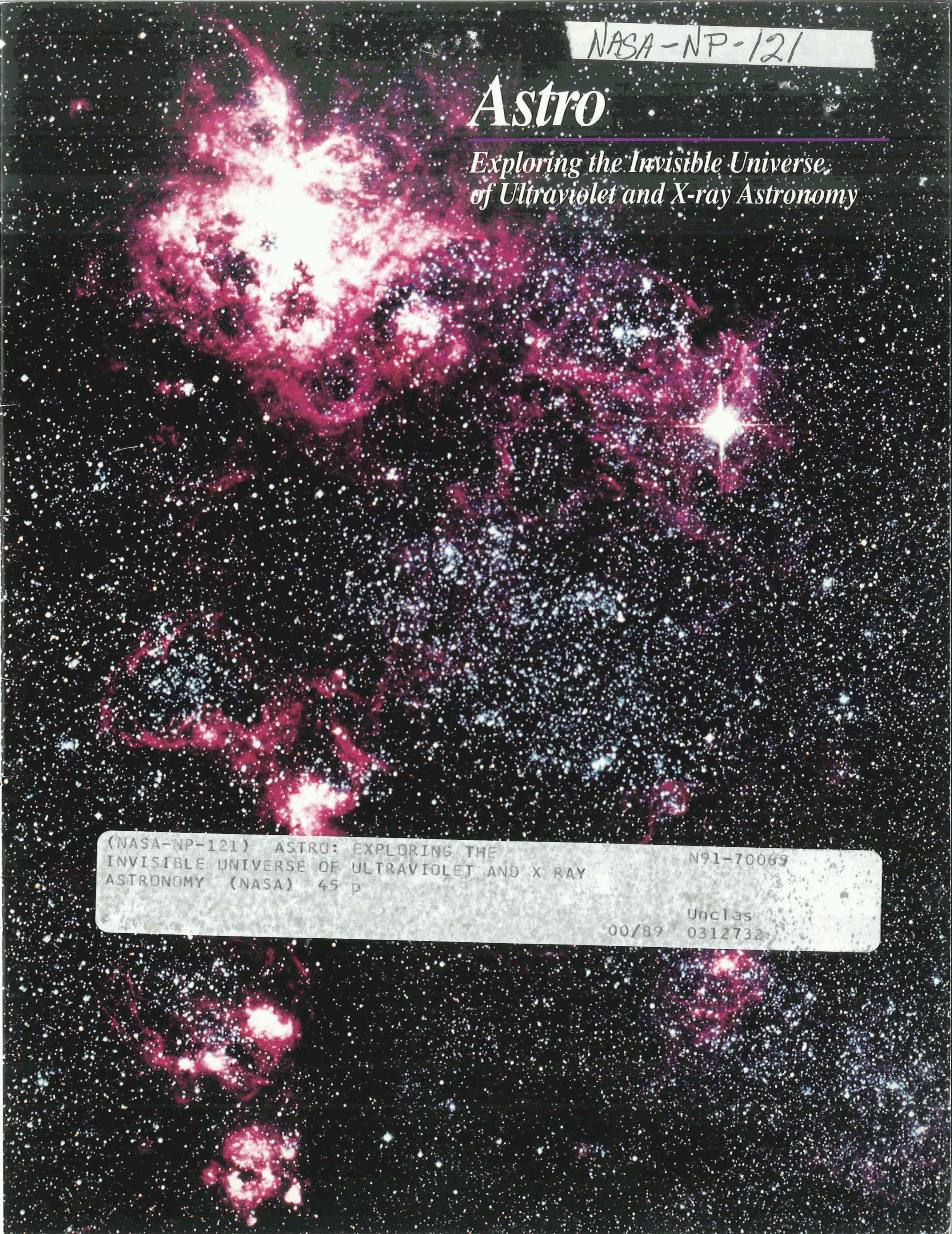
NASA-NP-121

Astro

Exploring the Invisible Universe of Ultraviolet and X-ray Astronomy



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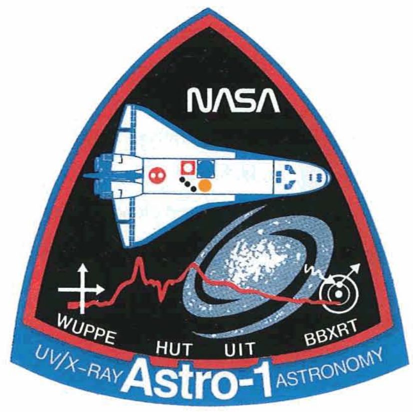
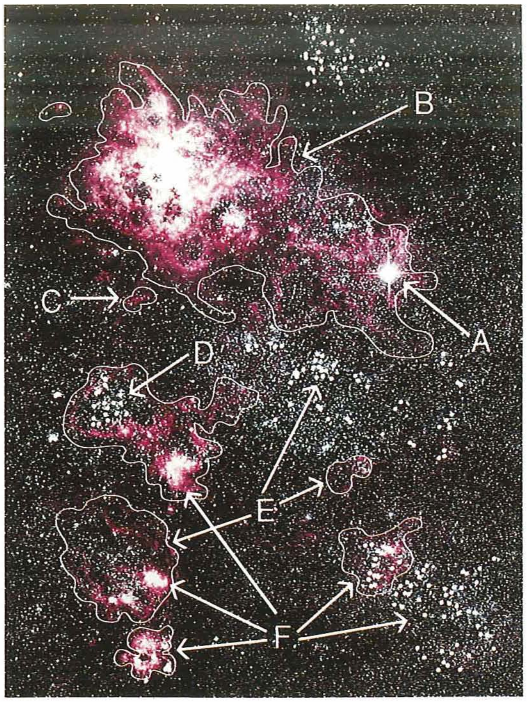


NASA
National Aeronautics and
Space Administration

NP 121



On the cover:

This European Southern Observatory photograph shows a portion of the Large Magellanic Cloud, the nearest galaxy to our own Milky Way. Many objects representing the variety of astronomical targets observable by Astro are captured in the image. Young, massive stars in stellar nurseries of ionized gas, wind-blown bubbles of gas, and the remains of stellar explosions (supernova remnants) are shown. To the right, SN 1987A, a star that exploded in early 1987, shines like a diamond. During a series of 9– to 11–day missions, Astro will study some of these objects and many more.

