puzzle," says Fall. "Why would plants waste all this energy?"

For University of Wisconsin plant physiologist Tom Sharkey, a compelling clue was the observation in field and greenhouse studies that isoprene emissions from plants are extremely sensitive to temperature: "Every time you get an increase in temperature, you get an increase in isoprene." So he and graduate student Eric Singsaas set up a system to find out whether isoprene helps plants take the heat.

To control a plant's exposure to isoprene, Sharkey and Singsaas had to prevent it from synthesizing any on its own. They did so by placing leaves of a potted kudzu plant—ordinarily a prolific isoprene emitter—inside a miniature climate-controlled chamber with an atmosphere free of carbon dioxide. Without carbon dioxide, the leaf couldn't photosynthesize, so its isoprene production was shut down. Next, the researchers raised its temperature while either adding isoprene or leaving it isoprene-free. The result: The chlorophyll of isoprene-exposed leaves stayed intact well beyond the point at which leaf chlorophyll without isoprene gave out—about 37°C, or the temperature of a scorching summer day.

The physiologists haven't worked out a mechanism, but they suspect that isoprene, which is fat soluble, might dissolve in the lipid membranes surrounding the chlorophyll molecule—the light-absorbing site in photosynthesis—and somehow serve as a glue to keep the whole thing from melting down when temperatures get above biological optimum. But because isoprene, a five-carbon chain, is so light, it quickly evaporates, prompting the plant to keep churning it out as the temperature climbs.

MARCEL ISY-SCHWART / IMAGE BANK

Hazy summer day. Plants emissions soften the view of the Blue Mountains in Australia.

The thermal protection theory might explain not only why isoprene emissions are highest on hot days but also why some plants emit more than others, Sharkey says. Isoprene production, he thinks, generally comes into play in plant species that are subject to short bursts of high temperatures. That may be why desert plants like the creosote bush don't seem to emit isoprene—presumably they have come up with other, more economical means for coping with constant high temperatures.

Colorado's Fall sees "some shortcomings" in that picture. "One of the main things that it doesn't explain is why plants in the same genera would include emitters and nonemitters" even when they experience the same temperature regimen, he says. Most oaks, for example, are on the high end of isoprene emission, but a few, such as cork oak, emit little or no isoprene, even at high temperatures. But he adds, "I think it's an interesting idea."

EPA's Geron agrees. "To me the thermal protection idea makes the most sense," he says. He thinks air-quality models may have to be modified to account for the greater flux of isoprene from heat-stressed plants; at the moment, the models assume all plants emit at a steady rate. A more biologically based model would actually show episodic increases in ozone, says Geron.

Already, the realization that natural sources of hydrocarbons can swamp any human contributions has spurred the National Oceanic and Atmospheric Administration (NOAA) and other agencies to rethink ozone-control strategies for rural areas and heavily wooded urban areas like Atlanta. Because plant hydrocarbons can't be controlled, researchers have been urging a shift in the focus of control efforts from hydrocarbons to nitrogen oxides, the other key ingredient of low-level ozone. EPA, NOAA, and industry and academic researchers have also drummed up a new 10-year research plan, the North American Research Strategy on Tropospheric Ozone, that puts high priority on determining how much natural sources contribute to ozone formation.

There should be plenty to learn, says Sharkey. For one thing, atmospheric chemists aren't sure of all the ingredients in the plant hazes; many others are not as easy to measure as isoprene but may contribute to ozone formation as well. Fall and his co-workers, for example, have recently devised a way to measure one such compound, methanol. Their preliminary analysis, in press in *Plant Physiology*, indicates that methanol, although less reactive than isoprene, may be emitted in quantities as large. "We're only beginning to learn about all the organic compounds plants are putting into the atmosphere," says Fall. And that means that the haze surrounding these questions is likely to persist, at least for a while.

–Christine Mlot

Christine Mlot lives near Blue Mounds, Wisconsin.

DARK MATTER

EROS, MACHO, And OGLE Net A Haul of Data

Explorers like Columbus and Vespucci went looking for gold and spices; instead, they found a couple of continents. Astronomers who search the heavens for the mysterious stuff called dark matter are having a similar experience: They haven't yet found much of what they set out to look for, but they are turning up all sorts of surprises that "are turning out to be as important as the dark matter" itself, says Alain Milsztajn of the Saclay Institute in France, a member of one of the search teams, called Expérience de Recherches d'Objets Sombres (EROS).

