ASTRONOMY

Extreme Ultraviolet Satellites Open New View of the Sky

BERKELEY, CALIFORNIA—Each time astronomers open a new window on the cosmos, a stream of surprises pours in. Radio telescopes found pulsars and noisy "radio galaxies"; infrared detectors probed clouds of cool dust and gas where stars are born; orbiting gamma ray telescopes detected gamma ray bursts. Now astronomers have yet another window in the electromagnetic spectrum: satellites that can detect and analyze extreme ultraviolet (EUV) radiation.

True to form, this new look at the cosmos has brought fresh mysteries along with tantalizing clues to old ones, as a colloquium on extreme ultraviolet astrophysics held here on 27 to 30 March made clear. "Even I was amazed at the richness of the results," says University of California, Berkeley, astronomer Stuart Bowyer. Bowyer, director of Berkeley's Center for Extreme Ultraviolet Astronomy (CEA) and the prime mover behind the National Aeronautics and Space Administration's Extreme Ultraviolet Explorer (EUVE) satellite, is hardly an impartial judge. But many of Bowyer's colleagues are echoing his enthusiasm. "The time of synthesis is not yet on us," says Donald Cox of the University of Wisconsin, "but the data coming in right now are what I've been waiting for the last 20 years."

Violet eye. The EUVE satellite.

Among the riches revealed by EUVE and ROSAT—a European–U.S. x-ray satellite sensitive to the short-wavelength end of the EUV band—are a galaxy-spanning halo of hot gas containing the mass of a trillion suns and a nearby star that is strangely brilliant at EUV wavelengths. The EUV band is also giving astronomers their clearest views of such objects as the gauzy atmospheres of young stars, the surfaces of hot white dwarfs, and the turbulent hearts of so-called "active" galaxies. These objects, with temperatures of tens of thousands to a few hundred thousand degrees, emit most of their radiation at EUV wavelengths, which extend from 75 to 100 angstroms up to 1000 angstroms.

EUV radiation from a distant source can also probe cooler interstellar gas along the line of sight, because atoms in the gas absorb certain EUV wavelengths, marking the spectrum with telltale absorption lines. Indeed, as EUV astronomers developed their instruments in the 1980s, some researchers predicted that interstellar absorption might spoil their view. Even the modest amount of gas that permeates the Milky Way, they predicted, would be enough to block the view beyond a few light-years, limiting the "EUV universe" to the few dozen closest stars.

But observations made soon after the launches of ROSAT in 1990 and EUVE in 1992 showed that the interstellar medium is surprisingly porous in the ultraviolet part of the spectrum, riddled with regions where unusually low density or a high level of ionization open a long view. Toward the constellation Canis Major, for example, the view extends for hundreds of light-years.

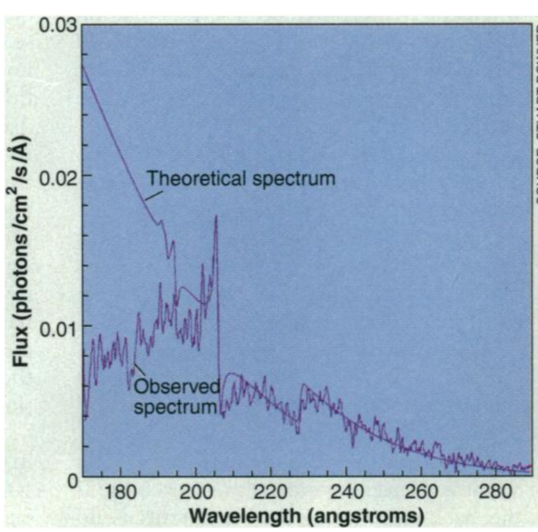
At the colloquium, John Vallerga and Barry Welsh of Eureka Scientific Inc. in Berkeley said they had identified one cause of that void. EUVE data, they reported, show that the hot young star Adara, 600 light-years away in the western hind foot of Canis Major, pours out seven times more EUV radiation at wavelengths greater than 450 angstroms than all other nearby stars combined. Adara's prodigious EUV output, which mystifies theorists, carves out a highly ionized region that stretches from the star almost to our solar system. Even so, the ionizing flux wouldn't be enough to clear the line of sight if the interstellar gas toward Adara weren't unusually tenuous as well. "It's a region of bizarre emptiness," says Cox.

