those traveling right to left become approximately left-hand circularly polarized (σ^-). Those photons interact with a rubidium atom in a three-level configuration, illustrated in the inset, in which two degenerate ground states having magnetic quantum numbers −1 and +1 share an excited state.

An atom in the $|-1\rangle$ state that absorbs a σ^+ photon will reradiate it as a σ^- photon and decay to the $|+1\rangle$ state. That the atom doesn't instead emit a σ^+ while decaying back to the $|-1\rangle$ state is due to a peculiarity of quantum cavity electrodynamics first uncovered a few years ago.[4] Technically, the atom radiates into the σ^+ and σ^- polarization states with equal probability. But because the emitted σ^+ photon has a π phase shift and is indistinguishable from the incident σ^+ photon, those two destructively interfere, and only the σ^- photon survives.

In the $|+1\rangle$ state, the atom is transparent to σ^+ photons. By symmetry, the $|+1\rangle$ state reflects, and the $|-1\rangle$ state transmits, σ^- photons. "The key," says Dayan, "is that the atom 'remembers' when it reflected a photon—it changes its state." That means photons can toggle the switch: A control photon injected at input 1 switches the atom to the $|+1\rangle$ state, and ensures that a subsequent photon, the target, will be routed to output 2. Likewise, a control photon injected at input 2 steers the target to output 1.

To integrate their switch into large-scale networks, Dayan and his colleagues will first need to devise a better atom–resonator coupling. At present they use an approach that Dayan helped develop as a postdoc with Jeff Kimble and Kerry Vahala at Caltech: They trap a cloud of laser-cooled atoms just above the silica resonator and then release it. Occasionally a free-falling atom passes through a Goldilocks zone about 100 nm from the resonator surface—close enough to interact with the resonator's evanescent field but not so close as to be pulled onto the resonator's surface by van der Waals forces. The atoms spend just microseconds in the evanescent field, but that's plenty of time to complete an experiment.

Still, a less ephemeral coupling might be established by holding the atom in an optical trap—an approach that's been successfully used to couple atoms with optical fibers. Also, Dayan notes that real atoms can be substituted with artificial ones such as quantum dots, which can more easily be pinned into place. "It's not the atom that's important," he says. "It's the scheme."

The researchers also look to improve the switch's fidelity. At present, the switch correctly transmits photons about 90% of the time but correctly reflects them only 65% of the time. In theory, those numbers should be closer to 100% and 90%, respectively. (The reflection operation's inefficiency is mainly because the polarization of the resonator's field isn't perfectly circular.) Assuming they can get close to those theoretical limits, Dayan and company should then be able to tackle more sophisticated quantum experiments, such as using the switches as quantum memories or quantum logic gates.

Rauschenbeutel thinks those are reachable goals. "There are some technical considerations they'll have to work out. For instance, one could imagine using a control photon in a superposition of TM and TE states to place the atomic switch in a superposition of toggled and untoggled states, but then you'd need to carefully orchestrate the ensuing switching sequence to avoid destroying that superposition. It will take some thought, but I'm pretty sure it's doable."

Ashley G. Smart

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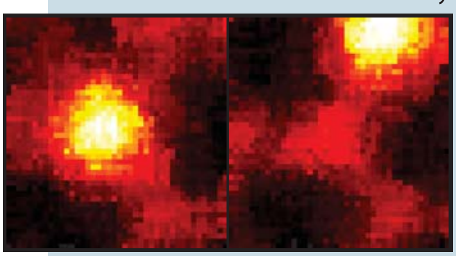
physics update

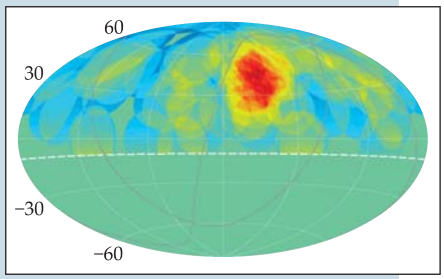
These items, with supplementary material, first appeared at http://www.physicstoday.org.

Walking a silicon atom through a graphene landscape. The electron beam in a transmission electron microscope (TEM) can displace atoms in a sample and sometimes cause what's called knock-on damage. Researchers at the University of Vienna, together with UK teams at the Daresbury SuperSTEM Laboratory and the University of Manchester and a team from Nion Co in the US, have now used those displacements to manipulate a sample one atom at a time. During TEM scans of silicon-doped graphene, they found that the electron beam can cause a Si atom to hop from one lattice site to a neighboring one about 0.14 nm away. The two TEM images here, taken 0.5 seconds apart, show a Si atom (bright spot) before and after such a hop. The hop itself happens on a time scale too fast to see with a TEM, so the researchers turned to molecular dynamics simulations,



which showed that the electron beam actually knocks out a carbon atom. But instead of escaping, the ejected C atom curves back toward the neighboring Si atom because of their mutually attractive interaction. At the same time, the Si atom relaxes toward the newly created vacancy. When all is said and done, the two atoms have swapped positions. Since the hopping is induced by displacing a C atom rather than directly affecting the Si atom, the researchers suggest that a narrow electron beam could direct the movement of a Si atom to any desired site. (T. Susi et al., *Phys. Rev. Lett.*, in press.) —SC

Extremely energetic cosmic rays from a preferred direction. Earth is continuously bombarded by cosmic rays—high-energy protons or nuclei—that come from beyond our galaxy. The energy spectrum falls rapidly at the so-called Greisen-Zatsepin-Kuzmin (GZK) cutoff of about 6×10^{19} eV, but cosmic rays have been observed with energies up to 3×10^{20} eV. Astrophysicists have long sought to determine what accelerates particles to such extraordinary energies.