Those surprises include new insights into the structure of the Milky Way's central bulge, vastly improved catalogs of variable stars, and a completely fresh approach to searching for planetary systems. And they could open up the cosmic equivalent of whole new continents to researchers who may care nothing about dark matter.

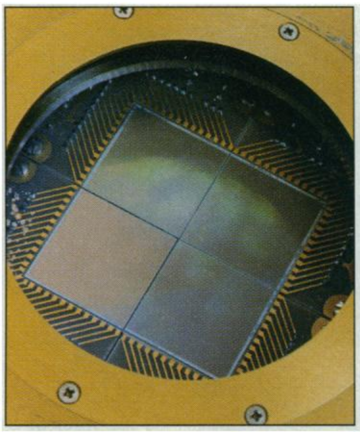
These extra benefits flow from "an absolutely new approach" to looking at the sky, according to Andrzej Udalski at Warsaw University Observatory and a member of another of the teams, the Optical Gravitational Lensing Experiment (OGLE). The new approach owes its existence to Princeton University's Bohdan Paczyński, who in 1986 came up with an idea initially considered "science fiction," Paczyński says.

Paczyński's science fiction was a novel way to observe dark matter. Observations of spiral galaxies such as the Milky Way had demonstrated that their outer stars revolve so rapidly that they would fly off into space if the gravity of some unseen—"dark"—matter were not holding them in place. Predicted by some theories to make up perhaps 90% of all matter in the universe, dark matter could take the form of roughly Jupiter-size chunks of ordinary matter that swarm in halos around galaxies like our own. Paczyński's bold proposal was that a phenomenon called gravitational lensing might be used to detect these mysterious objects.

Astronomers already knew that gravity bends starlight, causing objects between us and distant stars to act as lenses. Paczyński, who leads the OGLE group, pointed out that this effect should occasionally magnify the brightness of stars when dark objects in the Milky Way's halo pass in front of them. But he also knew it was wishful thinking to expect that these rare lensing events could be detected among the confusion of variable stars and difficult observations in dense star fields.

Technical achievements soon turned Paczyński's fiction into reality, however. One of the most impressive advances came out of a three-laboratory collaboration called the MACHO team, for Massive Compact Halo Object, which developed an exquisitely sensitive charge-coupled device camera and mounted it on a telescope at the Mount Stromlo Observatory in Australia in 1992. The MACHO, OGLE, and EROS teams soon began searching the skies.

So far, says Kem Cook of Lawrence Livermore National Laboratory, a member of the MACHO collaboration, "we haven't found a lot of matter between here and the Large Magellanic Cloud," a galaxy near our own. Only a handful of lensing events have been observed that could be from objects in the Milky Way's halo passing in front of the LMC's stars, says Cook. This paucity of events suggests that, if standard models of our galaxy are correct, no more than 30% of the dark matter in the halo of the Milky Way consists of compact objects. Researchers caution that it will take several more years of data to pin down this result.



LAWRENCE LIVERMORE NATIONAL LABORATORY

Sharp eye. Sensitive charge-coupled device sees rare lensing events.

But the meager catch of dark matter has been more than offset by a huge haul of other cosmological oddities brought up by the net that was intended to catch MACHOs. The teams' detectors record every flicker and twitch of variable stars, eclipsing binary stars, and lensing events unrelated to dark matter in the fields of view, producing "enormous quantities of astronomical spin-off," says Virginia Trimble, a physicist and astronomer at the University of California, Irvine.

The most straightforward spin-off is a growing catalog of objects such as Cepheid variables, whose absolute brightness is directly related to the period of their oscillation. This means that by observing the period, astronomers can translate their apparent brightness at Earth, which falls off in inverse proportion to the square of the separation, into a yardstick of distances to these stars. MACHO alone has found thousands of new Cepheids and RR Lyrae stars—fainter, smaller, and older variables that give an independent check of the yardstick and whose pulsation patterns evolve with the star and serve as age markers for cosmological structures older than about 10 billion years. The RR Lyrae phase of evolution is "the last hurrah" for many stars, says Mario Mateo of the University of Michigan, a collaborator in the OGLE team, which, like EROS, is making its own study of variables.

