

# PHYSICS UPDATE

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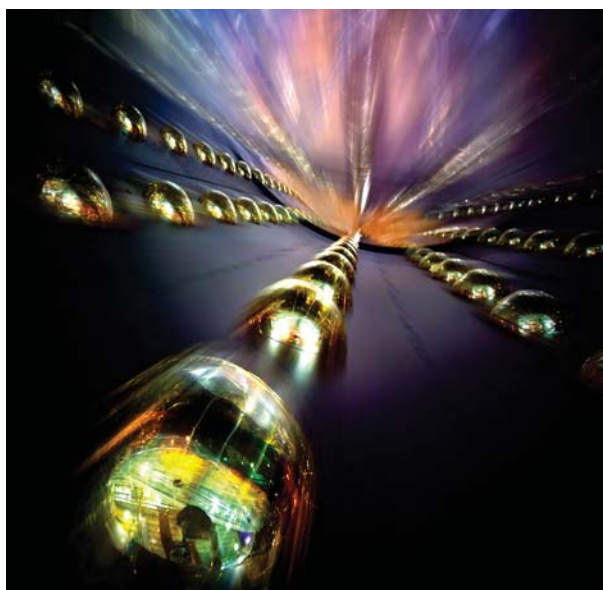
## AS NUCLEAR FUEL AGES, AN ANTINEUTRINO ANOMALY CHANGES

For several years now, detectors at three experiments—Daya Bay in China, RENO in South Korea, and Double Chooz in France—have been measuring the flux of electron antineutrinos emanating from nearby nuclear reactors. The experiments' main purpose has been to help quantify the oscillations of neutrinos from one flavor to another, but

along the way their precise measurements have sharpened a mystery that has troubled particle physicists and reactor physicists alike: The overall antineutrino flux is about 6% less than theory predicts. One explanation involves a "sterile" neutrino with a mass of about 1 eV that, unlike the three standard neutrinos, is not subject to the weak force that governs nuclear decay.

Now the Daya Bay group has analyzed 1230 days of data and identified a new factor that influences the antineutrino flux: the evolving isotopic composition of the nuclear fuel in the cores of the reactors at the Daya Bay and Ling Ao nuclear power plants. (The image shows the inside of one of the group's detectors.) The new results contradict the notion that sterile neutrinos are the source of the antineutrino flux anomaly.

Uranium-235 and plutonium-239 are the key components of the fuel at the Daya Bay and Ling Ao power plants. But over the course of the reactors' typically 18-month-long fuel cycles, the relative amount of  $^{239}\text{Pu}$  increases. By monitoring how the antineutrino flux evolves during the fuel cycles, the Daya Bay researchers determined the rate of change of flux with changing  $^{239}\text{Pu}$  fraction. They also teased out the individual contributions of  $^{239}\text{Pu}$  and  $^{235}\text{U}$  to the antineutrino flux.



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In the low-mass sterile-neutrino picture, the shortfall in antineutrino flux is independent of the isotopic mix that generates the antineutrinos. Therefore, the statistically significant evolution of flux measured over the course of a reactor cycle is inconsistent with such a neutrino. Moreover, when the researchers compared their reactor-physics model with the measured antineutrino fluxes from the two types of nuclear fuel, they found a good fit for the  $^{239}\text{Pu}$  and a poor fit for the  $^{235}\text{U}$ . They concluded that an improper understanding of the  $^{235}\text{U}$  contribution to the antineutrino flux is the likely cause of the flux anomaly. (F. P. An et al., *Phys. Rev. Lett.*, in press.) —SKB

## HOW FRICTION MELTS SLIDING ROCK

When two rock formations slide past one another during an earthquake, the friction generated melts the rock to create a liquid layer that eases further movement. At 1000–1550 °C, interface temperatures during sliding exceed the melting points of most minerals. Even so, examination of exhumed faults does not reveal evidence of the uniform, equilibrium melting that occurs at high temperature. In the case of quartzite rock (shown in the figure), the melting is especially puzzling. Minority components in the quartzite that have lower melting temperatures than their host will melt and resolidify. But so too does some of the quartzite, whose melting temperature is 1726 °C.

To identify the processes at play, Sung Keun Lee of Seoul National University and Raehee Han of Gyeongsang National University—both in South Korea—and their colleagues cleaved a cylindrical sample of Brazilian quartzite perpendicular to its axis and loaded the two disk-shaped pieces



into a rotary shear apparatus. The bottom piece was held stationary while the top piece, in contact with the bottom, was spun at a slip rate at the circumference of 1.3 m/s. Friction between the two pieces created a molten interface at the rim that was 0.7 mm thick and attained a temperature of about 1400 °C. When the researchers studied the interface after it had cooled, they found evidence of the same lack of uniform melting around the rim as

in samples from exhumed faults. Toward the center of the samples, where the slip rate was lower than at the rim, melting did not occur. But the friction did cause the samples to break up into powder.

Here was a key clue: As embodied by the Gibbs–Thomson equation, the smaller a piece of material is, the greater the energy of its curved surface with respect to the bulk. The upshot is to lower the powdered particles' melting temperature. What's more, the rapid temperature rise brought on by the sudden onset of friction had another effect: It triggered the metastable melting at 1400 °C of  $\beta$ -quartz, one of quartzite's principal crystalline phases. So when quartzite formations slide past each other, the friction does not have to reach the mineral's melting temperature for a lubricating layer to develop. (S. K. Lee et al., *Nat. Geosci.* **10**, 436, 2017.) —CD

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