A. Supernova 1987A

B. 30 Doradus, a chaotic region with hot stars, wind-blown gas bubbles, and supernova remnants

C. Supernova remnant

D. Stellar wind-blown gas bubbles

E. Ionized clouds of gas where stars form

F. Clusters of young stars

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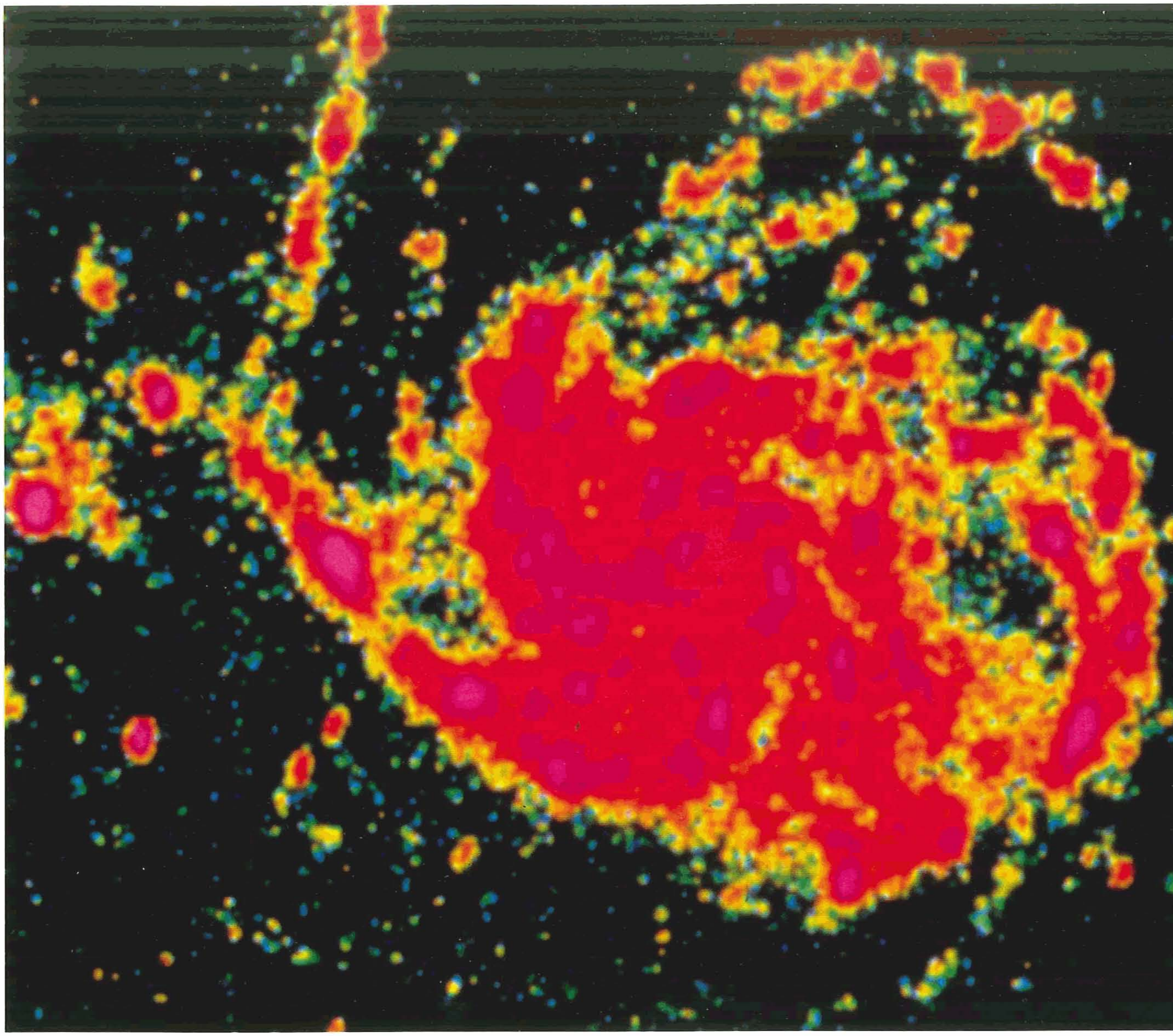



Exploring the Invisible Universe of Ultraviolet and X-Ray Astronomy

As we gaze at the stars, the Universe sometimes seems too big and complicated to comprehend. But our passion for exploration and our insatiable curiosity drive us to defy the unknown. We look to astronomers to contemplate concepts that extend our reach. Astronomers try to imagine the exquisite relationships of everything in the Universe. They base their theories on current observations and then test these theories by making more observations.

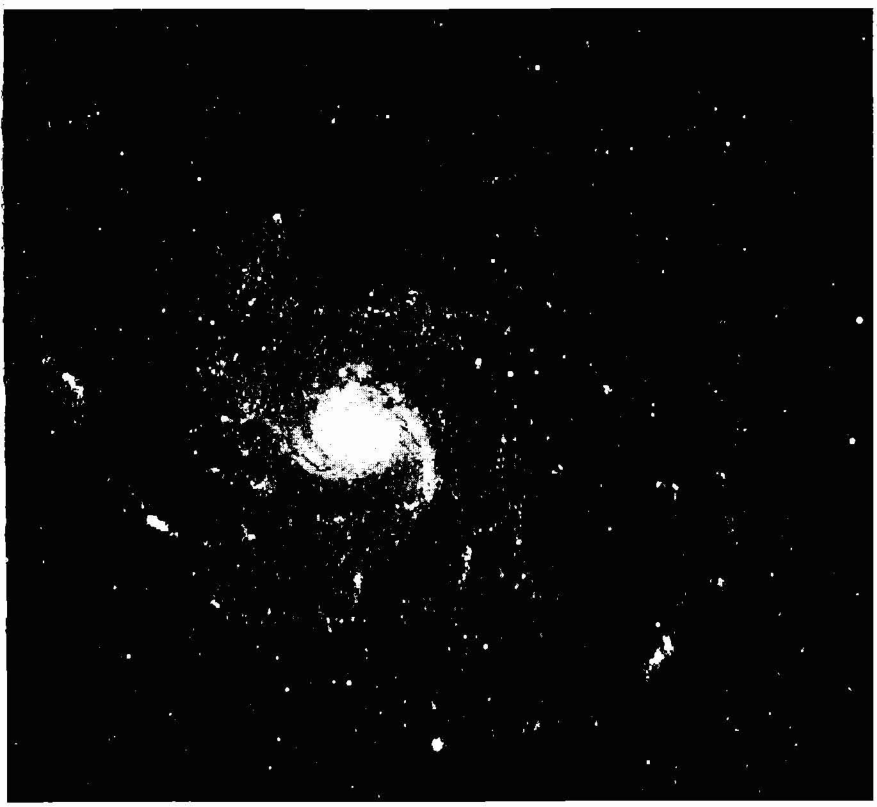
Technology is the tool of their imaginations. For thousands of years, all their knowledge about the Universe came from visible light sensed with their eyes. Then, the telescope transformed astronomy, enabling observers to discover other galaxies, many consisting of hundreds of billions of stars. More instruments were devised to reveal the size, shape, chemistry, and physics of stars many thousands of light-years away. Scientists studied stellar composition by breaking up starlight into its spectral components, just as raindrops separate sunlight into a rainbow of colors. Since each element, such as hydrogen and oxygen, emits and absorbs radiation at specific wavelengths, they could determine a star's makeup by analyzing its spectrum, its radiation fingerprint.

