Exploring the Extreme Ultraviolet

A NASA satellite probes the local bubble

By RON COWEN

Early next month, if all goes as planned, a Delta II rocket will launch a quartet of telescopes into space. This observatory, known as the Extreme Ultraviolet Explorer (EUVE), will probe nearby stars and interstellar gas from a vantage point 328 miles above Earth's surface.

But unlike other space-borne observatories, which have detected light emissions from distant X-ray, infrared and near-ultraviolet sources, this group of telescopes will have little chance of examining even the outskirts of our own galaxy — let alone objects at the edge of the observable universe.

It's not that this suite of telescopes lacks the light-gathering capabilities of other, farther-seeing instruments. It's just that this observatory is designed to detect a type of radiation, rich in information about stellar evolution, that occupies a highly elusive part of the electromagnetic spectrum: the extreme ultraviolet. Such radiation can't penetrate the patchy, tenuous fog of hydrogen atoms that fills much of the space between stars and absorbs extreme-ultraviolet light.

"God made this region of the electromagnetic spectrum to frustrate us," says Barry Y. Welsh of the University of California, Berkeley.

"It's an irritating region of the spectrum," agrees EUVE project scientist Robert V. Stachnik at NASA headquarters in Washington, D.C.

Yet such energetic radiation, sandwiched between X-rays and the longer-wavelength ultraviolet, can illuminate a largely unseen world of astrophysical processes and sources, Stachnik says. Such emissions can betray the presence of dense stellar remnants called white dwarfs; probe the lower atmosphere of hot young stars that rapidly burn their nuclear fuel; examine the environs of older, cooler stars that heat their outer atmospheres to temperatures of 100,000 kelvins or more; and study binary stars.

The EUVE can't detect very distant sources that glow in the extreme ultraviolet. But because of the nature of the interstellar medium near the sun, it *can* detect such radiation from Milky Way objects that lie within 300 light-years of Earth, or about one four-hundredth the radius of our galaxy, adds Stachnik.

That's because the sun resides in a warm, relatively gas-free region of the Milky Way — a huge, hot hole in space. A supernova explosion may have blown out gas from this location, thus creating the hole, or bubble, about 100,000 years ago, researchers speculate. The warm environment ionizes the few hydrogen atoms remaining there, preventing them from absorbing extreme-ultraviolet light and lifting the roadblock that stops the radiation from reaching Earth's vicinity.

By conducting an all-sky survey of nearby objects that emit extreme-ultraviolet light, EUVE will in effect map the shape and extent of the bubble. Since stars that lie beyond the bubble can be detected only dimly, if at all, the number and intensity of objects emitting extreme-ultraviolet light should reveal the contours of this local hole in the interstellar gas.

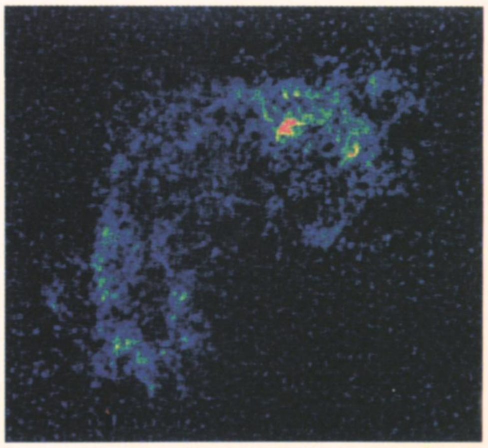
Recent evidence suggests that the Milky Way may contain a honeycomb of such hot bubbles surrounded by cold, denser regions where hydrogen atoms are abundant and extreme-ultraviolet radiation cannot pass through. Such a structure may offer a tantalizing loophole for the EUVE, notes Welsh. For if tunnel-like regions that contain just a few gas clouds connect the solar bubble with other giant cavities deeper in the Milky Way, then along certain directions the observatory may see farther toward the center of our galaxy. Similarly, if tunnels link the solar bubble with cavities that lie nearer the outskirts of the Milky Way, the observatory may sometimes have a clear view of quasars and other energetic objects many millions of light-years beyond our galaxy.

