Unveiling the Hidden Universe

Infrared observatory clears up dusty tales

By RON COWEN

Pérault et al./ESA

Blue patches in this infrared image of the region near the center of the Milky Way represent dark, dense clouds that may become star-forming regions similar to those in Orion. Red indicates the highest intensity, blue the lowest. The image was taken at a wavelength of 15 micrometers.

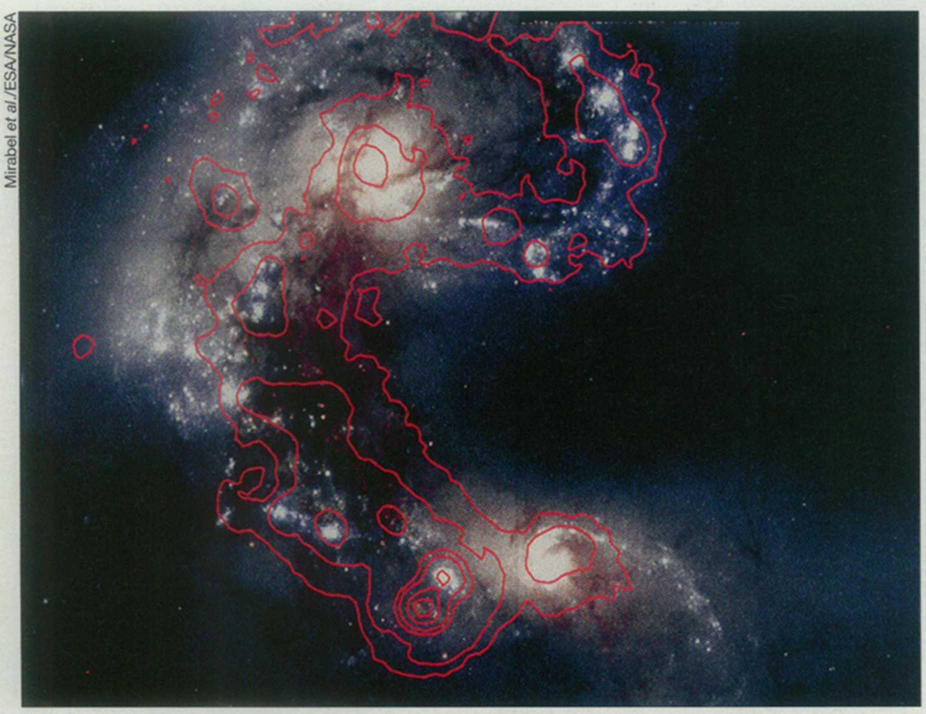
Peek in any apartment window, it's said, and you'll discover a unique story.

The same is true of the heavens, except that skywatchers face a special challenge. The windows through which they view the cosmos are often clouded by dust. An observer peering through a telescope in visible or ultraviolet light misses much of the drama in the universe, from a stellar nursery teeming with newborns to the fireworks generated by the collision of two galaxies.

Infrared telescopes can penetrate this dust, revealing much more of the story. They can also record emissions from heavenly bodies too cool to radiate light at shorter wavelengths and higher energies.

For 28 months, the European Space Agency's Infrared Space Observatory (ISO) has scanned the heavens from its vantage point in Earth's orbit. The mission, which ended in early April, generated remarkable new views of several familiar objects. It also examined the composition of these bodies by analyzing the intensity of light at wavelengths from 3 to 240 micrometers. Such a feat isn't possible with ground-based telescopes, which are hampered by water vapor and other molecules in Earth's atmosphere that both emit and absorb infrared light.

ISO scientists presented a roundup of the observatory's discoveries last month at a press briefing in London. Some of the most intriguing finds came relatively late in the mission, when the observatory examined a region of Orion, the nearest birthplace of massive stars.



Mirabel et al./ESA/NASA

In this overlay on a visible-light image of the colliding Antennae galaxies, red contours indicate regions in which infrared emissions are concentrated. These emissions, hidden in visible light, account for about 15 percent of the light radiated by the galaxies.

In visible light, Orion's well-known Horsehead nebula looks like a dark dust cloud. Viewed with a camera aboard the observatory, however, the Horsehead silhouette vanishes and young stars shine through. Areas rich in dust appear as bright filaments.

The space observatory paints a portrait of two other star-forming clouds within Orion, NGC 2068 and NGC 2071. In the infrared, clutches of young stars dot the landscape. ISO also detected the bright glow of polycyclic aromatic hydrocarbons in these nebula. These organic compounds have been found in the Martian meteorite ALH 84001 and in other interstellar clouds. Astronomers have suggested that these chemicals could provide some of the raw materials of life.

While observing the intensity of the stars at several infrared wavelengths,

Visible-light (left) and infrared images of the Horsehead nebula, part of the Orion star-forming region. In the infrared, the dark horse's head vanishes and a star shines through what had been its forehead (arrow).

