along the CERN beam direction, where $0 < \delta c' < \delta c$. In that frame, one would find that each signal at the CERN graphite target detector occurs after a corresponding signal at the Gran Sasso neutrino detector, which would be manifestly absurd.[1,2] Recently it has been found that OPERA's faster-than-light result was an error due to "a faulty cable connection."[3] Moreover, an independent research group, ICARUS, has announced that neutrinos obey nature's speed limit.[4]

References

1. R. C. Tolman, *The Theory of the Relativity of Motion*, U. California Press, Berkeley (1917), p. 54.
2. G. A. Benford, D. L. Book, W. A. Newcomb, *Phys. Rev. D* **2**, 263 (1970).
3. G. Brumfiel, *Nature* (16 March 2012), http://www.nature.com/news/neutrinos-not-faster-than-light-1.10249.
4. M. Antonello et al., http://arxiv.org/abs/1203.3433.

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■ **Chodos replies:** One must be careful. The history of science is littered with examples of ideas that people dismissed as manifestly absurd, only to find in due course that Nature disagreed. Whether neutrinos travel faster than light is an experimental question. If the OPERA result is wrong, as it now appears to be, neutrinos may still be superluminal, just not at as high a level as the parts per 10^{-5} that OPERA claimed. That is the meaning of my "odd comment" to which Nauenberg refers.

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A note on rocky planet formation

Bernard Wood presents a nice overview in his article, "The formation and differentiation of Earth" (PHYSICS TODAY, December 2011, page 40). For many years the prevailing model has been that rocky planets formed in our solar system as a consequence of a succession of impacts of large objects during the first 100 million years or so following the Sun's formation. That picture is the outcome of theoretical considerations combined with the study of asteroids, meteorites, and the rocky planets—Mercury, Venus, Earth, and Mars. Only recently has it become possible to confirm or deny by observation whether the rocky-planet formation time scale of 100 million years generally applies for Sun-like stars.

A collision of large, rocky-planet embryos that orbit young stars would typically eject a mélange of rocky debris, as illustrated in Wood's figure 1. Abundant dusty debris has now been observed in orbit around a handful of young, nearby stars with ages between 30 million and 100 million years.[1] The dust temperature, generally somewhat greater than the temperature of Earth, suggests that the colliding objects typically orbit at a distance from their stars similar to the distance from our sun to Venus. By contrast, there are no known examples of stars between, say, 100 million and 1000 million years old that have large quantities of orbiting warm dust particles. The most straightforward interpretation of those observations is that rocky planet formation around solar-mass stars is pretty much complete by the time the stars are 100 million years old, which agrees with what theory would have predicted.

The same study indicates that rocky planet formation, in a zone analogous to the region of the rocky planets in the solar system, is common and perhaps nearly ubiquitous around Sun-like stars.[1]

Reference

1. C. Melis, B. Zuckerman, J. H. Rhee, I. Song, *Astrophys. J. Lett.* **717**, L57 (2010).

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Coherence and precision in classical systems

The Quick Study "Collaboration and precision in quantum measurement" (PHYSICS TODAY, December 2011, page 72) by Rob Sewell and Morgan Mitchell points out that some quantum mechanical coherence, "quantum collaboration" in their language, allows for the magnetization of a gas to be measured with a precision of $1/N$, where N is the number of photons. For large N, $1/N$ is smaller than $1/\sqrt{N}$, so improves upon the usual $1/\sqrt{N}$ measurement limit; the authors comment that for noninteracting particles, the central limit theorem precludes better classical measurements.

However, coherence is not merely a quantum mechanical effect; many classical systems exhibit similar behavior. For example, one can search for ultrahigh-energy neutrino interactions in Antarctic ice by observing the coherent radio pulses emitted by the resulting particle showers. The observed electric field strength of the pulse scales as the square of the number of particles in the shower (reference 1; see also the article I wrote with Francis Halzen, PHYSICS TODAY, May 2008, page 29), so for a given uncertainty in field-strength measurement, the uncertainty in the number of shower particles scales as $1/N$. That is purely classical electromagnetism.

There are also examples of $1/N$ scaling without coherence. Consider a system consisting of a noninteracting gas in a reservoir at pressure P, and a small valve that controls access to a gas sensor. The best measurement of the valve's opening time comes from the first gas molecule observed by the sensor. As one increases the pressure (number of probe molecules N), the time delay between the gate opening and the sensor decreases in a $1/N$ fashion. For large N, that is more accurate than finding the mean arrival time of the molecules, with an accuracy of $1/\sqrt{N}$, and trying to correct for the average delay time.

These comments are not to take anything away from the nice study by Sewell and Mitchell. However, measurements that exhibit $1/N$ scaling are not limited to quantum systems, and are more common than one might imagine.

Reference

1. P. W. Gorham et al., *Phys. Rev. D* **72**, 023002 (2005).

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■ **Sewell and Mitchell reply:** Spencer Klein's insightful comments wonderfully illustrate the connections between seemingly disparate areas of research. His May 2008 article with Francis Halzen is indeed well worth going back for if you missed it the first time around.

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Correction

April 2012, page 22—The Update item titled "Gravity waves and heat in Mars's atmosphere" should give wind speeds on Mars as up to 400 km/h, not 400 km/s. ■