

Strong Evidence For Flavor Oscillation In Atmospheric Neutrinos

As we go to press, the applause has barely subsided for a 5 June talk by Takaaki Kajita at the Neutrino '98 conference in Takayama in the Japanese Alps, not far from the 50-kiloton Super Kamiokande underground water-Cherenkov neutrino detector. Speaking for the Japanese-American Super Kamiokande collaboration, Kajita reported by far the most convincing evidence to date of oscillation between different neutrino flavors. The evidence comes from the high-statistics observation of neutrinos created by cosmic-ray showers in the atmosphere. It appears that muon neutrinos on their way to the detector are exhibiting oscillatory metamorphosis into something *other than* electron neutrinos. Neutrino oscillation cannot happen if all flavors are massless. Details in the next issue. **BERTRAM SCHWARZSCHILD**

induced by solar winds or other sources of electrical currents in the ionosphere. The ratio of the electric to magnetic fields gives the complex impedance, from which one can extract the conductivity. The frequency bands are taken as a measure of the depth, with higher frequencies providing information about shallower structures. However, the data analysis is quite complicated. According to Evans, magnetotelluric results are a bit nonintuitive because one region of high conductivity will affect the value of fields throughout the region. So far, he and his colleagues have done what he calls "forward modeling," seeing if the data are consistent with certain patterns of conductivity. But they have not exhaustively explored the possibilities.

According to the MELT team's preliminary results, the background mantle structure agrees well with that

measured in a 1995 magnetotelluric study along a line from California to Hawaii.⁸ For a broad region in the upper 100 km beneath the East Pacific Rise, the researchers see conductivities that are higher than expected for a dry mantle. However, the conductivity is not high enough to support any more than about 1% of interconnected melt in that region. More melt may be present, but unless the pockets of melt are connected to one another, they will not have a substantial impact on the electrical conductivity. The conductive region may be broader to the west than to the east of the ridge crest. It is also possible that there is a narrow (only 10 km wide) region containing 4% of interconnected melt directly beneath the ridge, but this scenario is not required by the MELT team's data.

The magnetotelluric data reveal a striking anomaly: a region of high con-

ductivity at a depth of about 170 km, which the research team needs to explore more closely. Doing so will involve examining the role of water in the mantle. Water can raise the conductivity, of course, and maybe that alone is the cause of the high conductivity at 170 km. But when melt occurs (perhaps higher up in the mantle), the water can enter the mantle's melt phase, causing the remaining mantle to be drier.

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Microcalorimeters May Provide a Solution to the Big Problem of Small Contaminants

As microelectronic devices continue to shrink, submicrometer-sized contaminants pose a serious threat to semiconductor yields and performance—and thereby to the profits of the nearly \$200 billion a year industry. Chemical analysis of these tiny particles can suggest remedies for avoiding contamination by helping to pinpoint its sources. One of the most successful microchemical analysis tools combines electron microscopy with spectroscopic analysis of x rays excited in the target impurity by the microscope's electron beam. Unfortunately, the choice of x-ray detector has traditionally involved a trade-off between energy resolution and speed. So the semiconductor industry—where time equals a lot of money—has often had to supplement spectrometry with educated guesswork. Now, John Martinis, Kent Irwin, Gene Hilton and David Wollman, working at the National Institute of Standards and Technology facility in Boulder, Colorado, have developed an

In a drive to help the US semiconductor industry, researchers are developing x-ray spectrometers that will be able not just to identify any element in microscopic contaminants, but also to yield information about the element's chemical state.

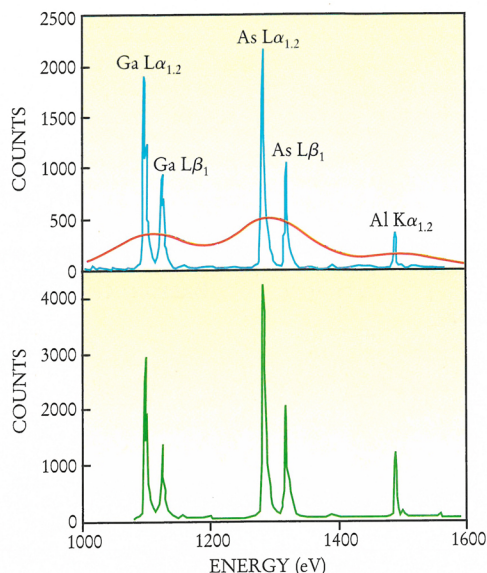
x-ray detector^{1,2} that they hope will remove some of that guesswork.