But even with our best visible light telescopes, we could not see a complete picture of the Universe. Visible light is a small part of the electromagnetic spectrum. Stars and other objects often emit more invisible radiation — radio waves, microwaves, infrared emission, ultraviolet emission, X-rays, and gamma rays — than visible light. From Earth, we can detect some radio and infrared wavelengths, but most radiation is absorbed by the atmosphere and never reaches telescopes on the ground. To detect invisible radiation, astronomers use balloons, rockets, and spacecraft to carry instruments above the atmosphere.

Each time we probe a new wavelength region, the Universe is found to be more vibrant and intricate than expected. Until this century, most people believed that the Universe was static. Like the calm surface of a distant sea, the Universe appeared quiet. But just as the ocean has crashing waves and turbulent currents and sustains a teeming world, the Universe is filled with motion and complex, evolving objects.

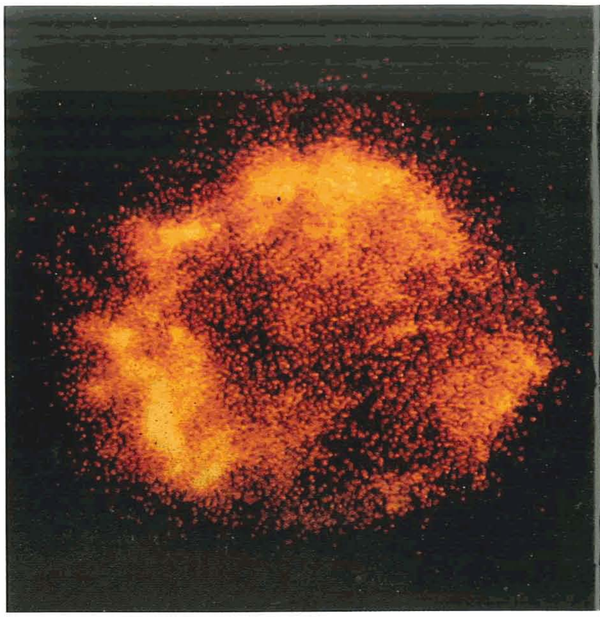
Observations have revealed a restless Universe with exploding stars, cannibal galaxies, and violent bursts of radiation. We are just beginning to explore the immense cosmic ocean, and there is much that we do not know. To learn more, we have to look deeper using new instruments and techniques.

To study invisible radiation from objects as thoroughly as we are studying their visible light, we need sensitive instruments in space. The National Aeronautics and Space Administration (NASA) has developed an observatory — Astro — that will detect ultraviolet and X-ray radiation from some of the most chaotic and fascinating objects in the Universe.



The outer spiral arms of the galaxy M101 stand out in this color-enhanced ultraviolet image. The visible image (right) does not distinguish regions of young, hot stars from old, cool stars in the spiral arms.

The Great Nebula in Orion is a stellar nursery.



This X-ray image of Cassiopeia A shows a shell of hot gas and dust, the debris of a star that exploded three centuries ago.

Astro will expose the hottest parts of galaxies: their active centers and dense globular clusters of stars shine with copious ultraviolet and X-ray emission. Quasars, perhaps the oldest and most energetic objects known, will be studied by Astro. The observatory may uncover objects that challenge our interpretation of the laws of physics: black holes that transform our concepts of space and time, and neutron stars so dense that a teaspoonful of their material may weigh a billion tons.

Astro will chronicle the life cycles of stars. When they are born and when they die, stars emit large amounts of ultraviolet and X-ray radiation. Astro will acquaint us with all ages and types of stars: stellar infants that have formed in dusty nebulae; dying stars that have collapsed to Earth-sized embers; and massive stars that burn energy faster and faster until they explode as supernovae. Astro will study how stars forged the iron in our blood and the calcium in our bones. It will observe pairs of stars that exchange hot gaseous matter as well as stellar clusters with millions of members.

To detect ultraviolet and X-ray radiation, Astro must be above the atmosphere. The Space Shuttle will carry Astro aloft for missions lasting from 9 to 11 days. Like an observatory on the ground, this new facility will be used by many scientists to answer questions about the Universe. In fact, some of those scientists will actually be members of the Shuttle crew who operate the observatory from space.

Four instruments make up the Astro Observatory: the Hopkins Ultraviolet Telescope (HUT), the Ultraviolet Imaging Telescope (UIT), the Wisconsin Ultraviolet Photo-Polarimeter Experiment (WUPPE), and the Broad Band X-Ray Telescope (BBXRT). By using more than one instrument, Astro can gather different types of information at the same time on the same objects. It is the first observatory that can simultaneously take ultraviolet pictures of objects, study their ultraviolet and X-ray spectra, and determine their brightness and structure through photometry and polarimetry.

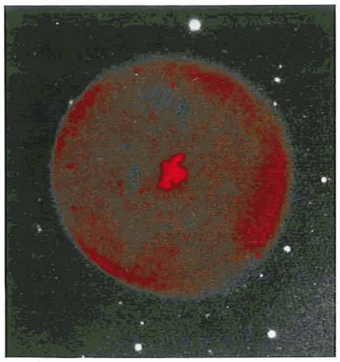
HUT examines far ultraviolet radiation, a rich part of the spectrum where many astrophysically important elements emit radiation, and extends observations into the region of extreme ultraviolet, the shortest, most energetic ultraviolet wavelengths. Many discoveries are expected as HUT probes this virtually unexplored region. HUT uses spectroscopy to reveal the chemistry and structure of stars and other objects. The signatures of many elements including hydrogen, helium, carbon, nitrogen, oxygen, silicon, and sulfur will be recorded.

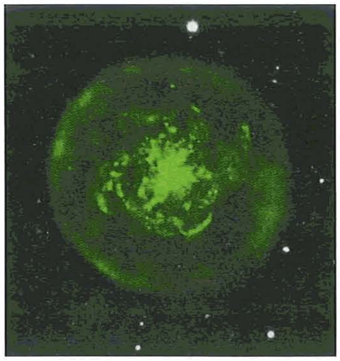
UIT takes the first extensive set of detailed ultraviolet photographs of the sky, most of which has never been imaged in the ultraviolet. This instrument can see areas larger than the apparent size of the sun viewed from Earth and will detect fainter ultraviolet sources than any seen before. It captures nearby galaxies, large clusters of stars, and distant clusters of galaxies on film. Astronomers can use the images, which are taken through filters to isolate different ultraviolet colors, to study the relative brightness, location, temperature, and structure of sources that emit strongly in the ultraviolet.

