. Light takes about 2.5 milliseconds to cover that distance; OPERA sees neutrinos begin to arrive about 60 nanoseconds sooner.

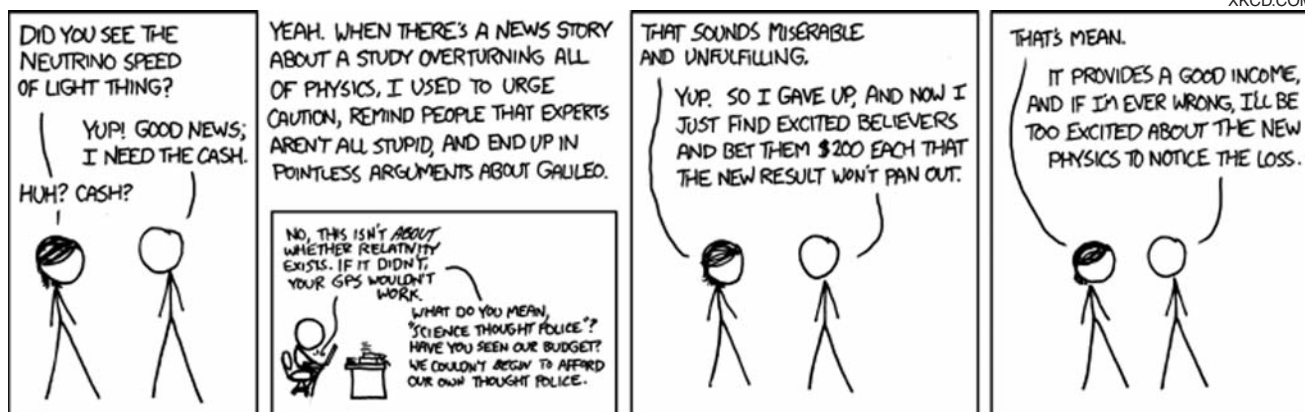
The neutrinos are produced by slamming protons from CERN's Super Proton Synchrotron into a graphite target; the collisions lead to the copious generation of pions and kaons, which then decay into muons and their neutrinos. The original proton burst lasts 10 microseconds and produces a similarly extended burst of neutrinos. Perhaps the aspect of the analysis that is most challenging to an outside observer is how OPERA can define the leading edge of the neutrino burst to only a few nanoseconds. By collecting data over three years and compiling more than 16 000 neutrino events, they claim to be able to do it.

As one might expect, many are looking closely at the design of the experiment⁴ and claim to find either an outright flaw in the analysis or a subtle effect that allows the neutrinos to seem

to exceed the speed of light even though they don't really. ("I wasn't speeding, officer. It's just that the wavepacket describing my car got a little too broad.") Others have constructed inventive scenarios to explain how neutrinos can pull it off—taking a shortcut through extra dimensions is one popular idea, as is the introduction of some hitherto undetected field that is restricted to Earth's vicinity. Most of the proposed explanations involve a violation of Lorentz invariance one way or another.⁵

One piece of information that would greatly help to sort things out is the energy dependence of the OPERA result. The experiment measures a spread of neutrino energies, but not with sufficient precision to determine how neutrino speed depends on energy. Among other things, energy dependence is crucial to making a meaningful comparison with the data from supernova 1987a, which place an upper limit on the deviation of neutrinos from light speed⁶ that is four orders of magnitude below what OPERA sees, at neutrino energies that were three orders of magnitude smaller.

Whatever its fate, the OPERA result alone will not determine whether neutrinos travel faster than light. If the result withstands scrutiny, it still must be confirmed by further experiment. The MINOS experiment that detects neutrinos from Fermilab in a mine in Minnesota seems the best poised to do that. Indeed, a 2007 MINOS measurement, with a neutrino beam of average energy 3 GeV, had insufficient accuracy to claim discovery but was at least

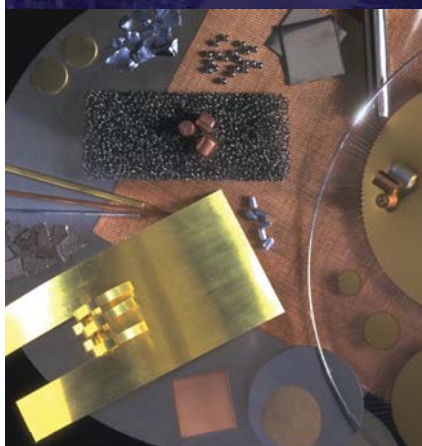


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consistent with a superluminal neutrino speed.⁷

On the other hand, if the OPERA result fails to survive, that will not prove that neutrinos don't travel faster than light. The idea of tachyonic neutrinos has been around for a long time, and work on tachyons more generally is even older.⁸ Over the past 25 years or so there have been hints—ranging from the measurement of the electron neutrino mass at the endpoint of beta decay to the measurement of the muon neutrino mass in pion decay—of tachyonic behavior, and both the MINOS and MiniBoone experiments have reported neutrino and antineutrino oscillations that could indicate violations of *CPT* symmetry. Because *CPT* symmetry follows from Lorentz invariance and other mild assumptions, those results might provide additional evidence supporting the apparent lack of Lorentz invariance in the neutrinos' superluminal propagation.

