For a big view of inner Earth, catch a few ...  

By Diana Steele

Geoneutrinos

Or originally used to detect elusive particles from space called neutrinos, the four-story detector at the Sudbury Neutrino Observatory could be rethought to detect antineutrinos produced by natural radioactivity inside Earth.

Were the Earth a crystal ball, you might gaze 2,900 kilometers down to its outer core with a telescope. The Earth, though, is frustratingly opaque — to light. Most knowledge of the planet’s internal structure comes from studying seismic waves, which give a kind of ultrasound image. Inferences about Earth’s internal chemistry rely on the elements found in near-surface rocks, meteorites and the sun.

Recently, geoscientists have developed a new tool for probing the Earth’s innards. Borrowing a page from astrophysics, they are using the curious subatomic particles known as neutrinos. Astrophysicists have used neutrino telescopes for decades to study neutrinos originating in the sun and elsewhere in the cosmos. Now earth scientists are taking a neutrino telescope and looking down, to illuminate the Earth’s interior by detecting “geoneutrinos” — neutrinos produced within the planet itself.

“Now, for the first time, we have the possibility of measuring the composition of the Earth in real time,” says William McDonough, a geochemist at the University of Maryland in College Park.

Geoneutrinos are actually antineutrinos, which are neutrinos’ antimatter counterpart, just as positrons are the antimatter partner to electrons. “Geoneutrinos” is just an easier word to say than “antineutrinos coming from inside the Earth,” McDonough says. Electrons and positrons have opposite electrical charges, but neutrinos and antineutrinos have no charge. So neutrinos and antineutrinos, confusingly, may or may not be the same particle.

Geoneutrinos were first observed in a detector deep inside a mine in Japan in 2005. Now an array of proposed new experiments are poised to get an even better glimpse of the Earth’s inner chemistry. These range from deep-mine detectors in Canada, the United States and Europe, to a mobile, submersible deep-ocean detector.

McDonough and two colleagues from the University of Hawaii gave an overview of the experiments in October in Eos, the weekly newspaper of the American Geophysical Union.

Original experimenters discussed new developments with earth scientists at a conference in September in Sudbury, Canada — the site of one of the proposed experiments.

Geoneutrinos originate from the radioactive decay of uranium, thorium and potassium in the Earth’s crust and mantle. Earth scientists are keen to learn more about the crucial role the decay of these elements may play in heating up the Earth and, in turn, driving convection in the Earth’s mantle.

Powering Earth

“The convection in the mantle is responsible for essentially all of the dynamics of geology that we see — moving continents and seafloor spreading,” says John Learned, a particle physicist at the University of Hawaii at Manoa. But whether radioactive decay dominates the heating action or is one of a number of players isn’t known. There’s even controversy over how much heat, in terms of power, the Earth puts out. Estimates range from 30 billion to 44 billion kilowatts.

Energy drives the movement of the geologic plates upon which the continents ride, says McDonough, “and the fuel for that is either entirely radioactive fuel or a subset of energy sources.” It’s like the energy mix in homes, he says. “We don’t get all of our electricity from coal, but some portion from nuclear and some portion from other sources. The question today is, ‘What are the energy sources driving the Earth’s engine?’

Among the other possible energy sources is heat left over from the planet’s formation by colliding meteorites. These planetary building blocks eventually accreted enough mass to become Earth. As the meteorites slammed into each other, their kinetic energy became thermal energy. Over time, the Earth has radiated this heat into space.

“We could have started out with a large amount of kinetic energy, and we’ve slowly dissipated it,” says McDonough, “or we could have started with a large amount of kinetic energy and rapidly dissipated it, depending on the atmospheric conditions.”

It’s difficult to measure how much heat might have come from this or other sources. But the new suite of geoneutrino detectors could pin down better numbers for the radioactive contribution.

Estimates are that radioactivity, mainly from uranium and thorium but also from potassium, accounts for at least 40 to 60 percent of Earth’s interior heat. “Stories that are most abundant in the crust, the top 30 kilometers of rock. But key to understanding Earth’s dynamics is knowing the amount of these elements in the mantle — the vast, viscous, slowly churning layer that stretches 2,900 kilometers from crust to molten outer core.”
Like the better-known solar neutrinos, geoneutrinos can pass through thousands of miles of solid rock without being stopped or even deflected. That makes them ideal for studying deep Earth—but also makes them very difficult to catch.