WUPPE gives us clues about the shape and size of objects by studying the way that their light is polarized. Usually waves of light move randomly — up, down, back, forth, and diagonally; however, if the light is polarized, all the waves move up and down in the same direction. By measuring how much the light is polarized, WUPPE can help determine the geometry of stars, the strength of magnetic fields, and the nature of gas and dust between the stars. Since the polarization of ultraviolet radiation has never been measured before, we can expect surprises and discoveries. WUPPE also uses photometry to measure the brightness of sources and spectroscopy to study their ultraviolet emission. WUPPE spectra cover the wavelengths between visible light and the exotic higher energy ultraviolet wavelength bands. For many objects, the WUPPE spectra will be combined with HUT spectra to obtain greater insight into the nature of sources.

BBXRT makes the first high-quality, high-energy spectra of many X-ray sources discovered by earlier satellites. It can see fainter and more energetic objects than any yet studied. It measures radiation from heavy elements such as iron, oxygen, silicon, and calcium. Variations in the spectra will tell us about violent events, such as matter being destroyed in the core of a galaxy or stellar explosions.

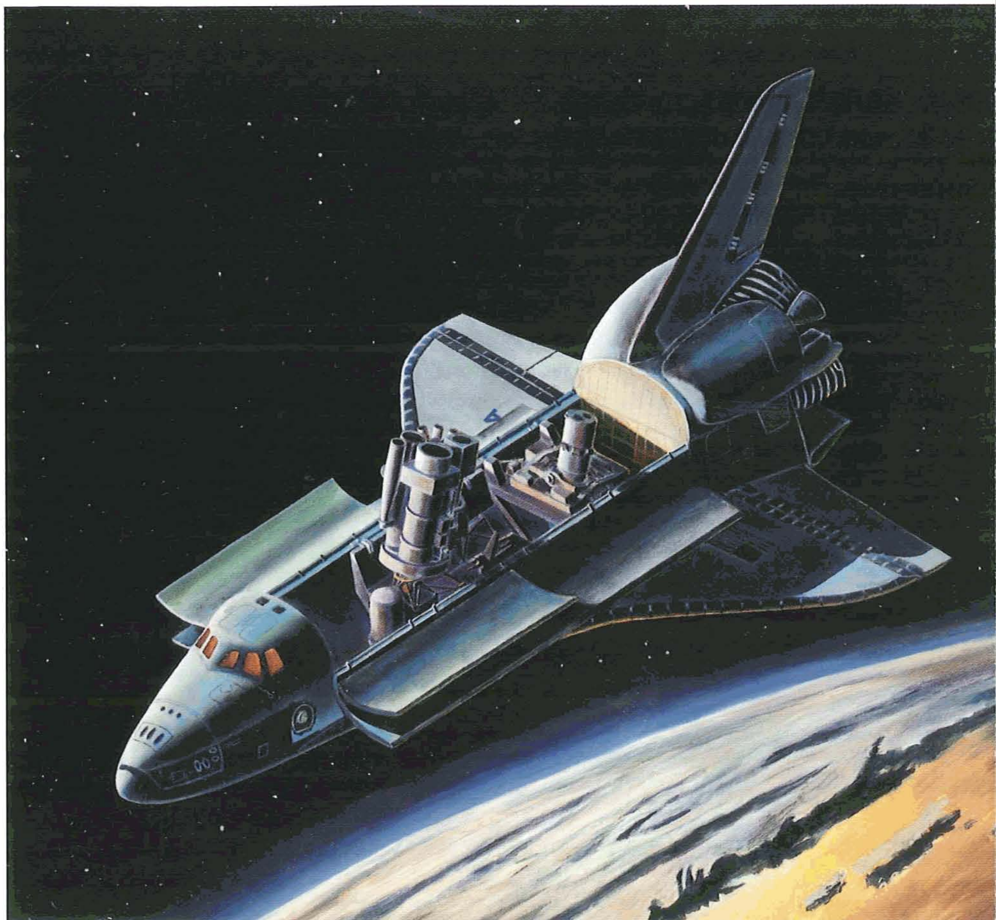
Each Astro instrument will make unique contributions to astronomy. Combined, these instruments constitute a powerful observatory. Astro is a feat of imagination and invention, a complement of instruments custom-made to answer puzzling astrophysical questions. The Astro Observatory is uniquely designed to open the Universe for detailed scrutiny. ▲





Images made in the light emitted by specific elements reveal the structure of objects. The planetary nebula Abell 30 imaged in hydrogen alpha (left) surrounds a white dwarf. In the light of oxygen III (right), oxygen-rich material ejected from the central star can be seen. The oxygen, which was made in the star, is being fed into the interstellar medium where it may someday become part of another generation of stars.

Shuttle-borne Astro Observatory



The Universe in Perspective

Visible light represents only a very tiny part of the radiation that makes up the electromagnetic spectrum. However, visible light is one of the main portions of the spectrum that passes through Earth's atmosphere from distant stars. For millennia, visible light was our only source of information about the Universe.

If visible light shines through a prism or another dispersing element, the radiation separates into its component colors, from blue (more energetic) at the short wavelength end to red (less energetic) at the long wavelength end. The ends of the visible light spectrum are not really "ends" at all but are simply the limits of response by the human eye. The electromagnetic spectrum extends across a broad range of wavelengths from very high-energy gamma rays to very low-energy radio waves, but most of the spectrum, including ultraviolet and X-ray radiation, does not penetrate Earth's atmosphere.

The space program has revolutionized astronomy by placing observational instruments outside the atmospheric veil where they can accurately detect all types of radiation. Very sensitive detectors, high-resolution imaging and spectral analysis techniques, and spaceflight have made it possible to see the Universe through new "windows." Our visual picture of the Universe was superficial: ultraviolet and X-ray astronomy are helping to reveal some of its mysteries.