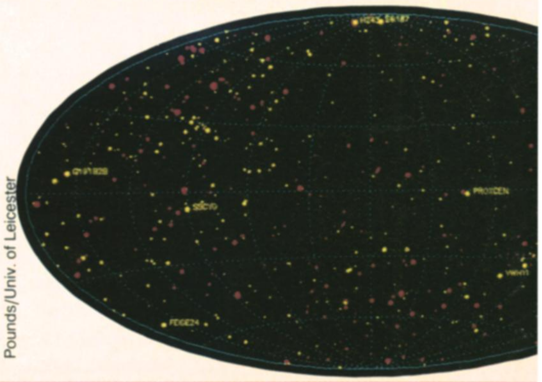
ROSAT eyes the extreme-ultraviolet

Since the research satellite ROSAT began surveying the heavens in July 1990, its ultraviolet telescope, known as the Wide-Field Camera, has spotted some 1,000 sources of extreme-ultraviolet radiation. Researchers are now focusing on 385 of the brightest of these sources, which will serve as guideposts for the EUVE mission, reports ROSAT investigator Kenneth A. Pounds of the University of Leicester in England.

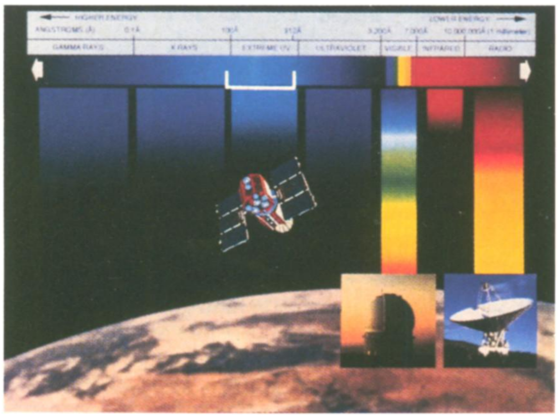
The camera, he notes, has revealed several surprises about white dwarfs, the dense remnants of stars up to a few times the mass of the sun. Though the instrument has detected more than 100 white dwarfs in the extreme ultraviolet, it has found only 15 — half as many as expected — with surface temperatures greater than 20,000 kelvins. Moreover, the hottest dwarfs imaged by the camera appear surprisingly faint.

Puzzling over the data, theorists now speculate that the energetic radiation from a hot dwarf thrusts into the star's lower atmosphere atoms of carbon, nitrogen and oxygen that normally reside below the visible surface of the star. The raised atoms act as a screen, preventing little, if any, of the dwarf's extreme-ultraviolet radiation from reaching ROSAT. Hydrogen and helium make up the bulk of a white dwarf's lower atmosphere, while carbon and heavier atoms contribute less than one ten-thousandth of its mass. Nonetheless, the findings suggest that these heavier atoms may dim or completely mask the light of a hot dwarf, Pounds



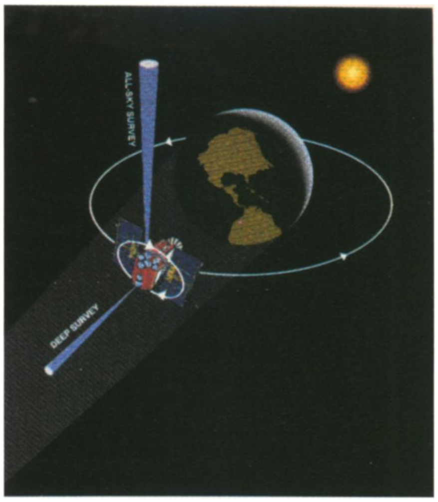


Pounds/Univ. of Leicester



Images: NASA

Left: Only radio waves and visible light fully penetrate Earth's atmosphere. Other wavelengths, including the extreme ultraviolet (bracketed region), can be studied only from space.



Above: Initially, three of the EUVE telescopes will map sources throughout the sky while a deep-survey instrument will point along Earth's shadow.