Possibilities include supernovae and relativistic jets from active galactic nuclei. Now the Telescope Array experiment has provided an enticing clue by identifying a "hotspot" in the northern sky that sends a disproportionate amount of ultrahigh-energy cosmic rays (UHECRs) our way. See the figure; red indicates greater flux.

(The Pierre Auger Observatory had previously spotted a weaker hotspot in the southern sky.) In a five-year scan that concluded in May 2013, the Telescope Array identified 72 cosmic rays with energies above the GZK limit, via the shower of particles created when the UHECRs interact with Earth's atmosphere. Ground-based scintillators recorded the arrival of shower particles, and fluorescence detectors monitored the energy deposited in atmospheric nitrogen. (See PHYSICS TODAY, May 2007, page 17.) About 25% of the observed UHECRs came from the direction of the hotspot, which fills only 6% of the northern sky. The hotspot is large enough to cover many potential UHECR sources; its extent arises in part because galactic and intergalactic magnetic fields bend UHECRs and thus muddle their source locations. Fortunately, particles with energies near and beyond the GZK cutoff bend little enough that a larger and more sensitive array may yet reveal their origins. (R. U. Abbasi et al., *Astrophys. J.* **790**, L21, 2014.) —SKB

Controlling a tipping point. The concept of a tipping point is familiar: A generally stable system evolves to where the stability disappears and the system suddenly and irreversibly switches to a dramatically different, perhaps catastrophic state. The system may be a power grid that experiences a slow rise in demand, leading to a large-scale power outage, or a climate system, subject to increasing greenhouse gases, that has an abrupt shift in mean temperature. For a system with multiple potential outcomes, Takashi Nishikawa (Northwestern University) and Edward Ott (University of Maryland) report that it may be possible to steer the system to a desirable outcome by giving it a small, carefully chosen push. They theoretically consider the evolution of a noisy one-dimensional system: At each iteration, the current position is mapped to a new position, where the mapping depends on a slowly varying parameter plus some random noise. When the parameter reaches a threshold value—a so-called bifurcation—the system will shift to one of two states, but which it is can depend very sensitively on the noise fluctuations or the particular details of how the parameter varies. The researchers show with simulations and analytically that if the noise amplitude is low, one can get a 90% chance of reaching the desired outcome through a one-time shift in the system's position by an amount just a few times larger than the noise level. Surprisingly, the required nudge is smallest during a window of opportunity that occurs a finite time after the bifurcation. Although the method can be generalized to higher dimensions, the authors caution that it requires having an accurate system model. (T. Nishikawa, E. Ott, *Chaos* **24**, 033107, 2014.) —RJF

The most distant stars in our galaxy. The Milky Way, the Sombrero (shown here), and other spiral galaxies are enveloped by huge spherical halos of dark matter, low-density gas, and sparsely distributed stars. John Bochanski of Haverford College and his collaborators are searching for our galaxy's outermost halo stars, whose properties carry clues about the galaxy's past. The search focuses on red giants. Besides being luminous—and therefore detectable at large distances—red giants have IR spectra that set them apart in photometric surveys from other stars except red dwarfs. But red dwarfs, being less luminous, are found at shorter distances; their apparent motions across the sky tend to be quicker than those of distant red giants. From two photometric surveys and one kinematic survey, Bochanski's team has identified

404 red giant candidates. Fifteen were subjected to the first round of spectroscopic observations. One candidate was unidentifiable, nine were red dwarfs, and three were not-too-distant red giants. But two candidates turned out to be red giants whose distances, 238 kiloparsecs (8.09×10^5 light-years) and 274 kiloparsecs (8.94×10^5 light-years), are roughly seven times larger than the diameter of our galaxy's disk. At those record-breaking distances, the ambient gas is too rare to feed star formation; the two stars were born elsewhere. Two origins are plausible: The stars could be leftovers from a satellite galaxy that the Milky Way consumed, or they could have been flung into the halo from our galaxy's disk by a violent event. (J. J. Bochanski et al., *Astrophys. J. Lett.* **790**, L5, 2014.) —CD

The sound of the slurry. The mining and minerals industry has long used flowing water as a cost-effective and safe way to move its waste tailings from their origin to a storage pond. (See the article in PHYSICS TODAY, March 2009, page 31.) And nuclear sludge such as that held in tanks at Hanford, Washington, in the US and at Sellafield in the UK can also be hydraulically transported for eventual treatment. But a hydraulic conveyor needs continual monitoring to avoid blockages, maintain pressures, and minimize corrosion. Many monitoring methods are in use, but the job quickly gets complicated when solid–liquid suspensions are difficult or dangerous to access as they tumble along a pipeline and when they consist of a range of particle sizes and densities. As part of his PhD work at the University of Leeds in the UK, Hugh Rice took an acoustic method that was previously used to characterize marine sediments and adapted it for optically opaque industrial flows. Using a pair of piezoelectric transducers operating at 2 MHz and 4 MHz, Rice and colleagues have obtained attenuation and backscattering coefficients for each of four particle types, ranging in size (40–700 μm), density (glass and plastic), and shape (spherical and jagged). Until now those coefficients were available only for quartz sand. Using a dual-frequency algorithm borrowed from marine science to invert the signals in flowing suspensions, the researchers tested the flow-measurement method in a pipe as shown here. The results showed particle segregation and different flows for different particles. Ultimately, Rice and company expect to use such measured coefficients to obtain concentration profiles and flow regimes in arbitrary industrial settings. (H. P. Rice et al., *J. Acoust. Soc. Am.* **136**, 156, 2014.) —SGB