That void and other, smaller gaps in the nearby interstellar medium have revealed surprises including white dwarfs with unexpectedly varied surface compositions. Because of the enormous force of gravity at the surfaces of white dwarfs, millions of times the force on Earth, most theorists expected the stars' EUV spectra to reveal nothing but hydrogen and a bit of helium; heavier nuclei should have been dragged into their interiors. But Stephane Vennes of the CEA and Michael Barstow of the University of Leicester, U.K., working independently, found the spectral signatures of iron and other heavy elements in EUVE data from the hottest white dwarfs, with surface temperatures of more than 40,000 K. The explanation, they say, lies in a process Vennes had predicted earlier, called "radiative levitation." Because the heavy elements in a white dwarf still retain some electrons, unlike the hydrogen and helium, the torrent of radiation from the star can buoy them up. As Bowyer puts it: "The electrons catch the photons like an umbrella catches the wind."

Perpendicular to the plane of the galaxy, where the interstellar medium thins out, voids in the gas open an even longer view. Through those openings, EUV astronomers peer millions or billions of light-years beyond our galaxy to a few of the most luminous EUV sources: the galaxylike powerhouses known as quasars and active galactic nuclei (AGNs).

There they have spotted what may be a clue to an old mystery: the nature of the subclass of AGNs known as BL Lac objects. Like other AGNs, BL Lacs are thought to be powered by a supermassive black hole, surrounded by a donut-shaped accretion disk and two high-speed jets shooting out from above and below the donut. The spectra of most AGNs reveal absorption and emission lines, thought to come from ionized material near and in the accretion disk. By measuring how much those spectral features are shifted toward the red end of the spectrum by the expansion of the universe, astronomers can estimate the distance of an AGN and hence its intrinsic brightness.

BL Lacs, however, have featureless spectra at visible wavelengths, perhaps because they are oriented so that our line of sight aims straight down one jet, whose tremendous velocities smear spectral features beyond recognition. As a result, astronomers haven't been able to estimate the distances of these



Showing its metal. Absorption by iron, unexpected at the surface of a white dwarf, causes the star's spectrum to dip at wavelengths below about 200 angstroms.

objects. The uncertainty has allowed some theorists to suggest that BL Lacs are not AGNs at all but a subset of quasars, which are far brighter and more distant. At the Berkeley conference, however, Arieh Königl of the University of Chicago reported finding an absorption line in EUVE data on the BL Lac object PKS 2155-304. He and his colleagues think that ions of magnesium, iron, and neon in clouds floating near the jet are absorbing radiation to produce the feature.

Its redshift, Königl and his colleagues say, implies a distance of "only" 1.5 billion light-years for PKS 2155-304, laying to rest the possibility that the object is actually a much more distant quasar. Says Bowyer, "EUV is telling us things about AGNs that you couldn't see in any other wavelength band."

It is doing the same for less exotic galaxies. Training EUVE's detectors on the elliptical galaxy M87, Richard Lieu of the CEA and his colleagues in Germany, the United Kingdom, and the United States saw a trillion-solar-mass halo of gas at up to a million degrees, enveloping the entire visible galaxy. X-ray observations of M87 had revealed an even more massive cloud at still higher temperatures, so the new EUVE data imply that two gas halos somehow coexist in the same space. Because million-degree gas has a wealth of emission lines that cool it efficiently, Lieu speculates that the EUV halo survives only because it is continuously replenished by supernova explosions that drive "stellar winds" of hot gas out of the galaxy.

But the discoveries, and the puzzles they bring, are only just beginning. By comparing EUVE and ROSAT data, for example, Jürgen Schmitt of the CEA and the Max Planck Institute for Extraterrestrial Physics in Garching has found scores of sources detected by one satellite but not the other. Because the probes made their surveys at different times, the explanation for at least some of the sources may be that they dim and brighten—but what they are, and why they should vary, no one knows.

All of which leaves EUV astronomers anxious to keep looking out their new window. A Japanese Mars probe scheduled for launch in 1998 should help keep that window open. Stripped of every nonessential gram, the craft will carry only one astronomical instrument to profit from the clear view of the stars available from interplanetary space: a miniature EUV detector.

–Donald Goldsmith

Donald Goldsmith is an astronomy writer in Berkeley. His next book, Einstein's Greatest Blunder? The Cosmological Constant and Other Fudge Factors in the Physics of the Universe, *will be published in August by Harvard University Press.*

ASTRONOMY

Found: Ash From the First Stars?