As recently as 20 years ago, astronomers had little interest in a mission to observe the extreme ultraviolet. Ground-based radio observations had indicated that hydrogen and other extreme-ultraviolet-absorbing gases were distributed uniformly throughout the interstellar medium. (Shorter-wavelength radiation, such as X-rays, and longer-wavelength ultraviolet and visible light would pass through these atoms virtually unimpeded.) Thus, astronomers reasoned, radiation in the extreme ultraviolet could not be seen from sources more than a few light-years from the sun.

"It wasn't clear you could see anything outside our own solar system," recalls Stachnik. Indeed, he notes, researchers dubbed this region of the electromagnetic spectrum "the unobservable ultraviolet."

That thinking began to change when the Copernicus satellite, launched in 1972, revealed that the interstellar medium consisted of a patchwork of cold (hydrogen-rich) and warm, ionized (hydrogen-poor) regions. And in 1975, a telescope aboard the Apollo-Soyuz mission detected five sources glowing in the extreme ultraviolet, including a white dwarf in the constellation Coma Berenices. Those findings, says Stachnik, "opened the window on the extreme ultraviolet," proving that the local interstellar medium had a density of hydrogen atoms low enough to permit observations near Earth. (Our planet's atmosphere still

universe

says.

White dwarfs also seem to star in another ROSAT mystery. Pounds and his colleagues found that some 20 hot young stars, called A stars, appear to have energetic, ultraviolet-emitting upper atmospheres, or coronas, even though astronomers believe such stars lack the ability to heat these regions. Pounds and his co-workers examined several of the A stars with a high-resolution, visible-light telescope and found indications that an unseen companion orbited each of the stars. He suspects that the hidden stars, rather than the A stars, are the source of the puzzling ultraviolet radiation.

Pounds believes the hidden companions are white dwarfs, since they glow brilliantly only in the extreme ultraviolet. "There's a whole population of white dwarfs hiding away that we were not aware of," he says. One intriguing possibility, notes Pounds, is that white dwarfs locked in orbit with another star might evolve differently from dwarfs that lack a partner.

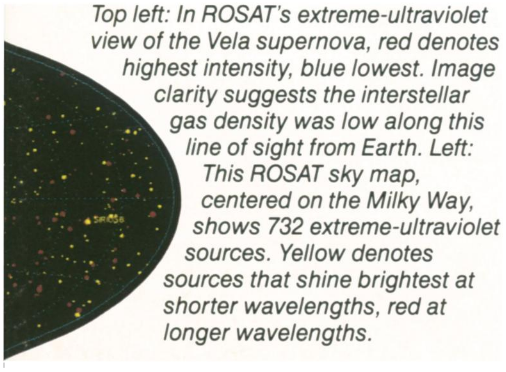
ROSAT has also glimpsed a dozen extreme-ultraviolet sources far beyond the Milky Way — possibly quasars and active galactic nuclei. The mere fact that ROSAT can detect such distant sources supports the notion that hydrogen atoms, which readily absorb extreme-ultraviolet light, do not blanket our galaxy uniformly. In addition, says Pounds, the observations suggest that extreme-ultraviolet sources at the core of distant galaxies have enough energy to burn off most of the hydrogen and other light-absorbing gases surrounding them, enabling the radiation to reach the Milky Way.

But the biggest surprises, Pounds says, may lie among the 15 percent of extreme-ultraviolet sources detected by ROSAT that have no known counterpart at any other wavelength. Some researchers have theorized that the sources are elderly, isolated neutron stars — superdense, burned-out stars that represent the final stage of evolution for stars with three to about eight times the mass of the sun. Young, rotating neutron stars that have large magnetic fields typically emit beams of radio waves, but as these stars age they slow down and radiate far less at these wavelengths.

Galaxies probably serve as burial grounds for countless of these elderly neutron stars, and emissions in the extreme ultraviolet may represent a key way to map them in the Milky Way, Pounds speculates. Though this older population would appear silent at radio wavelengths, these dense stars would still suck in material around them, emitting ultraviolet radiation in the process.

