MEETING AMERICAN ASTRONOMICAL SOCIETY

New Focus on Cool Planets and Hot Gas in Atlanta

ATLANTA—About 1700 members of the American Astronomical Society preceded the Super Bowl here last month for their 195th national meeting. Astronomers scored big with news about ubiquitous black holes and results from the Chandra X-ray Observatory (*Science*, 21 January, p. 411), but sessions on the Keck Observatory, planetary disks, and our galaxy's shroud of hot gas also drew notice.

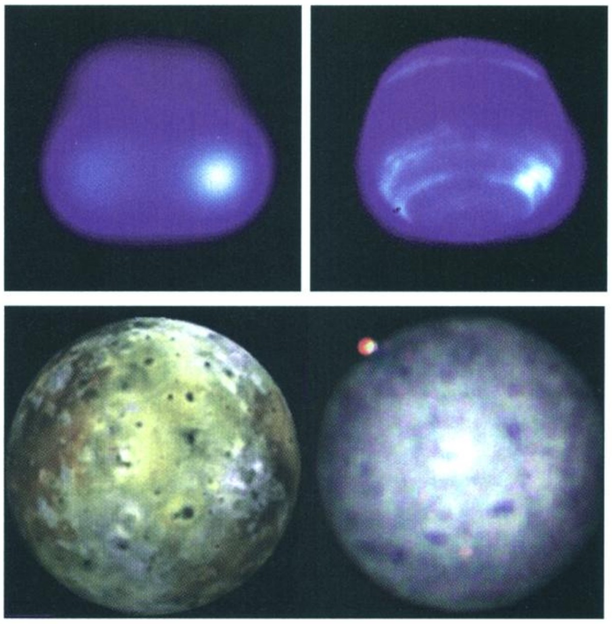
Sharp New Eyes for Keck II

With their monstrous 10-meter mirrors, the twin Keck I and II Telescopes at Mauna Kea, Hawaii, already have a competitive edge over other observatories on the ground. That edge has now become sharper, thanks to technical wizardry that lets Keck II see through Earth's atmosphere with startling clarity.

The wizardry is adaptive optics (AO), in which a thin mirror deforms rapidly to counteract the blurring effects of the continual sloshing of air above the telescope (*Science*, 19 November 1999, p. 1504). Astronomers have had good success with these complex systems at several telescopes, notably the 3.6-meter Canada-France-Hawaii Telescope atop Mauna Kea and the European Southern Observatory's 3.6-meter telescope at La Silla, Chile. Among the 8- to 10-meter Goliaths now dotting mountaintops, however, Keck is the first to use AO for scientific observations. "Keck's way out in front," says astronomer Matt Mountain, director of the Gemini Observatory and its two 8.1-meter telescopes in Hawaii and Chile. "We think their results are spectacular."

Several speakers showed before-and-after images from Keck II to a captivated audience at the meeting. (An identical system will go online at Keck I by June.) Astronomer Claire Max of the Lawrence Livermore National Laboratory in Livermore, California, prompted the biggest collective exhales with her infrared images of various objects in the solar system, including Neptune and Titan, Saturn's largest moon. Bright spots in Neptune's atmosphere, previously seen from the ground merely as blobs, resolved into a large stormy patch and windy streaks that closely resemble those seen by Voyager 2 in 1989. A succession of such images will expose changes over time, Max says, perhaps unveiling the forces that drive the fierce weather patterns in Neptune's atmosphere.

As for enigmatic Titan, Keck II now can penetrate the moon's thick layer of haze to see its surface within a narrow band of unabsorbed infrared light. The images reveal prominent dark blotches, which Max believes may represent "seas" of ethane and other hydrocarbons predicted to rain out from Titan's methane-rich atmosphere. A new instrument at Keck II, the Near Infrared Spectrometer, will enable Max and her colleagues to take spectra of these features and nail down their compositions more firmly.



Sharper image. Weather patterns in Neptune's atmosphere transform from indistinct blobs *(upper left)* to sharp storms and streaks (in false color, upper right) with a new adaptive-optics system on the Keck II Telescope in Hawaii. A Keck image of the volcanic moon Io *(lower right)* reveals an active eruption in false color near the edge, as well as the same surface features seen by the Galileo spacecraft in orbit around Jupiter *(lower left)*.

