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Hunt for the sterile neutrino heats up

The elusive particles, if they exist, could help solve some of the most pressing problems in astrophysics.

Neutrinos like to keep to themselves. These ghostly particles are so reluctant to interact with ordinary matter that billions zip harmlessly through each person every day, and it takes giant, specialized detectors to capture even a handful of them. Now astronomers are finding hints of an even more elusive type of neutrino, one so shy that it could never be detected directly: the sterile neutrino.

For more than a decade, this subatomic spectre has intrigued theorists and experimenters, but experimental efforts have had trouble catching them. Now, two observations in space — one in microwaves and the other in X-rays — are raising hopes again.

If sterile neutrinos could be identified, they would provide the first glimpse of a new realm of physics beyond the tried-and-tested standard model. They could also help to explain a host of astronomical puzzles, and perhaps even account for the invisible dark matter that is thought to make up 85% of the Universe's mass.

"The question of sterile neutrinos is absolutely crucial for nuclear particle physics and astrophysics," says William Louis of Los Alamos National Laboratory in New Mexico, who worked on a ground-based experiment in the mid-1990s that provided one of the first hints of sterile neutrinos.

The three types of ordinary neutrinos (see graphic) are hard enough to detect. They interact with matter through the weak nuclear force, which means they can pass through huge volumes of material yet collide with atomic nuclei only rarely. To catch them, physicists build detectors using tanks of mineral oil or heavy water, and they improve the odds by focusing on the torrents of neutrinos coming from nuclear reactors, particle accelerators and the Sun.

Unsociable particle

In 1998, results from an accelerator at CERN, Europe's particle-physics facility near Geneva, Switzerland, indicated that only the three known families, or flavours, of neutrinos could be affected by the weak force. Any beyond these three families would have to be 'sterile' — that is, immune to the weak nuclear force. And that would mean that they would pass straight through existing neutrino detectors.

Why would theorists invoke such an unsociable particle to begin with? Because of another surprising discovery made in 1998: that the three ordinary neutrinos have a small but definite mass.

The result came as a shock, and not simply because the standard model assumes that neutrinos have no mass. The masses of the three neutrinos, determined from the way they oscillate, or switch, from one flavour into another, turned out to be incredibly small: the heaviest ordinary neutrino is at least seven orders of magnitude lighter than the electron. Theorists reasoned that some other particle — perhaps a sterile neutrino — should sit in between.

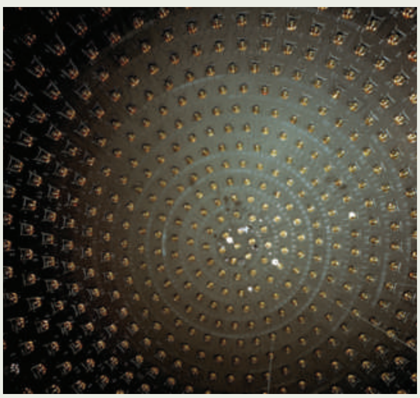
Hints of such a missing link have emerged from the Wilkinson Microwave Anisotropy Probe (WMAP), a spacecraft that since 2001 has been mapping tiny fluctuations in the radiation left over from the Big Bang. The pattern of fluctuations holds clues to the stew of particles that existed shortly after the Big Bang.

Results from the past seven years, which were released in January[1], suggest that the most likely number of neutrino families in the early Universe was four — implying that one more neutrino type awaits discovery. "To say that there's something else is a major deal," says principal investigator Charles Bennett of Johns Hopkins University in Baltimore, Maryland. But he cautions that the error bars are still wide enough that three might still be the maximum number. "I would call this intriguing, but I'm not losing any sleep right now."

A more recent clue has come from the orbiting Chandra X-ray Observatory. Sterile neutrinos, if they exist and if they are heavy enough, should emit faint pulses of X-rays as they decay into lighter neutrinos. Alexander Kusenko of the University of California, Los Angeles, has focused on regions of the sky thought to contain lots of dark matter but few stars or other light sources. Sure enough, he claims to have found[2] the predicted X-ray signature in Willman 1, a dim dwarf galaxy that orbits the Milky Way. But, like Bennett, Kusenko says that it is still too early to be claiming a discovery. "Everything seems to fit together," he says, "and it's tantalizing."