Recently, Pounds notes, some of his colleagues have begun to consider an intriguing idea that could provide an answer to another astronomical puzzle. Some of the unidentified sources detected by ROSAT may coincide with the location of gamma ray bursters, objects that unleash flashes of high-energy photons and then vanish. The highly uniform distribution of gamma ray bursts detected last year by the Compton Gamma Ray Observatory has surprised researchers because one likely source of the emissions — known, radio-emitting neutron stars in our Milky Way — clusters along the plane of our galaxy and could not produce such a radiation pattern (SN: 9/28/91, p.196). But an old, never-before-detected population of neutron stars scattered throughout the Milky Way might account for the uniform distribution of bursters — as well as some of the unidentified sources found by ROSAT.

— *R. Cowen*

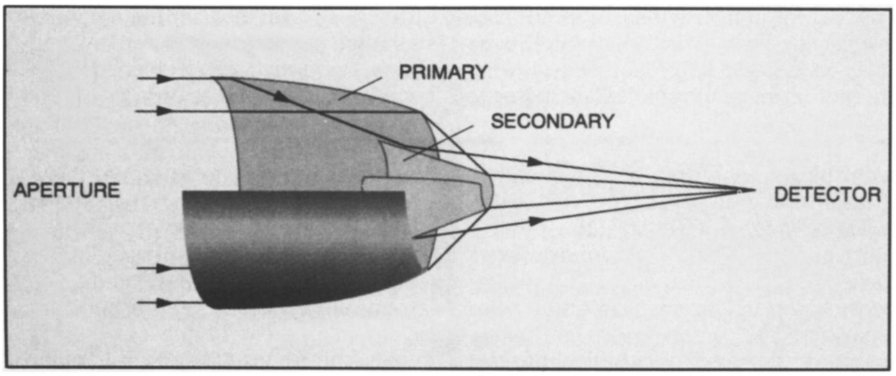


Top left: In ROSAT's extreme-ultraviolet view of the Vela supernova, red denotes highest intensity, blue lowest. Image clarity suggests the interstellar gas density was low along this line of sight from Earth. Left: This ROSAT sky map, centered on the Milky Way, shows 732 extreme-ultraviolet sources. Yellow denotes sources that shine brightest at shorter wavelengths, red at longer wavelengths.

prevents ground-based instruments from glimpsing objects in the extreme or near ultraviolet.)

During the past 15 years, several sounding rockets, both Voyager spacecraft, and the X-ray satellite EXOSAT have all viewed stars in the extreme ultraviolet. But it wasn't until 1990, says Stachnik, that the window on the extreme ultraviolet flew wide open. In June of that year, NASA launched a British-German-U.S. craft called the Roentgen Satellite, or ROSAT (SN: 6/29/91, p.408). Though this satellite, which continues to operate, primarily views X-ray sources, a camera aboard the craft has surveyed the sky in the extreme ultraviolet and identified a record 385 bright sources in this wavelength band (see sidebar).

The EUVE, designed jointly by researchers at NASA's Goddard Space Flight Center in Greenbelt, Md., and the University of California, Berkeley, will build upon the ROSAT sky map, surveying the celestial sphere in four ultraviolet wavelength bands, compared with the two bands provided by ROSAT.



NASA

An ordinary telescope mirror absorbs radiation at wavelengths shorter than visible light, including the extreme ultraviolet. But a mirror will reflect ultraviolet light if it strikes the glass at a steep enough angle. The supersmooth, cylindrical mirrors used in the EUVE allow ultraviolet reflections to occur.

Precision imaging won't be the new observatory's forte. Although tailored to detect the extreme ultraviolet, the satellite's state-of-the-art optics — supersmooth, cylindrical mirrors whose thicknesses vary by no more than 10 atoms — can't pinpoint sources to a region smaller than 3 arc-minutes, or about one-tenth the width of the full moon as it appears in the sky. But EUVE has an important feature that ROSAT lacks. It can analyze the spectra of ultraviolet sources, helping to identify the chemical composition, temperature, density and other characteristics of a variety of stars and their atmospheres. "The real cream on the cake is the spectroscopy," Stachnik says.