CREDITS: W. M. KECK OBSERVATORY/ADAPTIVE OPTICS TEAM AND NASA/JPL/GALILEO SSI TEAM (IO)

Keck engineer Scott Acton also displayed a dramatic image of Jupiter's moon Io. The AO team happened to observe Io on 26 November—soon after the Galileo spacecraft saw what may have been a "lava fountain" spewing from the moon's tortured surface (*Science*, 24 December 1999, p. 2436). The nearly edge-on view of the plume, combined with a similar view that night from NASA's Infrared Telescope Facility on Mauna Kea, should help planetary scientists narrow their estimates of its height and temperature.

Keck II's new capabilities promise insights beyond the solar system as well. For example, astronomer Andrea Ghez of the University of California, Los Angeles, is using the system to track the rapid motions of stars near the suspected black hole at the center of the Milky Way galaxy. The unblurred view lets Ghez see twice as many stars in far less time—single exposures that last 90 seconds rather than many rapid snapshots that add up to 30 minutes or more. "It's helping us tremendously," Ghez observes. Her team has begun to see the curvatures of the stars' orbits around the black hole, which should lead to much better estimates of its mass. Ghez also hopes that by monitoring the galactic center with AO for several years, she'll see evidence of gravitational lensing as the black hole distorts and amplifies the light from stars that pass behind it.

The $7.4 million system does have limitations. Like most other AO efforts today, it works only for infrared light. The shorter wavelengths of optical light would require far more tiny pistons to flex the mirror than the 349 already in place at Keck II—technically feasible, perhaps, but hugely expensive. Further, the camera that senses the atmospheric distortions needs a lot of light. Astronomers must therefore look at bright objects or other objects next to a bright star, confining them to just a few percent of the sky. That will change by the end of the year when Keck engineers and Livermore laser specialists complete a "laser guide star" system, in which a tiny spot of laser light high in the atmosphere will enable astronomers to point the telescope nearly anywhere they choose. Other major observatories, such as Gemini, also will use the laser guide star approach for their AO systems.

Keck II's early progress is a promising preview of such future efforts, says astronomer John Mather, project scientist for the Next Generation Space Telescope at NASA's Goddard Space Flight Center in Greenbelt, Maryland. "Some of these images made my heart jump and my stomach leap," Mather says. "I'm delighted to see adaptive optics working at last."

The FUSE of the Galaxy's Gas Circuit

Superheated gas from legions of exploding stars envelops our Milky Way, according to the first results from a new NASA satellite. The findings appear to resolve a decades-long debate over one of the most fundamental processes in cosmic evolution: How do the galaxy's new stars inherit gas from their long-dead ancestors?

The debate has simmered since 1956, when the late Princeton University astrophysicist Lyman Spitzer proposed that hot gas wraps the galaxy in a tenuous but energetic cocoon. Only a hot, invisible gas, he reasoned, would exert enough pressure to hold together the interstellar gas clouds that astronomers had spotted in the galaxy's ethereal halo, high above the flattened plane of the Milky Way.

By the mid-1970s, astronomers believed the halo gas arose from one of two possible sources. Some proposed "galactic fountains" of hot gas spewing upward from pockets of many supernovas. Others favored a cooler gas shroud arising from a lower energy process: ionization of atoms by ultraviolet radiation from newborn stars. Until recently, however, nobody could get a clear view of the gas itself, so decisive evidence was lacking. Moreover, not all astronomers were convinced that the gas billowed as far from the Milky Way's plane as Spitzer thought.

The new clues come from the Far Ultraviolet Spectroscopic Explorer, or FUSE. Launched in June 1999, FUSE stares at the light from distant bright objects, such as quasars. As this light arrows toward Earth, it pierces clouds of gas along the way. Atoms and molecules within the clouds absorb light at specific energies, leaving telltale dark imprints on the quasar's spectrum. The key ion that FUSE detected is oxygen VI, which can exist only at temperatures between 200,000° and 1,000,000°C. Previous ultraviolet satellites had seen oxygen VI within the Milky Way's disk, but they lacked the sensitivity to detect it at great distances in the halo.

Now, says astronomer Blair Savage of the University of Wisconsin, Madison, "we see evidence for hot gas in nearly every direction we look"—17 hits along 18 different lines of sight so far. The gas extends about 5000 to 10,000 light-years above the Milky Way's disk, Savage reports. (By comparison, the galaxy is about 100,000 light-years across.) The gas is patchy and remarkably thin: up to 10,000 times less dense than typical interstellar gas abundances of one atom per cubic centimeter.

Oxygen VI ions are signposts of violent astrophysical collisions, which strip away five of the eight electrons in each atom. The concussive deaths of giant stars in supernovas produce the only blast waves strong enough to forge oxygen VI en masse, says astronomer Kenneth Sembach of The Johns Hopkins University in Baltimore, Maryland. As Sembach and his colleagues envision it, dozens of supernovas working together blow bubbles of hot gas. Pressure builds until the bubbles, hemmed in by resistant gas and dust in the galaxy's plane, blast away from the disk along the path of least resistance. "It's like a balloon that bursts at its weak spot," Sembach says.