**Detecting geoneutrinos**

One surefire way to catch some is to build a detector that can collect and use the same detector as their cousin the neutrino. The SNO detector, which played an important role piggyback on and use the same detector as the mine near Sudbury, Ontario. SNO+ would sit underground in the Creighton nickel mine in Sudbury, Ontario. The geological setting makes it an ideal site for geoneutri-nos, like liquid hand soap. It’s less toxic than other, similar detectors,” Chen says. “It’s transparent, but it’s a safer scintillator,”

Converting SNO into SNO+ would detect the lower-energy geoneutri-nos—means changing out the fluid that filled the detector. SNO operated from 1999 to 2006 using heavy water — water with atoms of deuterium, heavy hydro-gen— to snag solar neutrinos. Pending final approval of funding, the detector will be filled with a hydrocarbon-based scintillation fluid, which, when a geoneu-trino is caught, will luminesce and trig-ger the detector.

The fluid is a common, mass-produced petrochemical called linear alkylben-zene, or LAB, used to make clear deter-gents, like liquid hand soap. It’s less toxic than most chemical liquid scintillators.

“It produces a lot of light, and it’s very transparent, but it’s a safer scintillator,” says SNO+ director Mark Chen. “It’s much easier to use it, especially in a set-ting where we are taking a thousand tons of it into an active mine.”

The detector is a four-story acrylic sphere surrounded by electronic eyes that scan the fluid for flashes of light char-aecistic of geoneutrinos’ presence.

Chen, a particle astrophysicist at Queens University in Kingston, Canada, hopes SNO+ will start up in late 2010. It would catch about 50 geoneutrinos a year, considerably more than either KamLAND or Borexino. The longer SNO+ runs, the better the picture it will get of the inner Earth.

Ontario’s nuclear power plants are far enough away to not overwhelm the geoneutrino signal. “Certain problem-at backgrounds from cosmic rays are even further reduced because we just happen to be deeper underground than other, similar detectors,” Chen says. With SNO+, he says, it will be possible to do some interesting things “with less background and improved precision.”

SNO+ has an ambitious scientific agenda that includes better understand-ing the fundamental nature of neutrinos. One goal is to pin down the mass of the neutrino—a quantity even more elu-sive than the neutrino itself. Another is to determine whether neutrinos and antineutrinos are the same particle—or not. The lack of charge makes it difficult to tell.

That question “connects to our understand-ing of the entire universe and might inform us about why … we see matter in the universe but much less antimatter,” Chen says.

**Mantle signature**

SNO+ is the furthest along of the up-coming geoneutrino experi-ments. Other detectors under discus-sion include one in the Homestake mine in South Dakota and a large detector to be built in Europe, possibly in Finland. Startup and operating costs are esti-mated to be on the order of hundreds of millions of dollars, and construction

Wouldn’t begin for at least several years. These detectors would be, for the most part, counting geoneutrinos that origi-nate in the Earth’s crust, where thorium and uranium are concentrated. Looking close to the crust is like having your eye close to a bright flashlight.

To get a better idea of what’s going on in the Earth, you need to get closer, and to keep it running for 10 years could cost around $200 million, he estimates. “That’s expensive, but it’s about a fac-tion of 10 less expensive than sending a spacecraft to another planet,” points out David Stevenson, a planetary physicist at the California Institute of Technology in Pasadena, who is not directly involved in the geoneutrino experiments. “and it’s conceivable to me that we could get the same information with the accuracy we desire by any other method,” he says. He also hopes for the unexpected. “I’ve learned as a planetary scientist, that when you go to a planet, you actually discover things, you are surprised,” he says. “And in the case of the neutrinos, you may be surprised. You may be surprised, for example, to discover that there’s a major source of radioactivity in a layer just above the core”—an idea proposed early last year by Dutch and South African scientists writing in the South African Journal of Science.

A physicist boats in water surrounding Canada’s SNO detector, which is filled with heavy water to detect neutrinos. A new fluid will be used to detect geoneutrinos.