International Ultraviolet Explorer Probes the Universe

New satellite telescope sheds light on many astronomical processes

The International Ultraviolet Explorer (IUE), launched 26 January 1978, already has broadened the horizons of ultraviolet astronomy. In the scant year since the telescope has been available to astronomers, it has achieved an assortment of firsts—including the first ultraviolet (UV) observation of a supernova, the first high-resolution UV spectrum of a star in another galaxy, and the first evidence that acetylene is present in the upper atmosphere of Saturn.

Data from the IUE may help astronomers answer important questions. For example, fortuitous eruptions have allowed the IUE to follow the outbursts of both a classical nova and a recurrent nova. The time course of UV emissions for the recurrent nova, WZ Sagittae (known to explode every 33 years), differs from that of more brilliant classical novas—good evidence that the two phenomena are not the same in mechanism or magnitude.

Ground-based telescopes cannot detect UV light from space, because UV cannot penetrate far into the earth's atmosphere. Therefore, UV astronomy is a young field, having been born in the 1950's when rockets and balloons carried the first small UV sensors aloft. Extensive UV surveys have been possible only during the past 10 years, when special telescopes were carried aboard a few satellites. The still-operating third Orbiting Astronomical Observatory, dubbed Copernicus, is the most successful and long-lived of these. It covers much of the ultraviolet, down to 950 angstroms, with high resolution (0.1 angstrom). However, none of the early instruments was sensitive enough to detect absorption or emission lines from dim and distant sources. That shortcoming does not apply to the IUE. It can produce high-quality spectra of objects more than a hundred times fainter than could be observed with previous UV telescopes.

The IUE is the first satellite telescope that allows astronomers to make decisions to modify immediately the future course of the observing program. Scientists visit a control center and see their target's spectrum first hand, displayed on a color television in the IUE control room, as soon as an observation is completed.

Much diverse information is already available from the IUE, in part because more than a hundred astronomers have been allotted observing time in order to pursue projects of their own interest. Astronomers sponsored by the National Aeronautics and Space Administration (NASA) control the IUE for 16 hours each day from an observatory at NASA's Goddard Space Flight Center in Greenbelt, Maryland. Scientists approved by the United Kingdom Science Research Council and the European Space Agency (ESA) operate the telescope the remainder of a 24-hour working day from ESA's tracking station in Villafranca, Spain.

The IUE transmits to a ground station an image of the spectral output of an astronomical object, rather than an image of the object itself. Prior satellites carried spectral instruments that scanned through the spectrum one wavelength at a time. In contrast, the IUE records simultaneously the entire spectrum in one of two available wavelength regions. For each range (either 1150 to 1950 angstroms or 1900 to 3200 angstroms), a grating splays out the incoming light according to its wavelength, and distributes it over the detector. When only one grating, called the cross-dispersing grating, is used, astronomers can observe very faint targets, but the spectral resolution is only 8 angstroms. By allowing the dispersed light to strike a second grating, known as an echelle grating, the spectral resolution is improved to 0.2 angstrom.

Exposure times of several hours permit the IUE to record spectra of quite faint or distant objects. However, even the shortest exposures are several seconds long, so the IUE is not suited to studying very rapid variations in a source's light output. Nonetheless, the high sensitivity and excellent resolution of the IUE allow astronomers to choose objects for study on the basis of their scientific interest, rather than because they are close and bright.

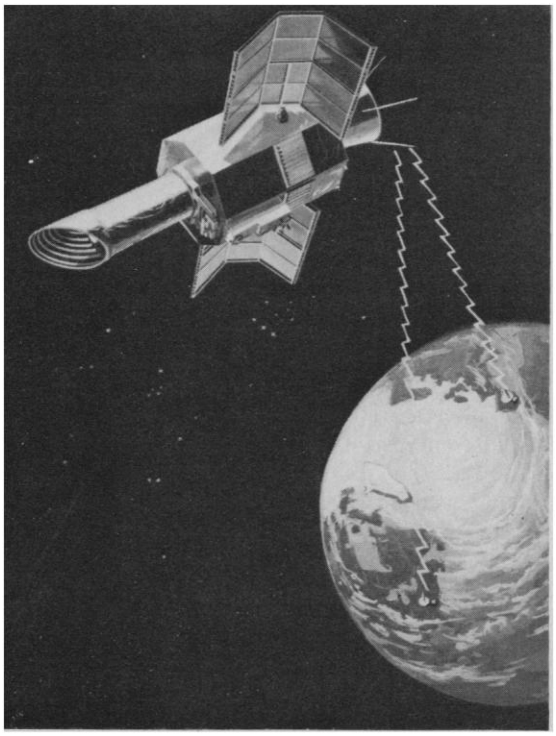
> IUE allows astronomers to choose objects for study on the basis of their scientific interest, rather than because they are close and bright.