FUSE thus has unveiled part of the long-suspected cycling of gas through the Milky Way, says astrophysicist J. Michael Shull of the University of Colorado, Boulder. After the galactic fountain streams upward, the gas cools and falls back onto the galaxy millions of years later to seed more generations of stars and planets. Each year, that cycle may process about 20 times as much gas as our sun contains, even though only one or two supernovas pop off in the Milky Way each century. Says Shull, "I think we've settled the debate: Supernovas drive an incredibly efficient engine of gas."

A Close Encounter at Beta Pictoris?

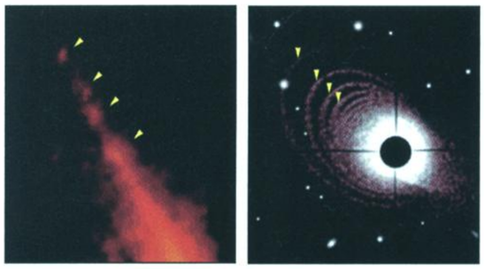
The bright star Beta Pictoris is a perplexing sight. Sixty-three light-years from Earth, it floats in space wreathed in a huge veil of debris that astronomers view edge-on. Left to its own devices, the dusty disk should swirl symmetrically, like the saucers of UFO fame. Instead, it's longer and thinner on one side and warped near the middle, prompting some astronomers to claim that at least one giant planet must be plowing through the disk and knocking it off kilter (*Science*, 16 January 1998, p. 322). Now, a newly discovered chain of clumps in part of the disk suggests—at least according to one interpretation—that a different force may have struck: the gravitational pull of a passing star.

The clumps surfaced during a comparison of a decade's worth of images from several observatories. A team led by astronomer Paul Kalas of the Space Telescope Science Institute in Baltimore, Maryland, digitally subtracted a smooth, ideal dust disk from the images. In each case, the astronomers saw seven otherwise hidden clumps along the long and thin side of the disk, but none on the shorter and fatter side. "This could be the cross section of an asymmetric ring system on a huge scale, many times the size of our solar system," Kalas says.

Kalas suspected that a star drifted past the disk recently and swept some of the dust into looping, elliptical orbits in its wake. To test his hypothesis, he called upon theorist John Larwood of Queen Mary and Westfield College in London to devise a computer simulation of the havoc that such an encounter would wreak. If a small star approached from below the disk and flew close to its edge, Larwood found, the star's gravity would fling dust particles into lopsided bands lasting about a million years before they merge back into the disk. Seen from the side, such bands would group into clumps like those in the telescope images of Beta Pictoris. A stellar flyby also would explain why the disk is so much larger than any other circumstellar shroud yet seen, Kalas adds: The interloper would have stretched the dust about twice as far into space as it ordinarily orbits.

Colleagues find Kalas's scenario intriguing but unlikely. "Stars are so widely separated that those interactions are very rare unless you're in a cluster, which Beta Pic is not," says astronomer Ben Zuckerman of the University of California, Los Angeles. A statistical calculation pins the chances of a random close encounter within the last million years at about 1 in 10,000, Kalas acknowledges. Undeterred, his team is scouring for the culprit in data from Hipparcos, a European satellite that charted the relative motions of thousands of stars. Several stars probably have wandered within a few light-years of Beta Pictoris, but the team has not yet spotted one that zipped by close enough to roil the disk so dramatically.

Further, the innermost and densest parts of the disk—where Hubble sees the most pronounced warping—probably could not be perturbed by a passing star, says astronomer Sally Heap of NASA's Goddard Space Flight Center in Greenbelt, Maryland. She maintains that a planetary or brown dwarf companion is "by far the simplest explanation" of the tilt at the disk's heart.



Star tracks. Subtle clumps of dust seen in this Hubble Space Telescope image of the disk around Beta Pictoris *(left)* resemble an edge-on view of gravitational disturbances triggered by a passing star in a simulation *(right)*.

CREDITS: NASA AND PAUL KALAS/SPACE TELESCOPE SCIENCE INSTITUTE

Even if Kalas and his colleagues can't prove their case, Zuckerman notes, spotting the string of clumps is a coup. "If it's really possible to resolve structures on such a small scale, it bodes well for future studies of planet-disk interactions," he says. Soon, astronomers may interpret blobs and bands within dusty disks as certain imprints of newly formed worlds. –ROBERT IRION