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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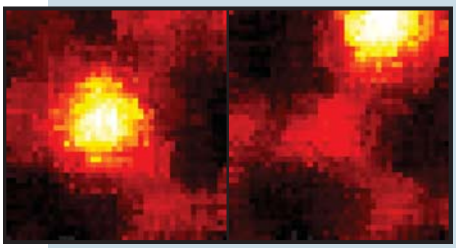
physics update

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.