The IUE has made it possible for astronomers to observe in detail the UV spectra of cool stars, with surface temperatures less than 7000 degrees Kelvin. Such stars are of great interest, in part because the sun is one. Emission lines in the UV spectrum of cool stars can be identified with specific molecules, atoms, or ions, thereby giving astronomers clues to the composition and temperature of the low-density gas in the stellar atmosphere.

Cool stars appear to have at least two differing types of atmospheres. According to Jeffrey L. Linsky and Bernhard M. Haisch at the Joint Institute for Laboratory Astrophysics in Boulder, Colorado, one type is like the sun, with a cool, lower atmosphere grading outward into a million-degree Kelvin corona; a second type lacks any material hotter than 20,000 degrees Kelvin. Andrea K. Dupree and her colleagues at the Harvard Smithsonian Center for Astrophysics think they have also observed cool stars with an intermediate type of atmosphere—hot gas is definitely present, but compared with the sun, there are unusually strong emissions from low-temperature material.

To explain the lack of a high-temperature corona in some cool stars, the astronomers postulate that an extremely strong "wind," carrying away mass possibly a million times faster than the solar wind, keeps a hot corona from forming. Linsky suggests that the wind might be driven by radiation pressure from photons emitted by hydrogen atoms near the surface of the star, although this mechanism has not yet been proved. These photons bombard the gas particles in the atmosphere and accelerate them. The

0036-8075/79/0302-0863$00.50/0



The International Ultraviolet Explorer (IUE) appears nearly stationary in the sky in its elliptical orbit 25,000 to 45,000 kilometers above the surface of the earth. From its vantage point the IUE can observe much of the heavens—only small sections, blocked by the earth or too close to the sun, cannot be examined. [Source: National Aeronautics and Space Administration]

cool stars lacking coronas have a gravitational field perhaps a thousand times weaker than that of the sun—not strong enough to keep the rapidly moving particles in the atmosphere.

Mass loss, in the form of winds, is a key process in the evolution of near-neighbor, interacting pairs of stars, known as binary stars. According to Yoji Kondo at Goddard, data from the IUE are enabling astronomers to document mass flow in binary star systems directly. In at least some cases, the stellar wind appears to be quite gusty—mass flow occurs in puffs rather than at a constant rate. In addition, says Kondo, much of the stellar wind material may be lost completely from the binary system, rather than accreted to the companion. In the case of U Cephei, the wind ejected from one star appears to shoot toward and around the companion before streaming into space.

Although many interesting processes, such as x-ray emission and the outbursts of novas, are frequently associated with star pairs, binary stars are by no means oddities of the heavens. At least in our part of the galaxy more than half the stars are known to be members of binaries. So-called peculiar binaries, however, attract more than their share of attention with their eccentric behavior or appearance.

Miroslav Plavec of the University of California at Los Angeles has found a very hot (25,000 degrees Kelvin) star hiding inside one of the stars in a type of binary recognized as peculiar on the basis of its visible light emissions. These emissions suggested that it was a yellow star (7000 degrees Kelvin) with some anomalous and previously unexplained spectral features due to much hotter material. With the IUE, Plavec has determined that the apparent yellow star in binaries like W Serpentis or SX Cassiopeiae is really just a dense disk of cool material nearly engulfing a hot, "blue" star. Only the poles of the blue star peek above and below the disk to produce the "hot" features seen in the star's visible light spectrum.

In addition to revealing the blue star, the UV emissions suggest the presence of ions usually found in gas at 100,000 to 200,000 degrees Kelvin. Could this mean that the star is like a set of nesting Russian dolls, with an even hotter source, perhaps a collapsed object, hiding inside the blue star? Possibly, says Plavec. But more likely the high ionization states are produced when the cool disk is bombarded by a concentrated stream of particles comprising the tremendous wind from the cool, invisible companion star. In fact, if there is a huge mass transfer, it would help to explain the thick, cool disk of matter that surrounds the hot star.

According to Plavec, W Serpentis and SX Cassiopeiae may be in a very short-lived, early stage in the evolution of star pairs. Binaries probably start as two ordinary neighboring stars, each evolving and expanding on its own. When one reaches a so-called critical volume, it starts losing mass to its companion. Plavec imagines that initially matter is transferred at an incredible rate—perhaps a thousand times faster than it is transferred in more normal binaries. Since only a handful of these peculiar binaries are known, they are assumed to represent a short-lived phase in the life of a binary.