Lennart Nordh and Göran Olofsson of Stockholm University and their colleagues identified groups of stellar objects so young that they are still lying inside placentas of gas and dust. As many as 20 percent of these objects have insufficient mass to qualify as bona fide, hydrogen-burning stars, says Gerry Gilmore of the University of Cambridge in England. With less than 8 percent of the mass of the sun, these cool, infrared-emitting objects will become brown dwarfs, fizzling out after they exhaust their supply of deuterium.

The space observatory uncovered other new features of Orion. The long-wavelength spectrometer revealed that a cloud near the sword of Orion contains a massive concentration of water vapor—enough to fill Earth's oceans 10 million times.

By volume, that's about 1 part in 2,000, or roughly 20 times the concentration detected in other gas clouds in the Milky Way. Nonetheless, "an enhanced concentration of water is precisely what we expected in this gas cloud," notes ISO astronomer Gary J. Melnick of the Harvard-Smithsonian Center for Astrophysics in Cambridge, Mass.

Astronomers had theorized that water vapor is abundant in stellar nurseries like Orion. Water provides a means of cooling such regions—and a cloud of gas and dust must cool in order to contract and form stars.

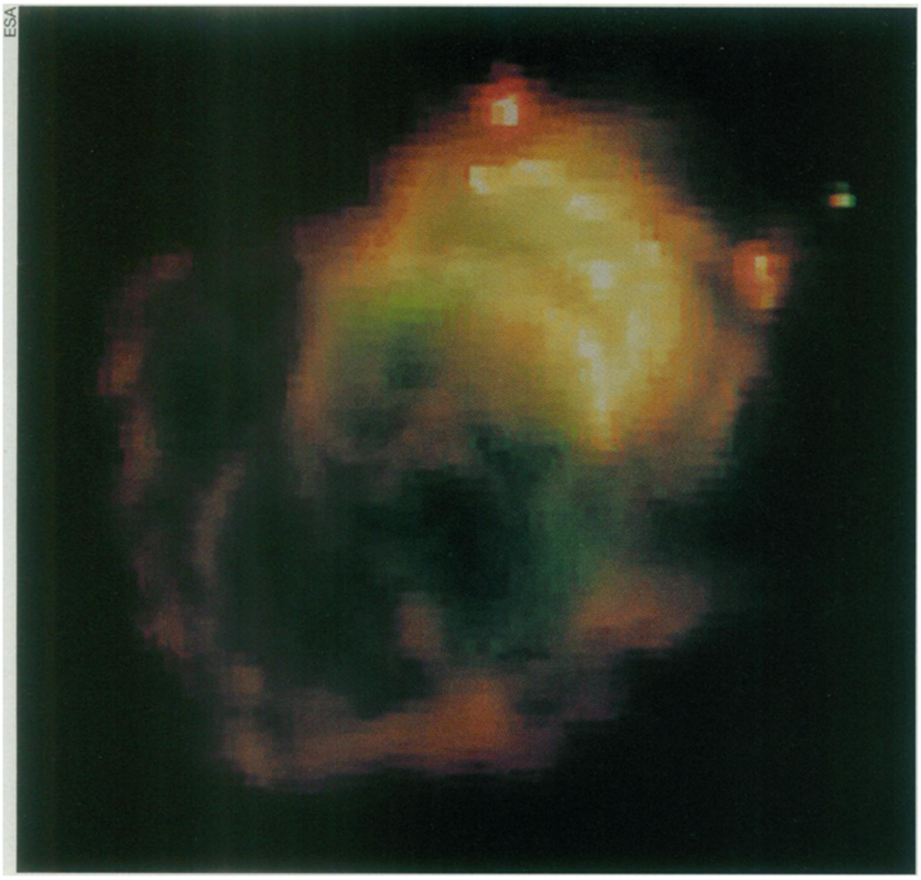
In Orion, as in other star-forming regions, winds from hot, young stars send out shock waves into the surrounding gas, notes Melnick. At temperatures above a few hundred kelvins, molecular hydrogen, which is abundant in the clouds, radiates most of the heat away. Below those temperatures, however, molecular hydrogen can no longer cool the region. At this point, water vapor radiates the surplus heat, allowing the cloud to grow denser and contract.

"It's in the critical region where the gas has partially cooled itself but is still too hot to collapse that the water vapor cooling becomes very significant," says Martin Harwit, an ISO researcher and former director of the National Air and Space Museum in Washington, D.C.

The vapor itself is generated by the shock waves, says Melnick. The waves cause unbound oxygen atoms to team up with molecular hydrogen and form water vapor. A similar process may have generated water in the solar system.

Harwit, Melnick, and their colleagues describe their study in the April 20 Astrophysical Journal Letters. Melnick notes that NASA's Submillimeter Wave Astronomical Satellite, now scheduled for launch in January 1999, will continue the studies of water vapor in Orion and search other parts of the Milky Way.

