the past few years, cosmic ray observatories such as the HiRes project in Utah have shown, to scientists' surprise, that cosmic rays with energies of 10^{20} eV and above do exist (*Science*, 19 May 2000, p. 1147), although how they form and where they come from remain a huge mystery.

"With the very existence of cosmic rays going out to 10^{20} eV, there have to be high-energy neutrinos out there, too. It's inescapable," says John Learned, an astroparticle physicist at the University of Hawaii, Manoa, and a pioneer in the field of ultrahigh-energy neutrinos.

Unfortunately, the current generation of neutrino detectors—Super-K, the Sudbury Neutrino Observatory, and other underground devices—are too small to see ultrahigh-energy neutrinos. To catch such rare particles interacting with matter, physicists need to watch an enormous patch of sky, ice, or water—the bigger, the better. That limitation gave Gratta an idea. The ocean, he mused, is plenty big—and the Navy already has listening posts in place. Gratta called the Office of Naval Research, the Naval Postgraduate School in Monterey, California, and other facilities in hopes of tapping into the flood of data coming in from those arrays. He eventually reached AUTEC personnel, and his team started listening for neutrinos.

"The AUTEC array has been in place for 30-odd years, working beautifully," says team member Mike Buckingham, an acoustician at Scripps. "It's quiet; it's fairly well shielded from shipping noise. You get natural sounds from surface processes, like breaking waves and bubbles, and biological sounds from marine mammals."

Right now, the team is calibrating the instrument and characterizing that background noise to figure out whether AUTEC is capable of picking up the sound of a passing neutrino. One technique involves dumping weighted light bulbs overboard and checking how the hydrophones pick up the pops when the bulbs implode, about 100 meters down. By calculating the energy and depth of the implosions, the team can measure the array's sensitivity. Such low-tech methods help make the AUTEC project a bargain, Gratta says. "It's extremely cheap. The budget for the last 2 years has been \$5000." A similar Russian project is under way off the coast of the Kamchatka Peninsula, Learned says.

Even as scientists exploit the military's underwater ears, they also are taking advantage of eavesdroppers in space. The Fast On-orbit Recording of Transient Events (FORTÉ) satellite was designed at the Los Alamos and Sandia national labs and launched in 1997 to help enforce a nuclear test ban. But for neutrino hunters, the ungainly looking spacecraft is a "wonderful, fortuitous thing," says Learned.

FORTÉ is an enormous antenna designed to pick up electromagnetic pulses, such as those created when a nuclear weapon detonates. It also picks up lightning strikes and other brief pulses of electromagnetic energy, such as those given off by a neutrino particle shower. Nikolai Lehtinen and Peter Gorham of the University of Hawaii, Manoa, got access to the data from September 1997 through December 1999, when the relevant antennae failed. "In the database there are around 4 million events, and we're looking at these events, trying to distinguish them from lightning," Lehtinen says. The team is focusing on electromagnetic waves issuing from the Greenland ice shelf. Limiting the search to signals from Earth's surface, Lehtinen explains, filters out air showers due to cosmic rays, which never survive long enough to hit the ground. Although it's too early to say for sure that Lehtinen has detected an ultrahigh-energy neutrino, there is a promising candidate event.

Even if AUTEC and FORTÉ never spot a neutrino, they have given physicists a head start in their search to detect ultrahigh-energy neutrinos. "It would cost millions and millions of dollars to build these things," Learned says. Even a null result will teach physicists about background noise that will affect future searches in the ocean or from high above Earth. And if they succeed, it will be an unexpected bonus from technologies designed to spot lumbering submarines and gigantic explosions rather than wispy particles.

–CHARLES SEIFE

FLORAL EVOLUTION

A Compromise On Floral Traits

Biologists are looking beyond pollinators to more subtle influences to learn how colorful, shapely flowers evolved

Late this summer, Candace Galen crouched in a Rocky Mountain meadow, watching bees dart from flower to flower. Most evolutionary ecologists would have admired this precise pollination dance—the close fit between bee and blossom. But Galen was waiting for a thief.

A nectar thief, to be exact. Galen, an ecologist at the University of Missouri, Columbia, studies the alpine skypilot (*Polemonium viscosum*), a purple perennial wildflower. Her research shows that pollinating bees are not the only ones pursuing the flower. Small, stealthy ants also devour the flower's nectar—and inflict a surprising amount of damage in the process. In fact, Galen suggests that both bee pollinator and ant predator might have inspired the skypilot's shape. "We know that flowers are compromise structures," Galen says. "And this is a good example."

Unpicky pollinators. Whether naturally shaped or experimentally altered, the flowers of a Mediterranean lavender were equally popular with pollinators.

CREDIT: CARLOS HERRERA

"Compromise," as Galen puts it, is fast becoming the new buzzword as researchers uncover the details of floral evolution. Many scientists have long explained flower fashions rather simply: From richly red bee balm to the cornflower's spiky crown, popular theory has gone, each flower has evolved the right color and shape to attract effective pollinators. The yucca plant, for instance, turns its flowers upward at dusk, to be pollinated exclusively by the yucca moth, which rolls up its heavy pollen like a snowball.

But today, a growing number of scientists are looking for more subtle evolutionary forces—from nectar thieves and herbivores to environmental demands and developmental changes—that might also sculpt floral traits. "We're taking a more pluralistic view," says evolutionary ecologist Sharon Strauss of the University of California, Davis. And they're raising some eyebrows in the process.