Some members of binary systems seem to explode, suddenly ejecting a shell of material and brightening significantly. A classical nova may brighten briefly by a factor of around 50,000 or more to become one of the brightest objects in the sky; while a recurrent nova, so called because the same star has been observed to erupt periodically, is less spectacular and may become only a thousand times brighter than normal. The flexibility afforded by continuous ground control of the IUE allowed researchers to divert the telescope to take advantage of two fortuitous stellar outbursts. Nova Cygni 1978 exploded in November, and WZ Sagittae, which had brightened in 1913 and 1946, brightened again in December 1978. The eruption of WZ Sagittae permitted the IUE to make the first UV observations of a recurrent nova.

In classical novas, material is thought to be permanently ejected from the star. The UV emissions of WZ Sagittae, however, suggest to Albert Boggess at Goddard that the recurrent nova's outburst is smaller and that the ejected gas may return to the star. The visible-light emissions for both types of explosions are essentially indistinguishable, and have led astronomers to wonder whether the size of the eruption might be the primary difference between the two types of novas. However, the different kinds of novas have different UV signatures. Boggess reports that the UV output of the recurrent nova, WZ Sagittae, follows its visible-light output closely—the UV and visible intensities both peak within several hours of the explosion. In contrast, the maximum UV brightness of a classical outburst, like Nova Cygni 1978, typically occurs about a month after the peak visible-light intensity. Astronomers think the delay in the UV peak intensity of the nova eruption is caused by the cool, massive, UV-opaque shell of ejected mass—it must expand to a lower density before the UV emissions from hotter regions inside the nova can escape.

Ultraviolet radiation is intermediate in energy between visible light and x-rays, and the IUE is proving to be an informative probe of x-ray sources. These include binary star systems and also globular clusters, dense groups of up to several hundred thousand uniformly old stars. No new star formation is thought to be occurring in the spherical clusters, which are located in the so-called halo of our galaxy—above and below the main galactic plane. In the early 1970's x-ray detectors aboard satellites observed that some, but not all, globular clusters included an x-ray source. Surprisingly, x-ray sources seem to be a thousand times more common in globular clusters than they are in the main plane of the galaxy. More recently, astronomers discovered that many of the x-ray sources in the globular clusters are bursters—objects whose power output increases tenfold in 1 second, and then returns to normal over the next 10 seconds. Recognizing bursters is a matter of luck, because their outbursts are short, erratic, and occasional.

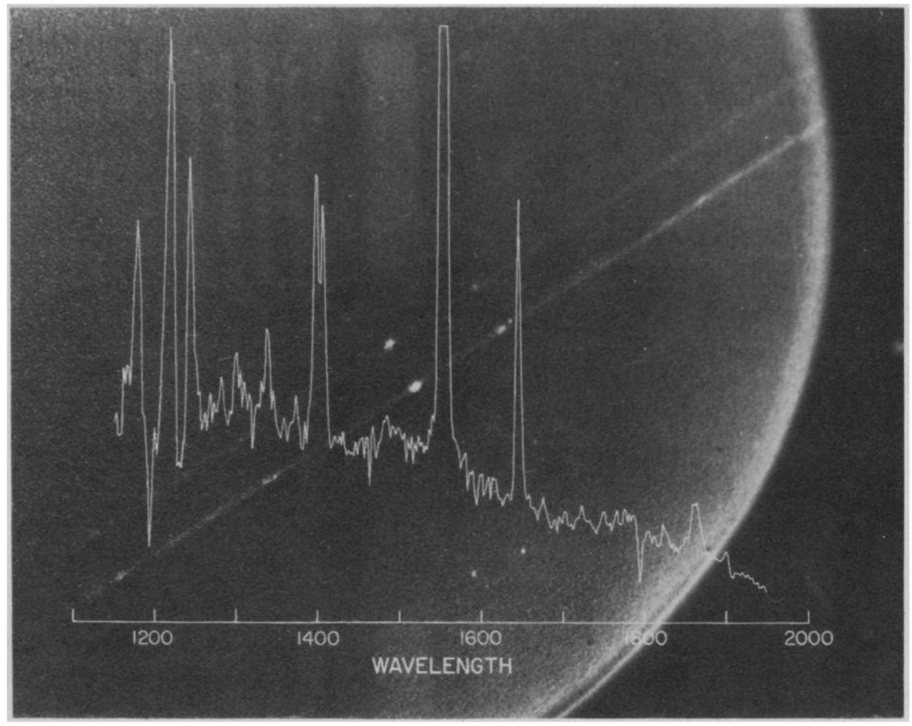
Astronomers are curious about globular clusters in general and their x-ray sources in particular. Since the x-ray emissions were first discovered, proposed explanations have included compact sources like black holes (several times as heavy as the sun) and neutron stars (about equal to the sun in mass).