For most of us, an occasional hike in Colorado or Maine satisfies the hankering to see nature in its pristine form. For astronomers, though, the search for primordial nature means a much longer journey.

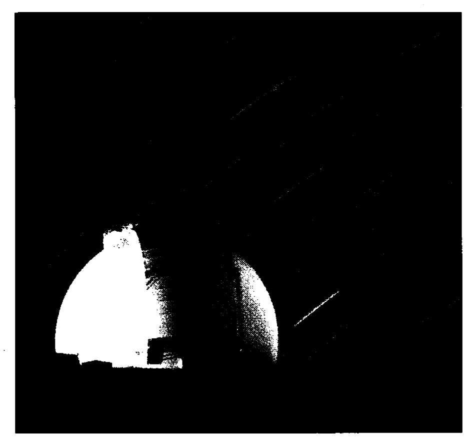
To see what the cosmos looked like before the first stars began to alter the pristine hydrogen and helium made in the big bang, observers peer billions of light-years away from Earth and billions of years back in time, to the vast clouds of hydrogen known as Lyman-α forest clouds because of the thicket of dark lines in their spectra. These clouds, thought to be the precursors of galaxies, have seemed free of the heavy elements that are the product of stellar burning. But now, like a hiker who finds a candy wrapper in a remote forest, astronomers are realizing that Lyman-α clouds may not be as pristine as they had thought.

Scrutinizing distant hydrogen clouds with the 10-meter Keck Telescope at Mauna Kea, Hawaii, the world's largest, groups from the University of Hawaii and the University of California, San Diego (UCSD), have shown that the clouds are "clearly contaminated with the products of stars," says Michael Shull, a researcher at the Joint Institute for Laboratory Astrophysics (JILA) of the University of Colorado, Boulder. The discovery of these products—atoms of carbon, an element that can only be made in stars—is as surprising as "getting to a Pacific island and finding elephants," says Jeremiah Ostriker of Princeton University. It may call for major revisions in the standard view of the early universe, in which the first stars winked on during the process of galaxy formation. At the same time, says Ostriker, an unseen first generation of stars could help clear up long-standing mysteries such as how present-day galaxies grew so large and how gas in the early universe became ionized.

Astronomers can study these clouds, which lie roughly 10 billion light-years away, only with the help of even more distant and enigmatic objects that shine with the intensity of hundreds of billions of suns: quasars. By lighting up the clouds from behind, the quasars serve as convenient probes. Most of the quasars' light streams unimpeded through the clouds, but a sprinkle of neutral, or un-ionized, hydrogen in the clouds absorbs photons at characteristic wavelengths, the most prominent being the Lyman-α line. When a quasar's light is collected in a telescope and sorted in a spectrograph according to wavelength, a forest of Lyman-α lines reveals clouds wafting between Earth and the quasar.

The spectra of rarer, denser clouds thought to be associated with young galaxies do show traces of carbon and other heavy elements. But in the more tenuous clouds scattered across the sky, "heroic efforts" have failed to reveal anything but isotopes of hydrogen, says Steven Vogt of the Lick Observatory at the University of California, Santa Cruz. Most researchers, he says, have concluded that these clouds consist of "primordial stuff left over from the big bang," just beginning to coalesce into the structures seen today. The clouds, in this view, collapsed to form small groups of stars, which then merged to make galaxies.

But Keck may now have muddied this picture. Keck combines its light-gathering ability with the world's largest and most sensitive spectrograph, designed by Vogt. The result was enough observing power for teams led by Lennox Cowie and Antoinette Songaila at the University of Hawaii and David Tytler and Xiao-Ming Fan at UCSD to detect not just hydrogen but also faint carbon lines in about half of the clouds they studied. (The results were announced by the Hawaii group in this month's *Astronomical Journal* and by the UCSD researchers at a recent workshop.) To Cowie, the finding implies that the clouds are "a pool of stuff that has been ejected from previous stars," which came and went so long ago that not even their embers can be seen.


RUSS UNDERWOOD

Where there's smoke ... The 10-meter Keck Telescope saw carbon in distant gas clouds.

By placing the birth and death of the earliest generation of stars before the development of galaxies, the results may call for a revision of standard cosmology. But, by creating one puzzle, they would also solve another: how the intergalactic medium in the early universe became ionized—as it must have been, or else it would absorb so much light that it would blot out our view of quasars.

Some researchers have suggested that the quasars themselves, or the turbulence gener-