Near the Milky Way's dusty core, the space observatory examined several cold, dark clouds that seem to resemble Orion in its earliest stages of formation. The patches appear to



Orion cloud in which ISO detected an abundance of water vapor.

have "just condensed out of the interstellar medium," says Gilmore. "They're just in the throes of condensing into star-forming units, but they haven't [yet] got stars to warm them up. So unlike the Horsehead nebula, these things are still black."

Their very existence in the inner region of the galaxy, where they are buffeted by stellar winds and ultraviolet light, "is a great puzzle," Gilmore adds. Michel Pérault of the National Center for Space Studies in Paris suggests that the density of the clouds, which is greater than that of the clouds in Orion, may offer protection. Ultraviolet radiation from neighboring stars may evaporate the outer layers of these clouds, leaving the cores intact, he speculates. The cores may even be able to snare additional material.

"It's likely that [these clouds] could become an Orion and may even get brighter than Orion," says Pérault. "If these things are on the verge of starting to collapse, it wouldn't take much more than a million years until you get the [formation of] young, bright stars."

Follow-up observations with IRAM, a 30-meter radio telescope in Pico Veleta, Spain, attest to the chilliness and high density of the clouds, he notes. A second infrared spacecraft, the U.S. Air Force's Midcourse Space Experiment, has also confirmed the cold, dark nature of these compact objects. M.P. Egan of the Air Force Research Laboratory in Bedford, Mass., and his colleagues described the study in the Feb. 20 ASTROPHYSICAL JOURNAL LETTERS.

Mark R. Morris of the University of California, Los Angeles says that the evolution of the clouds will depend on their exact location in the galaxy. At the core of the galaxy, intense magnetic fields are common, he notes. They thread through gas clouds and act as springs, which may prevent the clouds from collapsing immediately and forming stars. In addition, differences in gravitational forces across the clouds are amplified at the core. Such stresses could also prevent collapse. In that case, only a particularly energetic shock could get star formation going.

The space observatory's findings on the Antennae, two galaxies that smashed into each other about a million years earlier, reveal that their "most massive stars are completely hidden in the widely publicized images" taken in visible light by the Hubble Space Telescope, says I. Félix Mirabel of the Centre d'Études de Saclay in Gif-sur-Yvette, France.

Fifteen to 20 percent of the luminosity of these galaxies originated from a tiny region—roughly 150 light-years across—that looks dark in visible light. Its intense glow in infrared light comes from massive newborn stars "that have not yet cleared out all the dust and gas around them," says Mirabel. "The placenta clouds are still there."

The findings, he says, have implications on a truly cosmic scale.

Astronomers estimate the history of star formation in the universe by studying distant galaxies in visible light. If visible-light images fail to capture a substantial amount of star formation in relatively nearby galaxies like the Antennae, they are likely to miss even more in a distant galaxy, he asserts.

That's because the expansion of the universe lengthens, or reddens, light from distant galaxies. Ultraviolet light emitted by a faraway galaxy is shifted to visible light by the time it reaches Earth. Thus, a distant galaxy viewed in visible light reveals what the galaxy looked like billions of years earlier in the ultraviolet. Since dust obscures ultraviolet light even more effectively than it does visible wavelengths, a visible-light image can scarcely reveal the true nature of a faraway galaxy, Mirabel says.

"We are missing the grand design of galaxies," he says. He and his colleagues describe their findings in the May 1 ASTRONOMY AND ASTROPHYSICS.

ISO depended on a tank of liquid helium to maintain its temperature at a frigid 2 kelvins—cold enough to reduce sharply the infrared emissions from the satellite's telescope and prevent it from interfering with observations. Engineers expected the helium to run out 18 months after ISO was launched.

During those months, the position of the observatory did not allow it to view Orion without running the risk of letting light from such bright sources as the sun or Earth enter its aperture and boil off precious helium. Fortunately, the helium lasted an additional 10 months. During that time, ISO's orbit moved the observatory into a location from which it could view Orion safely. This confluence of circumstances enabled ISO to examine Orion for several weeks in October 1997 and March 1998.

ISO's temperature began to climb on April 8, and the craft took its last set of observations about a month later. Now, researchers are looking ahead to 2001, when two new infrared observatories, devoted entirely to astronomical studies, are scheduled to begin operation.

Featuring a 2.5-meter telescope nearly five times the size of ISO's, the Stratospheric Observatory for Infrared Astronomy is housed permanently in an airplane that will cruise 45,000 feet above Earth. At this altitude, the flying telescope can avoid 99 percent of water vapor's emissions and absorptions, which can interfere with observations.

Scheduled for launch the same year, the Space Infrared Telescope Facility will orbit Earth well above the atmosphere, providing astronomers with an even cleaner window through which to view the heavens. □