the secretion apparatus: Mutant *Yersinia* that lack YopN secrete other Yops constantly and in all directions, while normal bacteria secrete Yops only when triggered to do so by contact with eukaryotic cells, says Wolf-Watz. It's as if YopN is a valve that is turned on only by that direct cell-to-cell contact.

Data from other bacteria known to have the type III genes sketch the same functional picture. Last fall Wolf-Watz's group reported that when the *yopE* gene was put into *Salmonella*, the *Salmonella* made the YopE protein and deposited it into eukaryotic cells. "That says *Salmonella* has everything necessary to do the translocation," says Wolf-Watz. And Galán's group has preliminary evidence that a *Salmonella* virulence protein called SptP is also delivered into the host cell cytoplasm. *Shigella* also uses the type III system to deliver the virulence protein IpaA into host cells, according to Philippe Sansonetti of the Pasteur Institute.

Evidence reported last week says that plant pathogens do it too: At the ASM meeting, Cornell University plant pathologist Alan Collmer reported new results from his group and that of Sheng Yang He at Michigan State University. They found that the plant pathogen *Pseudomonas syringae* apparently uses the type III system to introduce a protein called AvrB into plant cells; that protein determines the plant's response to the pathogen. So from a flurry of studies a pattern has emerged: Like a missile with many kinds of warheads, different bacteria rely on the same delivery system to inject different proteins into their hosts.

Multiple warheads

Just how this system delivers its payload remains an unsolved mystery. Given the similarity of the type III proteins to those that assemble flagella, it's tempting to hypothesize that they form a flagellumlike structure that shoots proteins into the host cells. Indeed, Galán's group has electron micrographs showing such appendages all over the outside of *Salmonella* as they infect eukaryotic cells. But the role these appendages play in infection is still unclear. And Galán cautions against viewing the system as an automatic injector, for some virulence proteins secreted by the type III system may act on the outside of cells instead of entering them. "We cannot say the sole purpose of this system is to inject proteins into the cell," he says. "We know it can do that, but it is not necessarily the only thing it does."

One way or another, the system disables the host or makes it more hospitable to the bacterium. *Yersinia* deploys the Yops to keep from being eaten by macrophages, but *Salmonella* and *Shigella* use their type III–secreted proteins for a nearly opposite purpose: to induce non–immune cells to take the bacteria into their cytoplasm. That gives the bacteria a safe haven, "a privileged site where they won't be killed by the immune system," says microbiologist Samuel Miller of the University of Washington. The enteropathogenic *E. coli* have yet another goal: to cozy up as tightly as possible to cells of the intestinal epithelium. To this end, their virulence proteins alter the microfilaments inside intestinal cells, producing a bulge in the cell surface that serves as a pedestal to which the bacteria can bind tightly.

The biochemistry used to accomplish these diverse tasks is eerily unbacterial in nature. For example, YopH is a tyrosine phosphatase that apparently removes phosphate from signaling proteins inside macrophages, thus disrupting the signals that cause the macrophages to scarf up bacteria. But where would a bacterium get a gene for an enzyme that removes phosphate from tyrosine? That function is typical of eukaryotes, not bacteria, says Straley. And YopH is not alone. At least two other *Yersinia* virulence proteins are eukaryotic-type kinases—enzymes that add phosphate to proteins—and Miller's and Galán's labs recently found evidence for a tyrosine phosphatase in a *Salmonella* protein. "This is a common theme of virulence determinants, that they target biochemistry that is uniquely eukaryotic," says Straley. And that, she says, has led some people to speculate that these genes were stolen at some time in the past from eukaryotic cells.

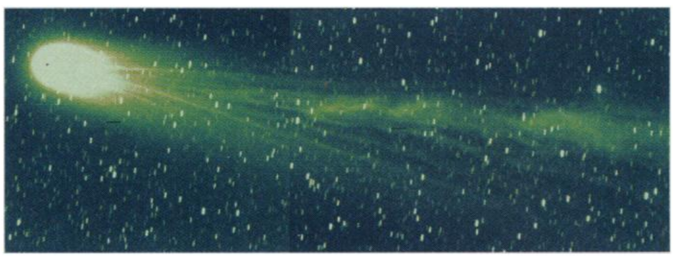
While researchers puzzle over the origins of the system, they continue to search for the type III system in other bacteria. So far, 10 or so bacterial species are known to have type III systems, but the story certainly won't end there. Harvard's Mekalanos says his lab is using polymerase chain reaction techniques to search systematically for the package of secretion genes in other gram-negative pathogens such as *Vibrio cholerae*. Other groups are looking for ways to use their knowledge of the system to disarm bacteria, perhaps by causing them to "prematurely ejaculate" their virulence proteins before they deliver them to their target cells, says Sansonetti. Researchers are also searching for host proteins targeted by the virulence molecules, to learn more about the cellular processes that the bacteria have chosen to sabotage.