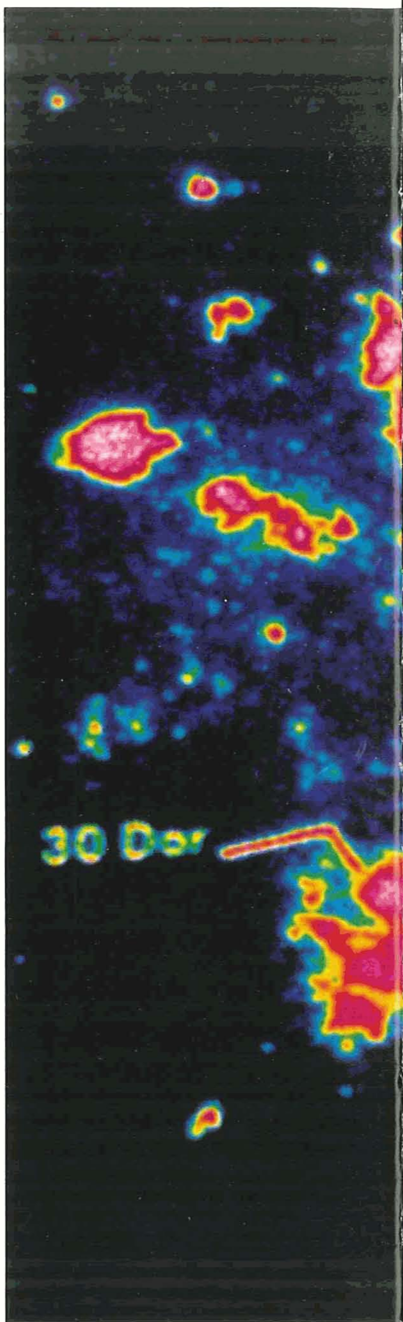
Ultraviolet Astronomy

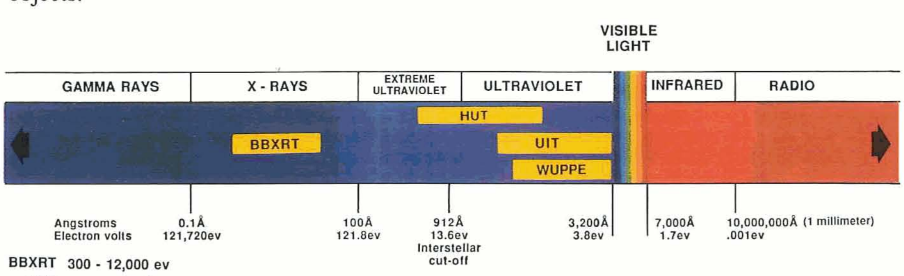
The ultraviolet (or simply UV) spectrum is just beyond the blue end of visible light. Ultraviolet wavelengths are measured in Angstroms (Å); an Angstrom equals one ten-billionth of a meter. UV wavelengths ranging from about 100 to 3,200 Angstroms (about 100,000 to 1,000 times smaller than a pinhead) are shorter and more energetic than visible light. By comparison, visible light spans the region from about 3,200 Å to 7,000 Å. The UV region is further subdivided into the extreme ultraviolet (EUV, 100 Å to 1,000 Å), the far ultraviolet (FUV, 1,000 Å to 2,000 Å), and the near ultraviolet (NUV, 2,000 Å to 3,200 Å) bands. Many types of celestial objects are interesting to astronomers because they emit most of their radiation in these ultraviolet bands.

The ultraviolet Universe looks quite different from the familiar stars and galaxies seen in visible light, many of which are actually relatively cool objects. Ultraviolet radiation is typically the signature of hotter objects, such as stars recently born or dying. If we could see the sky in ultraviolet, the cooler stars would fade away. We would see some very old stars growing hotter and producing high-energy radiation near their death. We could see clouds of gas and dust, stellar nurseries with hot, young massive stars. Disregarding the much more numerous cooler objects, we would have a less cluttered view of crowded areas such as dense star clusters or the spiral arms of galaxies.

Results from several rocket-borne instruments and satellites such as the Orbiting Astronomical Observatories, Astronomy Netherlands Satellite, Voyager, and International Ultraviolet Explorer indicate that the solar system, our Galaxy, and the Universe beyond are rich in UV radiation. However, these early observations have dealt almost exclusively with near and far ultraviolet emissions, because most mirrors and detectors could reach only to about 1,200 Å. Only the Orbiting Astronomical Observatory-3 (known as Copernicus), which studied relatively bright stars, recorded spectra down to 950 Å. Radiation at wavelengths shorter than 912 Å is absorbed by hydrogen, the most abundant element in the Universe, thus making it even more difficult to detect distant sources. Using new technology, Astro will see beyond this cutoff, called the Lyman limit. Only a few sources have been identified in the extreme ultraviolet, and discoveries are expected as Astro studies this relatively unexplored region of the electromagnetic spectrum.

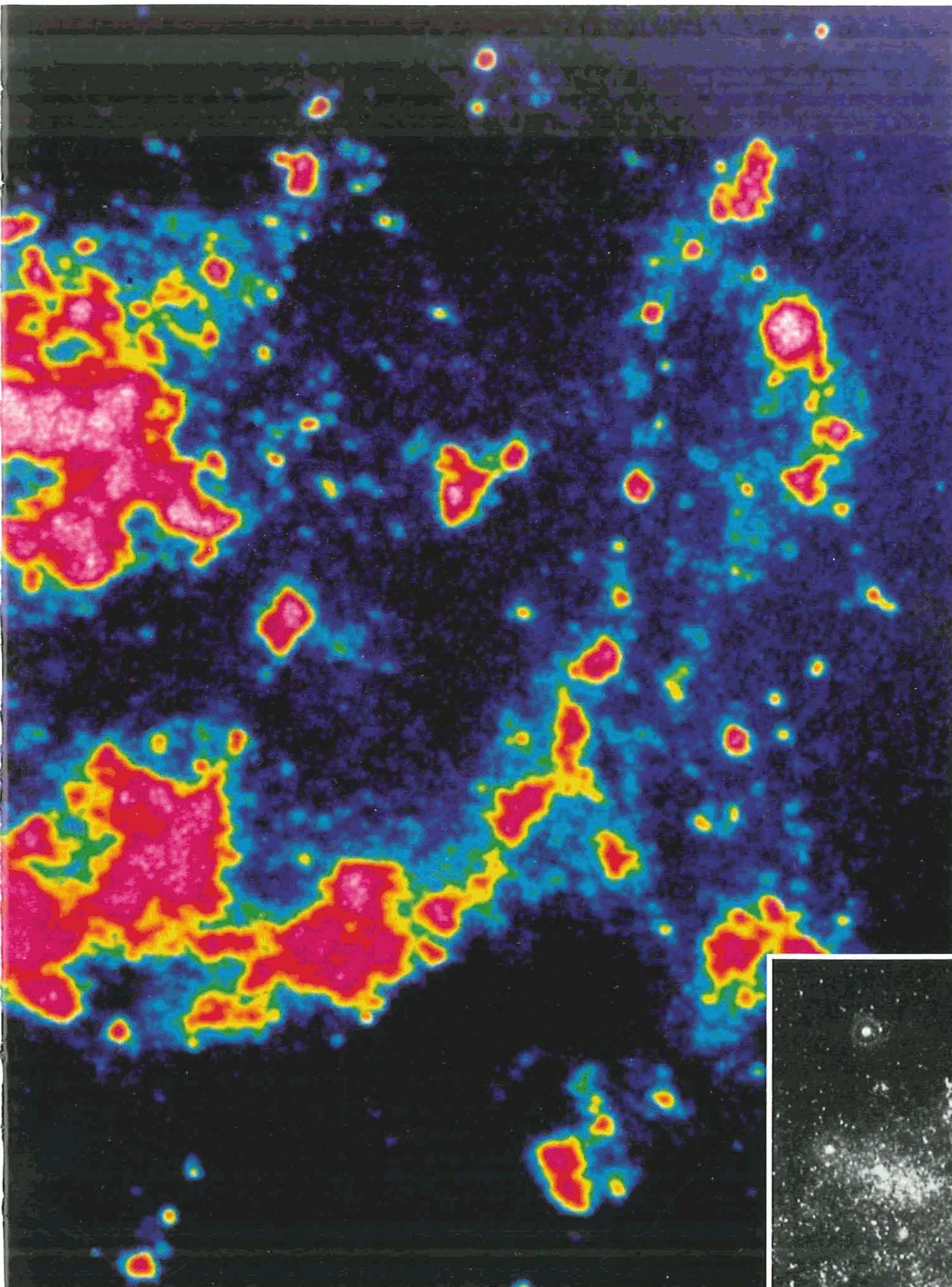
The Astro ultraviolet telescopes will make several different types of measurements simultaneously. As sources are examined across the UV spectrum and studied by various techniques, we will learn something new about the origin, structure, chemical composition, and evolution of many kinds of celestial objects.