In general, x-ray spectroscopy can be performed by two types of devices—wavelength-dispersive and energy-dispersive spectrometers. Wavelength-dispersive spectrometers use crystals to Bragg scatter x rays, which are then counted by a gas proportional counter. The short dead times of these counters make possible counting rates as high as 50 000 per second, and the narrow wavelength range scattered at the Bragg angle ensures excellent energy resolution. However, scanning over the entire x-ray spectrum (50 eV to 20 keV) in this mode involves changing

the scattering crystal orientation and switching between crystals—a very time consuming process.

In contrast, energy-dispersive spectrometers use a detector that measures the energy of each incident x ray, simultaneously covering the entire energy range of interest. In spite of the fact that their energy resolution is significantly worse, energy-dispersive spectrometers perform their function so much more quickly and cheaply than their wavelength-dispersive counterparts that they dominate the semiconductor industry.

For over a decade, researchers^{1,3,4} have been developing improved x-ray spectrometers based on microcalorimeters, which use sensitive thermometers to determine individual x-ray energies by measuring the temperature change they produce in an x-ray absorber. With the ability to cover the entire x-ray spectrum simultaneously and theoretical energy resolutions rivaling those of wavelength-dispersive spec-



X-RAY SPECTRA for AlGaAs as collected by the microcalorimeter developed at the National Institute of Standards and Technology (blue), by a conventional energy-dispersive semiconductor detector (red) and by a typical wavelength-dispersive spectrometer (in green, lower graph) show that the NIST device provides sufficient energy resolution (4 eV) to resolve closely spaced x-ray peaks that would be obscured for energy resolutions typical of a conventional energy-dispersive spectrometer.

trometers, microcalorimeters make attractive x-ray detectors. (See the figure above.) Moreover, unlike conventional energy-dispersive x-ray detectors, microcalorimeters have sufficient energy resolution to resolve the many closely spaced x-ray lines present at low energies. This property makes it possible to use them in conjunction with low-energy electron beams, which are less penetrating and so are better for identifying surface contaminants.

However, there are three major challenges involved in realizing the potential of these devices: First, there exists at some level a trade-off between detector efficiency and energy resolution. That is, an x ray of energy E will produce a temperature change in a detector of E/C , where C is the detector's heat capacity and is proportional to detector volume. Unfortunately, high detector efficiency requires a detector that is thick and has a large area. A very sensitive thermometer is necessary to overcome this tradeoff. Second, the fact that thermal fluctuations increase linearly with temperature—and that heat capacities increase at least linearly with temperature—necessitates operating these devices at millikelvin temperatures. Lastly, it is difficult to develop thermal devices that are fast enough to compete with estab-

lished technologies. The NIST microcalorimeter offers some creative solutions to these problems. (See the photo on page 21.)

Living on the edge

The most important innovation in the NIST microcalorimeter is the use of a sensitive superconducting transition-edge sensor (TES) thermometer—which operates in the very narrow temperature range of a metal–superconductor transition—in conjunction with electrothermal feedback, which helps regulate the thermal recovery time of the microcalorimeter. In the TES, a thin film of an aluminum/silver bilayer is deposited on a silicon nitride membrane. Aluminum becomes superconducting at about 1.2 K, while silver remains a normal metal. By changing the relative thicknesses of the two metals, the bilayer can be made to behave as a superconductor with an effective critical temperature, T_c , from 0 to 1 K. Near the effective T_c , the Al/Ag bilayer's resistance, R , is a strong function of temperature.

If the thermometer/absorber assembly is thermally coupled to a heat bath with a temperature below T_c and a voltage, V , is applied across the film, the assembly will achieve equilibrium when the resistive heating, V^2/R , equals the thermal power transferred to the heat bath by the device. Energy deposited by an x ray in the absorber raises the thin film's temperature; the corresponding increase in resistance is measured by a superconducting quantum interference device (SQUID) current sensor as a change in the current passing through the film. This mode of operation has an additional benefit: An increase in the thin-film resistance decreases the resistive heating in the calorimeter, decreasing the time it takes the microcalorimeter to return to equilibrium and effectively increasing its maximum counting rate by a factor of up to 100. The highly sensitive TES thermometer also makes it possible for the microcalorimeter to use absorbers with relatively high heat capacities. Such absorbers facilitate the rapid thermalization of x-ray energies and minimize spectral artifacts.

