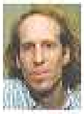


A Conversation with a Neutrino

Neutrinos are elusive critters, but scientists are learning how to listen to the tales they tell.

by Christopher Wanjek

Neutrinos are ghostlike particles that can pass through billions of kilometers of lead without touching a single atom. Neutrinos are indeed the ultimate cosmic snobs, hardly interacting with matter at all, but that's not stopping scientists from striking up a conversation with them.

Neutrinos have a compelling story to tell. Neutrinos from the Sun's core are the telltale signature of nuclear fusion. Neutrinos from the last close supernova, SN1987A, revealed that star explosions are a prime source of these particles, which bathe the universe. These findings helped Raymond Davis Jr. and Masatoshi Toshiba garner the 2002 Nobel Prize in Physics.

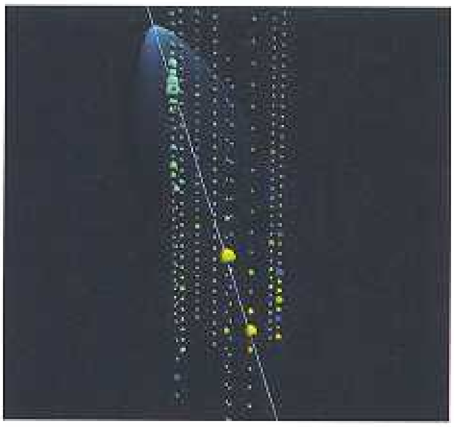
Neutrinos are elementary particles with no electrical charge and very little mass. They come in three flavors: electron neutrinos, muon neutrinos, and tau neutrinos. Each type is similar to its namesake particle, minus the charge. And each type of neutrino has the ability to mutate into another type of neutrino, yet another recent discovery.

Neutrinos' snobbishness makes them the perfect cosmic chroniclers, because no intervening matter distorts their message. Consider the case of a black hole or neutron star: As a strong source of gravity, such compact objects pull in dust and gas from their vicinity. The environment directly surrounding the compact object quickly becomes enshrouded. Light — even penetrating gamma rays — cannot easily escape this commotion. But neutrinos pass on through.

With a new generation of neutrino detectors now under construction, scientists expect to explore the universe as well as the nature of matter and energy in ways never before imagined. "Neutrino astronomy is in its infancy, with great results soon to come," says Luis Anchordoqui of Northeastern University. For example, he adds, "neutrinos can offer brand new information about how neutron stars work."

Anchordoqui is the lead author of an upcoming *Astrophysical Journal* paper describing neutrinos from a well-studied neutron star named A0535+26, which is part of a binary system. His team suggests that neutrinos are produced in the flow of matter from the companion star onto the neutron star. The neutrinos arise from protons whipped close to light speed by the neutron star's magnetic field, a trillion times stronger than our Sun's field.

More important, a neutrino catcher now being built at the South Pole, called IceCube, will be able to detect these neutrinos. This would mark the first detection of neutrinos from a specific source other than the Sun or SN1987A. IceCube, funded in part by the National Science Foundation, is an international, cubic-kilometer detector built in the clear, deep ice of the South Pole. IceCube attempts to catch neutrinos as they enter and pass entirely through Earth.



IceCube will use optical sensors to record Cerenkov radiation (blue cone, upper left) resulting from high-energy neutrinos passing through Antarctic ice. Illustration courtesy of Jodi Lamoureux and NSF.

"The neutrinos from A0535+26 would overwhelm those from any other neutron star system we know," says study coauthor Diego Torres of Lawrence Livermore National Laboratory. "A0535+26 is a periodic source, and it just may be the brightest observable source of the highest-energy neutrinos [in the range IceCube detects]. We could do multiwavelength-particle astronomy and reconstruct the formation and loss of the accretion disk by combining observations in X-rays, gamma rays, and neutrinos."

The team suggests that A0535+26 could be just the tip of the iceberg for IceCube. Neutrinos might also be produced inside a neutron star core. Detection of this type of neutrino would be tantamount to sampling neutron star matter, a paramount achievement that would at long last reveal the nature of the neutron star interior and the physics of matter under extreme gravity.

In a recent *Physical Review Letters*, Peter Mészáros of Penn State reported that neutrinos could also provide a 10-second warning before a gamma-ray burst. According to the popular fireball model, many gamma-ray bursts are massive star explosions. Before the fireball exits the stellar envelope to make gamma rays, it undergoes internal shocks. These shocks accelerate protons, which collide with X-rays in the newly forming jet cavity, which in turn create electrons, neutrinos, and antineutrinos. The neutrinos punch through the stellar envelope at least 10 seconds before the gamma rays are generated.

Furthermore, neutrino bursts appear even when there is no gamma-ray burst, when the stellar envelope chokes off gamma rays. "There could be a far larger number of similarly violent bursts detectable only through their ultrahigh energy neutrinos," says Mészáros. These bursts, too, would be in IceCube's range.

Because of their chameleon-like characteristic of changing flavors so readily, neutrinos speak of fundamental physics: the nature of various particles and the property of mass. The conversation is just under way, and it's sure to be a doozy.

CHRISTOPHER WANJEK of SP Systems supports NASA's Structure and Evolution of the Universe theme. He is author of the critically acclaimed new book Bad Medicine.