BBXRT 300 - 12,000 ev
HUT 425 - 1,850 Å
UIT 1,200-3,200 Å
WUPPE 1,400-3,200 Å

Spectral coverage of the Astro Observatory instruments: the shorter the wavelengths, the more energetic the radiation.



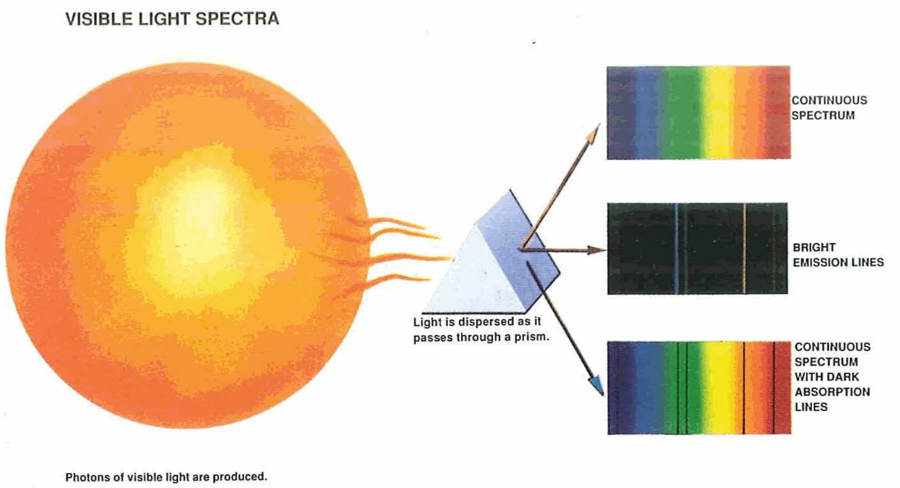
Hot ultraviolet sources stand out in this UV image of the Large Magellanic Cloud, a galaxy that is close enough to study in great detail. In visible starlight (below) it is hard to ascertain the hot spots.

X-Ray Astronomy

The X-ray spectrum is just beyond the ultraviolet in an even more energetic region with even shorter wavelengths. X-rays are emitted in wavelengths from 100 Å to 0.1 Å, but these wavelengths are so short (about the size of an atom) that astronomers usually talk about X-rays in terms of their energy, measured in electron volts. X-rays and all other types of electromagnetic radiation are emitted in particle-like packets of energy called photons. X-ray photons cover energies ranging from 100 to 100,000 electron volts. By comparison, a photon of visible light carries about 2 electron volts of energy.

The X-ray sky is filled with cosmic explosions where gases are heated to millions of degrees, and matter is accelerated to nearly the speed of light. Looking at the Universe in X-rays, we see a violent cosmos: stellar blasts, hot stars and galaxies, collapsed spinning stars, powerful quasars, and perhaps matter whirling around black holes. Thousands of X-ray sources have been identified, and most known types of celestial objects have been observed to emit X-rays.

The best view of the Universe in X-rays was obtained from 1978 to 1981 by NASA's High Energy Astronomy Observatory 2, the Einstein Observatory. This pioneering mission revealed more new and different X-ray sources than had ever been imagined, but it raised as many questions as it answered. Astronomers are eager to study X-ray sources in greater detail. The Astro Observatory will give us our first information on the chemistry, temperature, and structure of some of the most unusual and most interesting objects in the Universe.

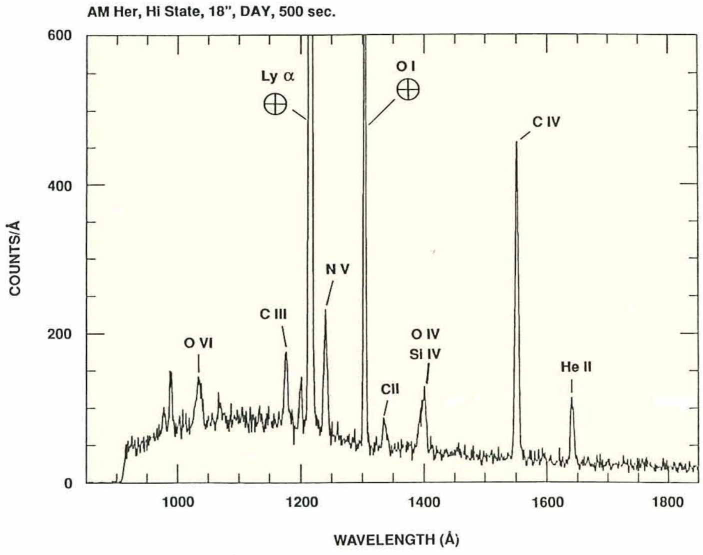


When white light passes through a prism, it is broken into individual colors that represent different visible wavelengths. Emission lines are created when elements emit brightly at particular wavelengths; absorption lines result when elements absorb light at specific wavelengths.