With the IUE, Dupree and Herbert Gursky at Harvard have found hot, blue stars near the centers of several globular clusters. These stars appear to be later evolutionary stages of the cool, red giant type of star observed to be on the outside of each cluster. According to Gursky, one fascinating feature of the distribution of the hot stars is that they are grouped very tightly near the center of cluster. The localized distribution of hot stars is one more feature of globular clusters that must be explained by theorists. Gursky, a self-proclaimed black hole enthusiast, has not been able to see how a black hole at the center of the cluster might explain the distribution of hot stars. However, he proposes that the motions of these hot stars, circulating around the center of the globular cluster, might give astronomers clues to the nature of the core of the cluster. Unfortunately, the IUE has insufficient spatial resolution, only 3 arc seconds, to unravel the inner dynamics of globular clusters.

In one globular cluster, the Harvard group feels it may have located the x-ray source. A small, UV-bright object has unusual emissions in the short-wavelength end of the IUE's range. The emissions do not resemble spectral lines, nor do they appear to have a spectral profile characteristic of the glowing of a hot object. Gursky suspects that the radiation may be a UV extension of the x-ray emissions themselves.

Ultraviolet can also be used to probe the invisible, low-density gas pervading the space between stars—the interstellar medium. A chemical species in the gas preferentially absorbs light with the right amount of energy to raise an electron to a higher energy state. Thus, light shining through the gas, as from a distant, hot star, is observed to be lacking certain wavelengths. These are the wavelengths absorbed by the interstellar gas, and the line absorptions give astronomers clues to the elements and ionization states present in the interstellar medium.

Blair D. Savage and Klaas S. de Boer at the University of Wisconsin in Madison report that there is interstellar material in the outer halo of the galaxy, and that it seems to be very hot—suggestive of what they call a "galactic corona." To look at this region of space, Savage and de Boer had to use backlighting from individual stars in the Large Magellanic Cloud, a nearby galaxy. Absorption lines imposed on the spectra of these stars, the first high-resolution UV spectra of stars in another galaxy, reveal the presence of highly ionized material, indicating temperatures of about 100,000 degrees Kelvin. Broadening and Doppler shifting of the lines indicates that the hot gas probably is located in the galactic halo, far above the main plane of the galaxy. The halo gas might be kept hot by occasional supernova explosions in the galaxy.



The detector images from two exposures of the low-resolution, short-wavelength UV spectrum of AM Herculis appear as faint diagonal lines in this photograph of the television screen in the IUE control room. Strong emission lines appear as bright spots on each spectral image. For the superimposed graph the digitized data from one exposure have been replotted as a recognizable spectrum, with intensity graphed against wavelength. AM Herculis is a binary star system with an orbital period of about 3 hours, and the astronomers are interested in determining how the UV emissions change with the orbital phase. The scientists took advantage of the IUE's two apertures (a field of 3 arc seconds and a field of 20 arc seconds) to make two sequential 45-minute exposures, and thereby catch the system in two different phases. Emission lines in the spectrum have been identified with highly ionized species, including N^{4+}, Si^{3+}, and C^{3+}, whose electrons presumably have been ripped off by the x-rays emitted by the binary system. [Source: Harvard Smithsonian Center for Astrophysics]

Planetary astronomers are quite excited about the capabilities of the telescope. The aperture of 3 arc seconds, too coarse to follow the motions of stars in globular clusters, is excellent for studying spatial variations in the upper atmosphere of Jupiter. The atmospheres of objects in our own solar system are thought to be excellent laboratories for studying the photochemical processes that build complicated organic molecules—the basis of life on earth. Fortunately, many organic molecules have distinctive UV signatures. Already Warren Moos at Johns Hopkins University has evidence that there is acetylene in the upper atmosphere of Saturn. It is the heaviest organic molecule to be found to date in that part of the atmosphere. Venus, Jupiter, Neptune, Uranus, and Titan have also been examined, but much of the data have yet to be refined.

In addition to studying the galaxy, astronomers use IUE to investigate more distant objects, like the incredibly energetic Seyfert galaxies and quasars. Ultraviolet comparisons of quasars supports the notion that they are similar to each other, and that they really are as far away as astronomers think.

In its first year of operation, the IUE has proved to be a versatile telescope. Capable of producing high-resolution UV spectra of relatively faint objects, it has expanded the horizons of UV astronomy greatly. With continuous ground control, the IUE observing program is much more flexible than that of previous astronomical satellites. The IUE has been used in coordination with other telescopes, on the ground and in space, to provide simultaneous observations of interesting objects in several spectral regions. If the successes of the IUE presage the abilities of the space telescope, astronomers can hardly wait for that instrument to be carried aloft by the space shuttle.

—Beverly Karplus Hartline