The RR Lyrae catalog has already yielded intriguing clues about the evolution of the Milky Way, says Alex Rodgers of Mount Stromlo. According to conventional wisdom, our galaxy's disk, bulge, and halo all formed together. But Rodgers and others have turned up several distinct populations of RR Lyrae stars in the halo, with different ages, while MACHO has shown that similar stars in the LMC are younger and all of nearly the same age. Rodgers thinks this means that the halo has grown by sucking in stars and other matter from satellite galaxies like the LMC after the disk and bulge were already there.

Beyond these known classes of variables, MACHO has caught at least one new beastie in its net: blue bumpers, stars up to 10,000 times as bright as the sun that intermittently brighten by about 20%, then dim again, says Livermore's Cook. "People have made a stab at trying to understand" the bumpers, says Cook, but they remain essentially unexplained.

OGLE has produced some surprises of a different kind. It began by taking a more "conservative" approach than MACHO or EROS, says Paczyński—or so he thought. Instead of aiming to bag dark matter in the halo right away, his team first tested its techniques by training its telescope on the galactic bulge, "where we *knew* there must be ... lensing events due to ordinary stars," explains Paczyński. Dim, invisible stars in the foreground of the bulge should lens brighter stars in the background.

The conservative approach turned up about three times the expected number of lensing events. The result has since been confirmed by MACHO. The explanation, Paczynski believes, is that his team failed to take into account the likelihood that the bulge is shaped not like a spheroid but like a watermelon with one of the ends pointed nearly toward us, enhancing a background star's chances of being lensed by something in front of it. If this explanation is correct, the Milky Way should technically be called a "barred spiral" galaxy.

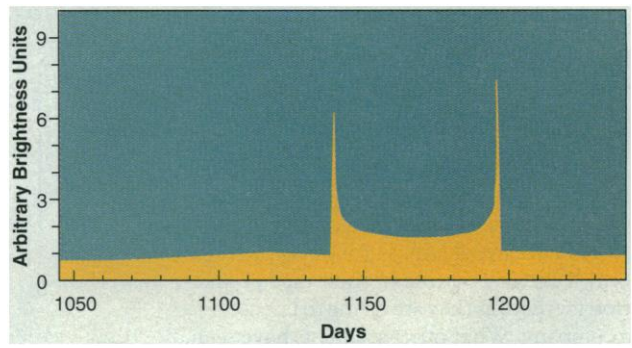
"People have suspected the existence of the bar for 10 years" based on optical and infrared asymmetries in the bulge, says Mateo. But as the number of lensing events increases from the 13 captured so far, says Mateo, they should be able to sketch, for the first time, a picture of the bar's finer details, such as the precise angle it makes with our line of sight.

What could be the biggest sensation from the OGLE detectors came during these same scans of the bulge. Instead of a simple bump, one star's light curve drew out a shape resembling the silhouette of the top of a cat's head (see graph). The shape and 60-day duration of "OGLE #7" was later confirmed by MACHO, which happened to have the same star in its field of view. And a variation of the curve turned up in a separate event captured by a second French team, called DUO for Disk Unseen Objects.

OGLE #7 presents "a very strong case for binary lensing" caused by light passing through binary stars or planetary systems, says Shude Mao of the Harvard-Smithsonian Center for Astrophysics. Mao thinks such events, if they keep turning up, could be used as counters for binary stars near the galactic center or as a novel way to search for planetary systems. The shape could reveal the mass ratio of the system's components, says Mao, if sampled finely enough in time. This measurement would require an "early-warning system" to pinpoint a possible binary event-in-progress and allow researchers to find narrow spikes—representing possible planets—only hours or days wide. Such a system has already been set up among several of the groups, although there have so far been no new binary nibbles on the line. Nevertheless, says Warsaw University's Udalski, "I believe detection of planets is just a matter of time."

If the paucity of lensing events in the halo holds up, however, the most important spin-off of these searches could be another voyage of discovery: an intensification of the search for more exotic forms of dark matter, such as hypothesized particles that whiz almost undetected through space and interact only via gravity. But those searching for compact halo objects aren't ready to return to port yet. They understand that you never know what might lie over the next horizon.

–James Glanz



SOURCE: MACHO/LAWRENCE LIVERMORE NATIONAL LABORATORY

Double hit. This profile, first spotted by OGLE and confirmed by MACHO, may be caused by lensing by a binary system.

James Glanz is a science writer in Chicago