The search is on for a practical use for the new knowledge, but biologists are also marveling at the fact that such diverse bacteria have put this common machinery to use for their own individual ends. It's a fascinating habit of biological systems, says Mekalanos, "that once a problem is solved, it will be used over and over again for different purposes." And even if those purposes are the nefarious ones of disease-causing bacteria, one has to admire nature's ingenuity nevertheless.

–**Marcia Barinaga**

COMET CHEMISTRY

Hyakutake Produces Another Surprise



H. MIKUZ / CRNI VRH OBSERVATORY

Unexpected element. Analysis of comet Hyakutake reveals ethane.

When comet Hyakutake sped past Earth last March, it did more than put on a breathtaking light show. It also delivered a series of scientific surprises, beginning with the first x-rays ever detected from a comet (*Science*, 12 April, p. 194). Now, as a paper in this issue reports, the surprises are continuing with a revelation about Hyakutake's composition that is hard to reconcile with standard explanations of how comets originated.

In this case, "surprise is more than a mild understatement—it was serendipity," says Michael DiSanti, an astronomer at Catholic University of America in Washington, D.C. On page 1310, DiSanti and his colleagues report that Hyakutake contains abundant ethane and methane, compounds never before confirmed in comets. The ethane was a shock because astronomers had assumed it wasn't present in the primordial cloud of material that gave rise to the solar system. The new findings "really require us to rethink entirely our ideas about how comets formed," says Michael Mumma of the Goddard Space Flight Center in Greenbelt, Maryland, who led the collaboration.

Analyzing the composition of comets is a challenge, because they are small and cool, emitting most of their radiation in the infrared region of the spectrum, which is largely blocked by Earth's atmosphere. But Mumma and his colleagues thought Hyakutake's close approach—to within 10% of the Earth-sun distance at one point—might give them a better look at comet composition. Using an infrared spectrometer at NASA's Infrared Telescope Facility atop Mauna Kea, Hawaii, they set out to find methane, which Mumma describes as "one of the Holy Grail species that astronomers have been trying to find." Because methane is abundant in interstellar space, researchers had expected it would be abundant in the early solar system, and hence in comets.

So far, astronomers haven't been able to detect anything more than hints of the compound in comets. But Mumma and his team, using a more sensitive instrument, had two advantages: Hyakutake's brightness and its rapid motion relative to Earth, which Doppler-shifted its methane lines away from the signature of methane in Earth's atmosphere, making them possible to detect. The team first detected methane on 23 March and calculated that it makes up about 1% of the comet's ice.

The team then searched for methanol, which earlier observers had been able to detect in comets because it is so abundant, amounting to about 5% of their ice. But the methanol lines that appeared in Hyakutake were weak, implying that it contains about a tenth as much methanol as other comets. When the researchers adjusted their equipment to search for stronger methanol lines, however, they were shocked to see bright emission lines from an unknown gas. "This was really astonishing," Mumma says. "It was obvious that we had a major discovery on our hands." Extensive database searching and more tests finally proved the gas to be ethane. More important, the ethane level in Hyakutake was nearly 1%, close to that of methane.

This unusual chemistry poses a direct challenge to existing ideas about comet formation in the early solar system. According to one long-standing theory, comets formed from unaltered interstellar ice grains. But Hyakutake can't have originated that way, because methanol is found at higher levels in interstellar space and ethane is unlikely to be made under the same conditions. At the same time, it also challenges another theory, which holds that the early sun first vaporized interstellar ice, which later condensed onto grains that became comets. The chemical reactions expected to take place during the gaseous phase of this process would have left the comets with 1000 times more methane than ethane.

One possibility, say Mumma and his colleagues, is that the primordial cloud of gas, dust, and ice that collapsed to form the solar system had regions cold enough to prevent methanol formation, yet convert acetylene to ethane. Ethane-rich comets would then preserve ice grains from specific regions of the primordial cloud. But for this chemical diversity to have been preserved in comets, the cloud would have had to collapse without being mixed and homogenized.