Detecting Ultraviolet and X-Ray Radiation

The Astro ultraviolet telescopes photograph the UV sky (imaging), measure the energy distribution of UV wavelengths (spectroscopy), and analyze the intensity and orientation of UV light (photometry and polarimetry). The Astro X-ray telescope uses spectroscopy to measure the energy distribution of X-ray photons.

Special cameras and films are used to photograph the UV sky in the same manner that we photograph the visible world. Rocket-borne telescopes on suborbital flights captured the first ultraviolet photographs from space. A pioneering UV photography experiment was flown on NASA's Orbiting Astronomical Observatory-2, and ultraviolet photographs of a few regions of the sky were obtained during the Apollo missions. However, most of the sky remains to be imaged in UV light. Images record the



Ultraviolet radiation is passed through a spectrograph to measure the emissions produced at specific wavelengths. This simulated spectrum from the Hopkins Ultraviolet Telescope shows emissions expected from the Am Her star. Bright emission lines of oxygen (O VI), nitrogen (N V), silicon (Si IV), carbon (C II, C III, C IV), helium (He II), and others are shown. The lines marked ⊕ are emissions produced by Earth's atmosphere.

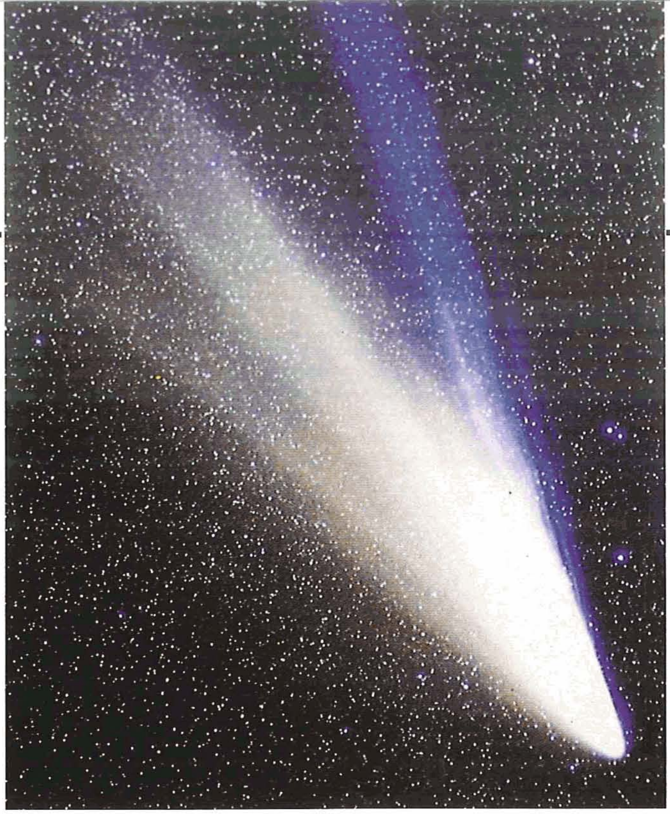
relative brightness, location, and structure of a large number of objects simultaneously. Images taken through selected filters can be compared to determine the temperatures of stars.

By techniques of spectroscopy, radiation can be separated into its component wavelengths or energies. Different chemical elements emit or absorb radiation at certain characteristic wavelengths (energies), producing spectral lines; these lines are signatures that uniquely identify the elements. Spectra of many objects contain emission or absorption lines throughout the UV and X-ray range which are due to elements (or ionization stages of elements) that are not present in the visible range. The relative characteristics of these lines provide information on chemical abundances and physical conditions of sources that is unavailable from any other wavelength region.

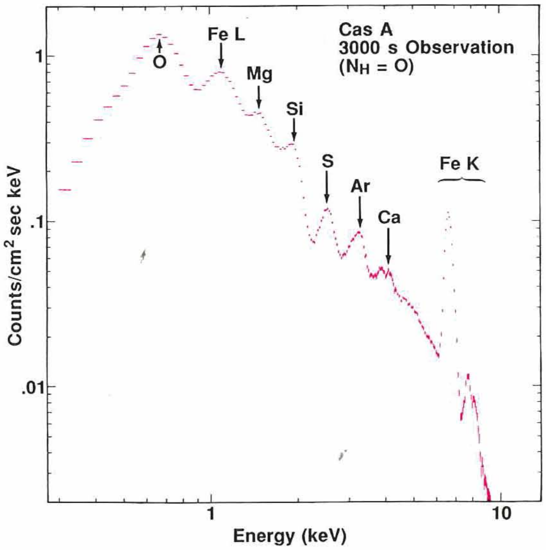
The UV band contains lines from many of the light and intermediate mass elements, including hydrogen, helium, carbon, nitrogen, oxygen, and neon. The X-ray band includes some of these elements as well as heavier ones such as iron, silicon, sulfur, and magnesium. These lines represent a tremendous range of gas temperatures and energy states of elements, information needed to interpret the physical conditions of objects.

Light scattered by interstellar dust is often polarized or oriented in a specific plane. This has been detected in visible wavelengths but has never been studied in the ultraviolet. Ultraviolet radiation is more readily absorbed or scattered by gas and dust than is visible light. Interstellar dust, tiny smoke-like particles that drift between the stars, is not very dense. However, as radiation travels tremendous distances from stars to us, dust and gas interacts with UV radiation, especially in the dusty plane of our Galaxy, the Milky Way. Theoretical investigations have shown that dust with different compositions or size distributions will scatter and absorb UV radiation in different ways. Hence, by observing distant stars whose radiation has been affected by interstellar dust scattering, we can actually learn something about the properties of this dust.

Polarized light seems to be most prevalent in regions where interstellar dust and magnetic fields are found together. Polarization can be used to study both dust and magnetic fields that would otherwise be invisible and can reveal the strength of magnetic fields of some stars and galaxies. In conjunction with photometry, which measures the brightness of sources, it can be used to discern much about the size and shape of objects. The technique of polarimetry has yet to be exploited in ultraviolet astronomy.

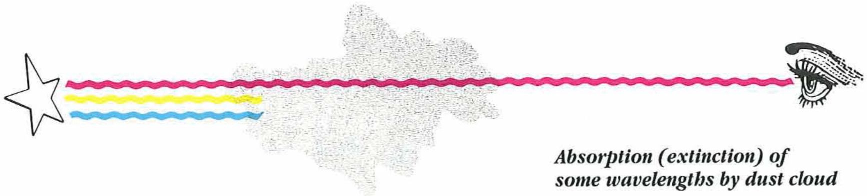


The light in the tail of a comet is reflected sunlight. As the sunlight is scattered by dust, it is polarized.

