term, aerial probes of large forest ecosystems in the Northeastern United States, which were done with his Princeton colleague Stephen Pacala.

From studies like these, Levin and his colleagues found that there is a remarkable regularity in the data on many ecosystem properties, such as species diversity and dispersal rates, that seems independent of the scale of the study in which the data were obtained. The researchers could show this by plotting the variations in the different properties against the sizes of the ecosystems in which they were determined, both on logarithmic scales. The resulting lines were linear with a characteristic slope for each variation measured over broad ranges of scale. The work suggests, Levin says, that there may be "laws that allow one to make comparisons among studies carried out on different scales." If so, ecologists could have more confidence about offering solutions for large-scale environmental problems based on studies carried out on more modest scales.

As might be expected in a science that is just now groping for mature theories, not all ecologists agree that such broad generalizations will ever be possible. Roughgarden, for one, maintains that biological systems may be far more complex than physical systems, and that it may be impossible, and not particularly useful, to wrap them up in neat packages of theory. Even Levin concedes the task of finding mathematical tools needed to information from one scale to another will be challenging. Still, there does seem to be agreement in the field that while theoretical ecology is a young science, it is now showing enough signs of maturity—including the ability to affect practical matters and to make predictions about the future—that it must be taken seriously.

–Anne Simon Moffat

Additional Reading

S. A. Levin, Ed., "Mathematics and Biology: The Interface—Challenges and Opportunities," pub. by Lawrence Berkeley Laboratory, University of California, 1992.

S. Pimm *et al.*, "Times to Extinction for Small Populations of Large Birds," *Proc. Nat'l. Acad. Sci.* **90**, 449 (1993).

ATOMIC PHYSICS

Atom Beams Split by Gentle Persuasion

An atom, says quantum mechanics, is both particle and wave, and researchers in the growing field of atom optics have been taking quantum mechanics at its word. They've shown they can manipulate beams of atoms just like light waves, developing lenses to focus the atom beams, mirrors to reflect them, and even gratings to create atomic diffraction patterns. But the tool with the most promising applications—an atom interferometer—has proved maddeningly hard to perfect. Now, however, two groups of physicists working independently have taken a big step toward practical atom interferometry.

An atom interferometer works in the same way as its cousin, the optical interferometer: It splits a single beam, sends the resulting pair of beams along different paths, and then recombines them, creating an interference pattern. The interference pattern is extremely sensitive to conditions encountered by the two beams on their separate paths, such as slight variations in distance or differing magnetic fields.

Atom interferometers are potentially far more sensitive than optical interferometers. But one major hurdle has stood in the way of putting atom interferometers to work: It has been impossible to get the beams very far apart. Not only does this make it difficult to expose the two beams to different conditions, but the sensitivity of one application —an atomic gyroscope—depends directly on the area enclosed by the two beams. That's the challenge taken on by the two groups, one at the National Institute of Standards and Technology and the University of Colorado and the other at Harvard University.

William Phillips of NIST, a member of one of the two teams, explains the problem: Attempts to push two atom beams apart usually damage the coherence between them, blurring the interference pattern. Moving the atoms with lasers, for instance, tends to create random differences between the beams, since the laser push is due to the atoms absorbing photons and later spontaneously emitting them—a random process. "You must avoid any randomness anywhere," Phillips says. (Researchers using a slightly different technique have managed to split beams coherently and at large angles, but the technique isn't suitable for interferometry.)

The key to deflecting beams of atoms without upsetting their composure, the two groups report in the 14 February *Physical Review Letters*, was to work with "dark state" atoms—atoms in quantum states that will not absorb and reemit laser light that is itself in certain states. For example, if an atom with three available spin states (1, 0 and -1) is in the spin 1 state, it cannot absorb laser light that is circularly polarized so that all its photons have spin 1—absorbing a photon would give the atom a spin of 2, which is not possible. The result, in these experiments, was that the atoms "stole" momentum from photons without ever absorbing them. "It's really amazing that light can be used to transfer momentum like that," says atom optics pioneer David Pritchard of MIT.

Mara Prentiss of the Harvard team offers the following analogy to explain how the process worked. Imagine a system of three pendulums in a row, coupled with springs. The three pendulums represent three possible quantum states of the atoms that Prentiss' team worked with. The pendulum on the left corresponds to the spin 1 state of the atoms, the one on the right to a spin -1 state, and the one in the middle to the excited state through which the atoms would normally pass as they changed their spin state. The atoms in the beam remain dark as long as the excited state remains empty—or, in the analogy, the middle pendulum never moves. The key to the experiment, Prentiss says, is to move atoms from the spin 1 state to the spin -1 state without exciting the middle state.

The experiment begins with a beam of helium atoms, some in a spin 1 state and the rest in a different state that will be unaffected throughout the effort. In the analogy, the left pendulum is swinging freely, attached to an infinitely weak spring, while the right pendulum, attached to an infinitely strong spring, is not moving at all. Now, Prentiss says, gradually strengthen the left spring and simultaneously weaken the right one, so that the left pendulum slows down somewhat and the right one starts to move. Continue the process, and eventually all the motion will be on the right, with the left pendulum still—and the middle one will have never moved.

In practice, the force exerted by the springs is provided by two circularly polarized lasers that are pointed across the beam of helium atoms. After passing through the slowing changing field created by these two lasers, the spin 1 atoms have all changed to spin -1, without ever passing through the excited state. They remained dark.

But why should this change of spin state cause the atoms to move? Prentiss explains this by "a bookkeeping argument." Conservation of spin implies that for every atom that changed from spin 1 to spin -1, a photon in the laser light must have changed from spin -1 to spin 1. And the photon could only switch its spin if it also reversed its momentum, which implies—by conservation of momentum—that the atom must have changed its momentum in an equal but opposite way. That change of momentum is what deflects the atoms in the spin 1 state without any absorption or emission of photons.

In theory, Prentiss says, this procedure should allow large separations of coherent atomic beams. Although the initial demonstrations only gave the atoms the barest nudge, the process can be repeated over and over again, separating the two beams as much as desired without hurting their coherence.

–Robert Pool