Instead, Mumma and his colleagues favor what he calls the processed interstellar ice model, in which the chemical diversity formed later, after the primordial cloud collapsed to form the solar system. Ultraviolet radiation from the early sun, they say, could have driven low-temperature chemical reactions in the ice grains, breaking the bonds in methane and turning it into ethane, while destroying methanol at the same time. Hydrogen atoms freed in the first step would then have converted the acetylene to ethane.

"I think [that picture] is entirely reasonable," says Yvonne Pendleton, an astrophysicist at Ames Research Center in Moffett Field, California. "What we needed was a good comet to come along so we could verify it." The theory implies that comets with high ethane levels, like Hyakutake, originated closer to the early sun, perhaps in the Jupiter-Saturn zone. Comets with more methanol, like most of the others analyzed so far, may have originated farther out, near the present positions of Uranus and Neptune, where the ice grains would have been exposed to less radiation and retained more of their original, interstellar composition.

Later, the gravity of the newborn planets would have hurled the comets like pebbles from a slingshot into the far reaches of the solar system, where they now reside. But if Mumma and his colleagues are right, they contain a scrambled record of the chemical diversity within the primordial solar system. Future cometary visitors may add new pages to that record.

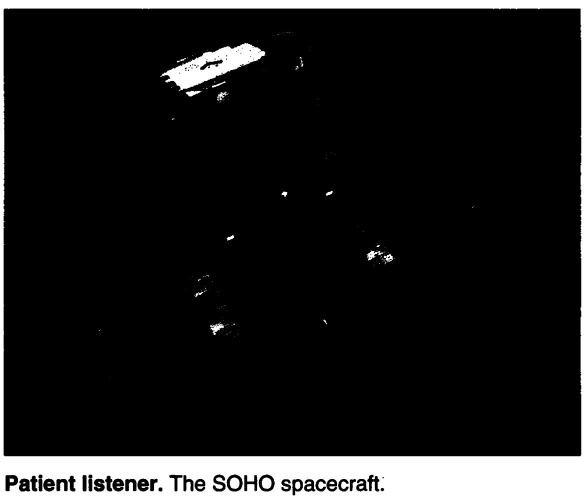
–Kim Peterson

SOLAR PHYSICS

SOHO Probes Sun's Interior By Tuning In to Its Vibrations

To eavesdrop on the sun, it's best to find a very, very quiet perch. SOHO, the solar observatory launched by the European Space Agency (ESA) last December, has just that: a listening post 1.5 million kilometers sunward of Earth, well away from the turbulence of the atmosphere, where it can tune in to the sun 24 hours a day. SOHO carries experiments studying everything from the sun's corona and magnetic field to the solar wind (*Science*, 10 May, p. 813). But three of the spacecraft's 11 instrument packages are devoted to listening: detecting the sun's vibrations, which hold clues to its structure, from the turbulent surface layers all the way down to the nuclear furnace at its heart.

Solar physicists are already hard at work applying this strategy, called helioseismology, from the ground, through a global network of telescopes called GONG (see Articles, this issue). But while ground-based observations are cheaper and more flexible, solar physicists say the only way to pick up the sun's subtlest notes is to go into space. "The community recognized 20 years ago that we needed a vantage from space in order to do helioseismology correctly. We also needed the ground-based network [GONG], and now we are in the fortunate position of having both," says GONG scientist Jack Harvey of the National Solar Observatory (NSO) in Tucson, Arizona. They are already finding out just how fortunate. At last week's American Geophysical Union spring meeting in Baltimore, SOHO researchers reported results from the satellite's first 4 months, including records of known oscillations that far surpass the clarity of ground-based measurements and new insights into the churning of the sun's outer layers.


ESA

Patient listener. The SOHO spacecraft.

SOHO, like ground-based telescopes, can only "listen" to the sun's vibrations indirectly: by monitoring their effects on the sun's surface. By watching for fine-scale undulations, for example, one of SOHO's three helioseismology experiments, the Solar Oscillations Investigation (SOI), is detecting the sun's equivalent of seismic waves, which hold clues to small-scale structures just beneath the sun's surface.

SOI monitors the solar surface by sending sunlight through a filter that transmits only a very narrow wavelength range, centered on an absorption line of nickel, an element found on the visible surface of the sun. The light then falls on a charge-coupled device (CCD), a very sensitive electronic detector, that has 1 million pixels, 700,000 of them occupied by the solar image. If the gases