To attain temperatures below the Al/Ag bilayer's effective T_c , the NIST-Boulder group used a liquid-helium bath and an adiabatic demagnetization

refrigerator. The refrigerator uses the endothermic process of demagnetization in paramagnetic materials to reach millikelvin temperatures.

To compensate for the small size and resulting low geometric efficiency of their microcalorimeter, the NIST researchers capitalized on a recently developed x-ray focusing device, the polycapillary x-ray optic. This device consists of thousands of fused tapered glass capillaries that effectively focus x rays by means of total internal reflection. The x-ray optic increased the effective area of the NIST microcalorimeter, making its efficiency comparable to that of a wavelength-dispersive spectrometer. "The existence of excellent x-ray polycapillary optics allowed us to focus on improving single-pixel performance, resulting in a practical x-ray spectrometer that can help US industry now," says Wollman.

A hot property—and getting hotter

Even as the NIST researchers continue improving their detector, a competition has been waged between several companies to determine who will commercialize the technology. Once the commercialization rights have been granted, NIST hopes that a viable x-ray spectrometer based on the NIST microcalorimeter will be available within a few years.

Even if exclusive rights are granted to a single company, the NIST technology may face competition. Eric Silver of the Harvard-Smithsonian Center for Astrophysics is hoping to commercialize his own microcalorimeter.⁴ Silver's device determines x-ray energies by measuring the temperature change they produce in a superconducting x-ray absorber with a doped germanium thermometer. Teaming with Norm Madden, Jeff Beeman and Eugene Haller of Lawrence Livermore National Laboratory, Silver is also working on a mechanical cryocooler system that would eliminate the need for liquid helium—a real plus for clean-room operations. To isolate the scanning electron microscope from the vibrations of the cryocooler, the group has also developed an x-ray optic that focuses x rays onto the microcalorimeter located several feet away from the SEM.

Currently, the NIST researchers are continuing to push their microcalorimeter's energy resolution and count rate toward their theoretical limits of around 1 eV and well over 1000 counts per second. With these numbers, they hope to be able to detect the small shifts in x-ray energies that characterize a contaminant's chemical state as well as its chemical identity.⁵ So far, with a resolution of 3 eV, they have been able to detect the relatively large



THE MICROCALORIMETER-BASED x-ray spectrometer (on left side of center table) developed by researchers at the National Institute of Standards and Technology (NIST) in Boulder, Colorado, is designed to be used with a scanning electron microscope (white) on right side of center table. The spectrometer uses an adiabatic demagnetization refrigerator (gold-colored cylinder) to reach millikelvin temperatures. The microcalorimeter is located at the end of an extension from the refrigerator, near the sample inside the SEM. The control console and signal processing electronics are located to the right and left, respectively, of the microcalorimeter/SEM assembly.

chemical shifts between iron and its various oxidation states (about 0.8 eV). And then? "Ultimately," says Wollman, "we hope to use an array of high-resolution TES microcalorimeters to make a revolutionary system capable of counting 100 000 x rays per second and with a total area of 40 square millimeters."

They are also looking at other applications for their technology. One promising avenue involves using the microcalorimeter as an ion detector in mass spectrometry. The high quantum efficiency of these detectors for large masses make them attractive for use with massive ions such as proteins and DNA. Already, without optimizing their system for the task, the NIST researchers have shed light on how molecules may break up as they are accelerated within the mass spectrometer.⁶ "DNA sequencing using mass spectrometry may ultimately provide sequencing several orders of magnitude faster than current gel-electrophoresis methods," says Hilton. "Although at this stage we are mostly trying to understand issues related to detector and spectrometer performance, we hope to demonstrate high

resolution mass spectrometry for DNA strands up to 1000 base pairs long." Other possible applications are in astronomy, where microcalorimeters would be the first devices sensitive to single photons from infrared to gamma rays. So it would seem that for x-ray microcalorimeters, even the sky poses no limits.

RAY LADBURY

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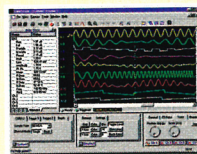
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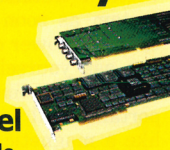


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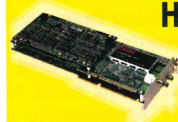


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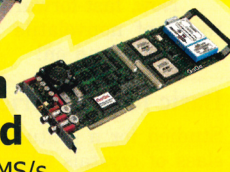
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