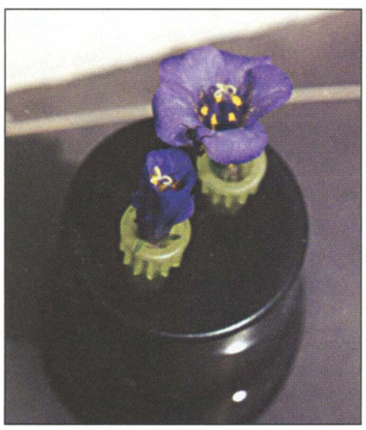
Some pollinators, according to the new work, might not deserve their starring evolutionary roles. Reporting last year in the *Journal of Evolutionary Biology*, Carlos Herrera of the

Estación Biológica de Doñana in Seville, Spain, questioned whether pollinators really shaped the flowers of a Mediterranean lavender, *Lavandula latifolia*. Like all species in the mint family, this lavender wears a two-lipped corolla, or double-layered whorl of flower petals.

If pollinators had driven the evolution of this floral shape, Herrera reasoned, they should strongly prefer it. So with fine scissors and a magnifying glass, he snipped away either the upper, or most of the lower, corolla lip in roughly 300 flowers, leaving an additional 300 as natural two-lipped controls, at a field site in southeastern Spain.

To his surprise, Herrera found that the pollinators weren't picky: They frequented the misshapen lavender flowers as often, and pollinated them as successfully, as the two-lipped variety. He concluded that today's bees, butterflies, and insects did not "selectively choose" the lavender's distinct floral style. Instead, Herrera argues, the entire mint family likely developed the two-lipped corolla long ago, before lavender met up with these modern pollinators. "There is an urgent need to critically reevaluate some mainstream ideas" about the all-importance of current pollinators in deciding floral traits, he says.

In other settings, researchers are paying closer attention to uninvited floral visitors. Galen has found that when looting ants crawl inside skypilot blossoms for nectar, they rip the flower's style out of the way, haul it upward, and heave it, like trash, past the flower's mouth. Afterward, the damaged flower cannot set seed. Reporting last year in *Evolution*, Galen demonstrated that ants favor flowers with easy access via a flared, short corolla. Alpine skypilot populations in ant-damaged areas, she predicts, will likely evolve a more narrow, tubular neck to welcome pollinating bees but deter ants. "Ants could have a significant impact on the evolution of the flower's shape," Galen says.



Shaped by thieves? Rocky Mountain field experiments find that nectar-thieving ants might play a part in shaping the alpine skypilot wildflower.

In addition to ants, flowers face a traveling mob of other predators, including slugs, aphids, thrips, and caterpillars. Researchers want to know how these actors affect floral design. In work to be published in the journal *Ecology*, Strauss and her colleagues have found that both pollinators and herbivores tend to prefer wild radish plants bearing yellow or white flowers rather than plants with pink or bronze blossoms. How do the selective pressures of pollinator and predator play out?

"We're not always good at identifying the important selective agents for a floral trait," Strauss says. "Pollinators seemed to be the obvious choice for a long time—and clearly, they are important. However, we're finding there are a lot of other forces we've been less likely to look at."

But traditionalists aren't prepared to surrender the pollinators' primacy. "One could do the odd study and show an effect from predators in one species," says Spencer Barrett, an evolutionary biologist at the University of Toronto. "But I'm not sure that one or even a few studies are going to overturn the intuitively reasonable hypothesis that flowers are so varied in shape and size because they have been modeled by natural selection by pollinators."

Douglas Schemske, an evolutionary biologist at Michigan State University in East Lansing, agrees. "We really don't have efficient means for measuring selection in all but the strongest cases," says Schemske. "If somebody says they didn't find evidence of pollinator selection, is it really missing, or, say, is their sample size not big enough?"

What's more, Schemske contends, even if a study fails to find pollinator selection for a floral trait today, that selection still could have happened in the past. That's a difficult argument to counter, notes Galen: "You could always say something happened in the past, and we just can't measure it."

But revisionists are acquiring the tools needed to probe historic influences as well. Reporting this summer in the *Journal of Evolutionary Biology*, W. Scott Armbruster of the Norwegian University of Science and Technology in Trondheim and the University of Alaska, Fairbanks, used comparative phylogenetics to see whether past pollinators—or unrelated developmental changes—were more likely to have inspired diverse flower colors in a vine, *Dalechampia*, and in maple trees.

Dalechampia is a tender vine prized for its colorful floral bracts, or petal-like leaves. Armbruster retraced the evolutionary origins of four color types in various *Dalechampia* species, along with the emergence of the vine's major pollinators. In this study, widely praised as innovative, Armbruster didn't find a tight evolutionary link between pollinators and color.

A colorful moment. A new phylogenetic study suggests that *Dalechampia* evolved new colors as a biochemical defense, not to lure pollinators.

Instead, he concluded that new *Dalechampia* bract colors emerged at the same time that the plants acquired the purple-red pigment anthocyanin in unrelated vegetative organs, probably as a biochemical defense against harmful radiation, drought, herbivores, or pathogens. In other words, the bract colors likely evolved simply as a byproduct of the protective vegetative pigments—not in response to the pressure of major pollinators, which remained unchanged at that time in the historical record.

"I'm interested in evolution via natural selection as much as the next person," says Armbruster. "But my feeling is that we have to work our way through a series of simpler explanations before we invoke adaptation for every floral trait." No one knows, he adds, just how often such developmental or genetic events, versus pollinator selection, have pushed flowers to evolve a given design. "Maybe this happens rarely, or maybe it happens often," Armbruster says. "We don't have enough data to know the balance of the processes."

But he hopes that will change. As more scientists bring sophisticated tools and questions to the study of floral evolution, Armbruster adds, the field will better reflect reality. "A plant is out there experiencing all these forces simultaneously," he says. "It's only biologists who look at them one at a time."

–KATHRYN BROWN

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