The first research observations will begin about six weeks after launch. For six months, the new observatory will use three scanning telescopes, each the size of a 55-gallon oil drum, to conduct its extreme-ultraviolet survey. At the same time, a fourth, "deep-survey" telescope will view fainter sources inside the dark cone cast by Earth's shadow, where bright ultraviolet emissions from our planet's atmosphere can't interfere with measurements of faint radiation from distant stars. Together, the four telescopes will detect extreme-ultraviolet radiation ranging in wavelength from about 70 angstroms to 760 angstroms.

For the remainder of the mission, expected to last at least 18 additional months, the deep-survey telescope will analyze the spectra of selected targets, some of them identified for the first time during the initial sky scan.

"That's when the physics starts," Stachnik says.

Among other features, the spectroscopic studies will investigate the hot outer atmospheres, or coronas, of relatively old, low-mass stars, Welsh notes. Although the visible surface of such stars remains somewhat cool, the stars spew out streams of highly charged particles that heat their upper atmospheres to temperatures ranging from 100,000 kelvins to 2 million kelvins. Such temperatures are associated with emissions in the extreme ultraviolet, Welsh adds.

Up until now, he says, astronomers have extensively studied the upper atmosphere of only one star — our sun. "We've got one example [of a corona] at one temperature, but we don't know whether that's typical for a star or totally atypical," Welsh notes. "The EUVE will totally revolutionize coronal astrophysics."

Young, massive stars — which burn more rapidly and thus exhaust their nuclear fuel far more quickly than their older, lower-mass relatives — represent another target for the observatory. These stars have strong stellar winds that slam into their lower atmosphere, prompting the emission of extreme-ultraviolet light, he adds.

The observatory will also hunt for white dwarfs — tiny, dense stars that remain after puffed-up stars called red giants collapse. A typical white dwarf is no bigger than Earth but has the mass of the sun; indeed, our sun will become a dwarf near the end of its lifetime. Soon after their formation, notes Welsh, white dwarfs release a tremendous amount of heat in the form of extreme-ultraviolet radiation.

"The cooling process associated with white dwarfs tells a lot about the physics at the endpoint of stellar evolution," he says.

The EUVE will also examine other types of stars, including binary systems, in which one star orbits another. Observations of certain binaries, known as cataclysmic variable stars, will involve a special collaboration with observers on the ground, notes Stachnik. Cataclysmic variables periodically erupt after one member of the stellar duo — typically a white dwarf — gravitationally steals gas from its companion, usually a star similar in mass to the sun. The stolen material forms a disk around the dwarf; when enough gas from the disk spirals onto the dwarf, it prompts the star to undergo an outburst of radiation.

During the mission, a network of amateur astronomers using visible-light telescopes will monitor some 275 cataclysmic variables and tell a coordinating group — the American Association of Variable Star Observers (AAVSO) in Cambridge, Mass. — which ones have just erupted. In turn, that group will relay the information to EUVE researchers, who may choose to examine the stars with the observatory. Says AAVSO Director Janet Mattei: "In this age it's particularly special that amateurs with their own telescopes can really contribute — and in such a crucial and vital way — to experiments like this."

The EUVE will also analyze emissions from Jupiter's moon, Io, the most volcanically active body known in the solar system. Io's volcanoes spew out huge amounts of sulfur dioxide, which become ionized and form a doughnut-shaped ring around Jupiter. Jupiter's magnetic field directs some of the sulfur and oxygen ions into the planet's north and south polar regions, where the charged particles crash into the Jovian atmosphere and create auroras similar to those observed near Earth's poles. Detecting the faint extreme-ultraviolet radiation from the Jovian auroras will help astronomers to understand better the interactions between Io and Jupiter, notes Welsh.

In addition to examining known sources of extreme ultraviolet radiation, the observatory may have an unexpected payoff — the possibility of discovering a new class of objects that radiates only at these wavelengths.

"This mission is a gap filler; it's certainly not what you call one of the Great Observatories," admits Stachnik. "It [primarily] looks right in our own backyard. . . . But whenever you throw open a new window like this, you never know where you might discover something." ☐