Neutrinos are mysterious, and they are very hard to study experimentally. To say that we don't understand everything about them is a vast understatement. They may or may not be tachyonic, but even the smart money can bet that the further elucidation of their properties will reveal new and surprising results that, one hopes, will lead to deeper insights into the subatomic world.

Letters

Desert solar hubs not new but risky

An item by Toni Feder titled "Scientists help make deserts into solar-energy hubs" (PHYSICS TODAY, July 2011, page 21) refers to upcoming implementations of concentrated solar power (CSP) technology as pilot projects. However, nearly 100 years ago, Philadelphia scientist Frank Shuman applied the CSP concept to a system he built in Meadi, Egypt. He used reflective troughs to power a steam engine that operated a pump to bring irrigation water to the desert. Along with his pilot project, "by 1914, Shuman was talking of building 20 000 square miles of collector in the Sahara"¹ for producing energy from the Sun. Although CSP components have improved since then, old photographs of Shuman's facility in Egypt look remarkably like the one on the July 2011 cover of PHYSICS TODAY.

Since there are conflicting views on the job-creating potential of renewable energy, scientists promoting solar-energy hubs in the desert might want to review the findings of reference 2,

References

1. T. Adam et al. (OPERA collaboration), <http://arxiv.org/abs/1109.4897>.
2. A. G. Cohen, S. L. Glashow, *Phys. Rev. Lett.* **107**, 181803 (2011); M. Antonello et al. (ICARUS collaboration), <http://arxiv.org/abs/1110.3763>.
3. G. Amelino-Camelia et al., <http://arxiv.org/abs/1110.0521>; R. Ehrlich, <http://arxiv.org/abs/1110.0736>.
4. See, for example, J. Knobloch, <http://arxiv.org/abs/1110.0595>; D. V. Naumov, V. A. Naumov, <http://arxiv.org/abs/1110.0989>; A. Mecozzi, M. Bellini, <http://arxiv.org/abs/1110.1253>; D. V. Ahluwalia, S. P. Horvath, D. Schrit, <http://arxiv.org/abs/1110.1162>.
5. See, for example, S. Hannestad, M. S. Sloth, <http://arxiv.org/abs/1109.6282>; A. Nicolaidis, <http://arxiv.org/abs/1109.6354>; S. S. Gubser, <http://arxiv.org/abs/1109.5687>; G. Dvali, A. Vikman, <http://arxiv.org/abs/1109.5685>; L. Iorio, <http://arxiv.org/abs/1109.6249>; J. Alexandre, J. Ellis, N. E. Mavromatos, <http://arxiv.org/abs/1109.6296>.
6. K. Hirata et al., *Phys. Rev. Lett.* **58**, 1490 (1987); R. M. Bionta et al., *Phys. Rev. Lett.* **58**, 1494 (1987).
7. P. Adamson et al. (MINOS collaboration), *Phys. Rev. D* **76**, 072005 (2007).
8. A. Chodos, A. I. Hauser, V. A. Kostelecký, *Phys. Lett. B* **150**, 431 (1985); G. Feinberg, *Phys. Rev.* **159**, 1089 (1967).

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which makes the following claim:

Europe's current policy and strategy for supporting the so-called "green jobs" or renewable energy dates back to 1997, and has become one of the principal justifications for U.S. "green jobs" proposals. Yet an examination of Europe's experience reveals these policies to be terribly economically counterproductive.

But then review the follow-up report by Eric Lantz and Suzanne Tegen, which claims that the methodology used by Gabriel Calzada Álvarez and colleagues "does not reflect an employment impact analysis."³

Attention should also be paid to the termination of large CSP projects. For example, a proposed 290-megawatt CSP plant for Arizona Public Service was terminated in 2009 because Lockheed Martin Corp "decided not to go forward with the project due to the size and the final risk profile of the EPC [engineering, procurement, and construction] contract, among other factors."⁴

Are water supplies in the desert ade-