Kusenko's neutrinos would be heavy and plentiful enough to be the dark-matter particles themselves. But the WMAP data point in another direction, towards a sterile neutrino at the lighter end of the spectrum of possible masses. George Fuller, director of the Center for Astrophysics and Space Science at the University of California, San Diego, in La Jolla, would find this lighter mass agreeable, because it would help him to solve a long-standing problem with supernovae. These massive star

Neutrino hunters



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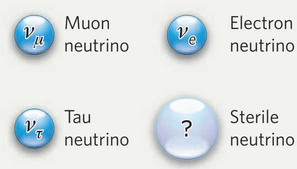
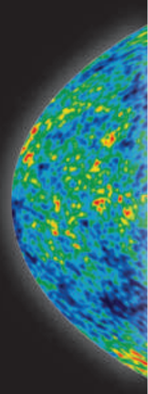
The Mini Booster Neutrino Experiment (MiniBooNE) uses 1,280 photomultiplier tubes to capture faint flashes made when a neutrino or an antineutrino hits liquid inside a giant tank. New data from that experiment could be pointing to the existence of four kinds of neutrinos, raising the chances that sterile neutrinos may be real.

FERTILE HOPES FOR A STERILE NEUTRINO

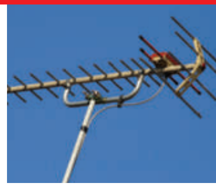
Neutrinos are elusive particles that interact with ordinary matter through the weak nuclear force, which means they can fly through Earth with little chance of hitting any nuclei along the way. They come in three types and can switch, or oscillate, from one to the other.

Some experiments have suggested the existence of a fourth type of neutrino. Unlike ordinary neutrinos, this 'sterile' neutrino would not feel the effects of the weak nuclear force, making them even more difficult to detect.





NASA/WMAP SCIENCE TEAM



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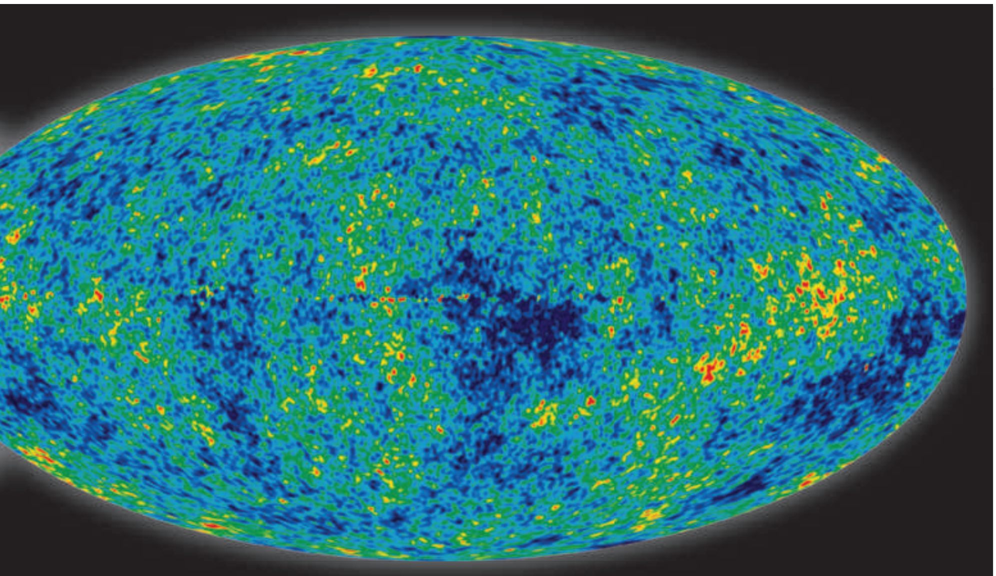

Astronomers have found hints of sterile neutrinos in the faint microwave radiation that fills the Universe and is left over from the Big Bang. The Wilkinson Microwave Anisotropy Probe satellite tracks the temperature variations (shown above) and polarization of this radiation.

explosions cause neutrons to fuse together, creating elements heavier than iron that end up in other stars and in planets. But they also produce inordinate numbers of neutrinos, which should, in theory, inhibit fusion because they kill off neutrons by changing them into protons and electrons.

Sterile neutrinos could provide a way out. If some of the neutrinos created in supernovae morphed into sterile ones, they would fly off without interacting with neutrons, leaving many of them intact. "We're very interested in this, because the stakes are so high," says Fuller.

> "The question of sterile neutrinos is absolutely crucial for nuclear particle physics and astrophysics."

Mixed messages

Sobering news for the sterile-neutrino hunters came this month[3] from the Main Injector Neutrino Oscillation Search (MINOS), an experiment that shoots a beam of neutrinos from an accelerator at the Fermi National Accelerator Laboratory (Fermilab) in Batavia, Illinois, underground to a detector 735 kilometres away in Minnesota to observe neutrino oscillations. The MINOS data show that one family of neutrinos does not have a high propensity for turning into sterile ones, although spokesman Robert Plunkett says that the results do leave room for sterile neutrinos. "We're limiting the parameter space for them."

Another Fermilab experiment, built to follow up on the earliest clues to sterile neutrinos, potentially offers more encouragement. The original evidence came from an experiment at Los Alamos in which Louis took part. From 1993 to 1998, he and his colleagues used the Liquid Scintillator Neutrino Detector experiment to shoot antineutrinos — neutrinos' antimatter counterparts — into 167 tonnes of mineral oil. Their data on how antineutrinos switch from one species to another suggested four distinct flavours. A decade later, data from a follow-up test also at Fermilab — the Mini Booster Neutrino Experiment, or MiniBooNE — found no evidence of a fourth neutrino type. But the MiniBooNE had used a beam of neutrinos, making it difficult to compare its results with the antineutrino data from Los Alamos. Now, after collecting data for a year and a half with antineutrinos, the MiniBooNE experiment sees a different pattern (see 'Neutrino hunters'). When combined with other antineutrino experiments worldwide, says Louis, its data fit "beautifully" to a 3 + 1 model: three ordinary neutrinos plus a sterile one[4].

Louis, who is also a part of the MiniBooNE collaboration, says that the next batch of data, to be released this summer, should give a better idea of whether this fleeting interloper has finally been caught. ■

Eric Hand

1. Komatsu, E. *et al.* Preprint at http://arxiv.org/abs/1001.4538v1 (2010).
2. Lowenstein, M. & Kusenko, A. Preprint at http://arxiv.org/abs/0912.0552 (2009).
3. Adamson, P. *et al. Phys. Rev. D* **81**, 052004 (2010).
4. Karagiorgi, G., Djurcic, Z., Conrad, J. M., Shaevitz, M. H. & Sorel, M. *Phys. Rev. D* **80**, 073001 (2009).

Hobbit origins pushed back

When the remains of tiny hominins — nicknamed hobbits — were found on the isolated Indonesian island of Flores in 2003, it sparked an epic hunt to understand the origins of these diminutive cousins of modern humans.

Now, discoveries of stone flakes used as primitive tools on the island suggest that the hobbit's ancestors were there a million years ago, at least 120,000 years earlier than previously thought (A. Brumm *et al. Nature* doi:10.1038/nature08844; 2010). "Whatever species made it to the island 1 million years ago, it was probably an ancestor of *Homo floresiensis*," says William Jungers, an anthropologist at Stony Brook University in New York.

The metre-high *H. floresiensis* lived on the island until at least 17,000 years ago, and its small stature probably evolved in response to the island's sparse resources. The simple stone tools demonstrate the skills of its ancestors — people who must have hopscotched across islands from mainland Asia, traversing deep and swift ocean channels, before arriving on Flores.

In 2005, Adam Brumm, an archaeologist at the University of Wollongong in Australia, found the first of about 45 stone tools while exploring a bowl-shaped gully on the island that was like "a hot, steamy wok". Three years later, researchers at Roskilde University in Denmark analysed the ratio of two isotopes of argon trapped in volcanic ash overlaying the tools to determine their age.

Previous tool discoveries showed that hominins had arrived on Flores by 880,000 years ago, suggesting that the hobbit's ancestors might have wiped out some of the island's peculiar indigenous animals, such as the pygmy elephant-like *Stegodon sondaari* and giant tortoises (*Geochelone spp.*), which both disappeared at around the same time.

The new finds imply that the hobbit's ancestors coexisted with the creatures for much longer, raising the possibility that a natural disaster was behind the disappearance of the animals.

The team will return to Flores this summer, hoping to find older sediments that could hold earlier evidence of the island's first hominins. ■

Rex Dalton