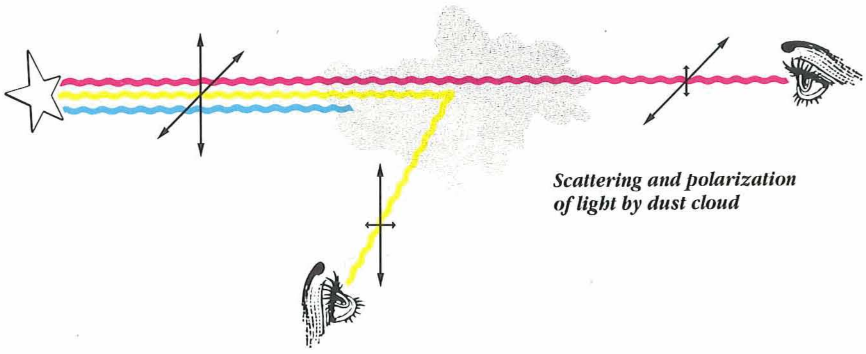


This simulated Broad Band X-Ray Telescope spectrum shows the energy of X-ray photons that might be typical of supernova remnants like Cassiopeia A. Oxygen (O), iron (Fe), magnesium (Mg), silicon (Si), sulfur (S), argon (Ar), and calcium (Ca) emit prominently from 500 to 10,000 electron volts (0.5 to 10 keV). Two groups of lines from iron are seen. Lines involving the innermost shell of the iron atom are labeled Fe K; lines involving the next shell are labeled Fe L.

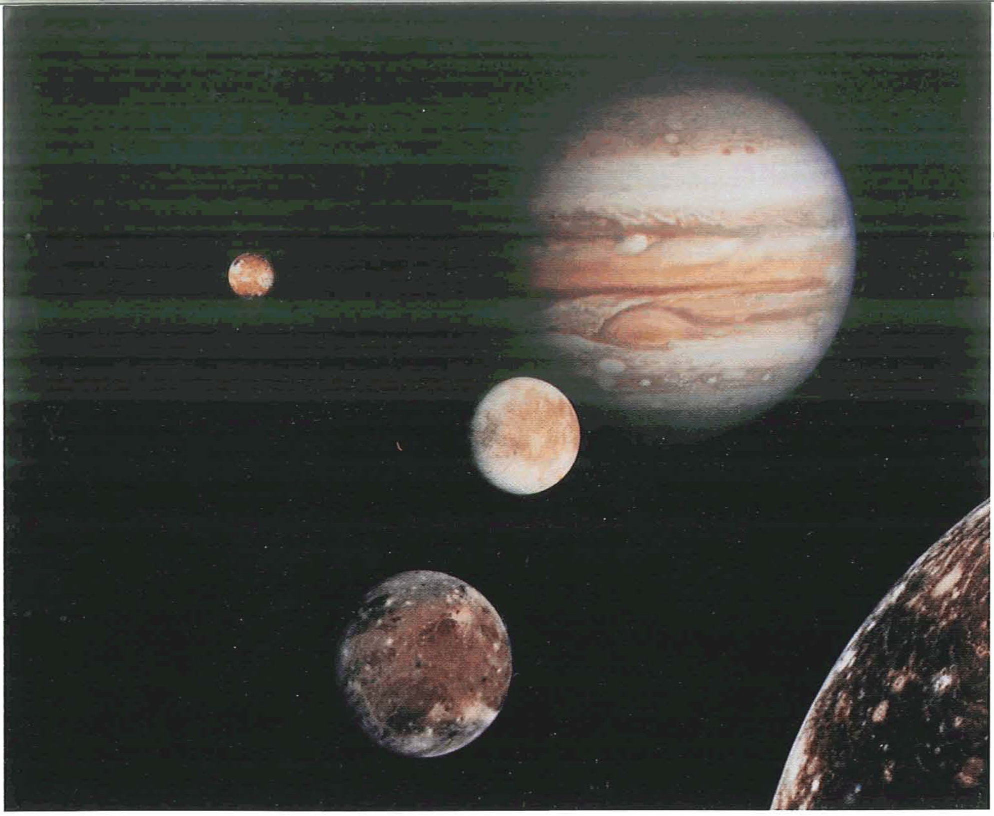
Below: Absorption, scattering, and polarization of light by a dust cloud



Absorption (extinction) of some wavelengths by dust cloud



Scattering and polarization of light by dust cloud



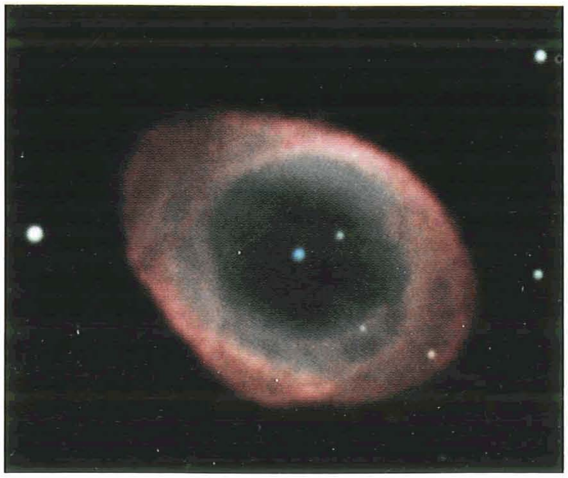
Astro studies ultraviolet emission from Jupiter and its moons, pictured in this composite of visible light images made by Voyager.

Astro Investigates the Universe

Astro views the cosmos from Earth orbit. It will observe our solar system — the sun and its family of nine planets and their moons. Astro will examine the chemistry of planetary atmospheres and the interactions of their magnetic fields. Jupiter with its exceptionally strong magnetic fields and turbulent atmosphere is of particular interest to Astro observers. Astronomers also want to study comets as they interact with light and particles from the sun to produce bright, streaming tails.

Astro will peer far beyond our solar system, located in a remote spiral arm of the Milky Way Galaxy, to study many types of stars. Our sun is one of an estimated several hundred billion stars in our Galaxy. Stars like our sun are the most common type: fiery spheres of gas, about 1 million times larger in volume than Earth, with nuclear furnaces that reach temperatures of millions of degrees. Today, our sun is a stable, middle-aged star, but some 5 billion years hence it will swell and swallow the inner planets including Earth. As a **red giant**, it may eject a shell of dust and gas, a **planetary nebula**. As the sun fades, it will collapse to an object no bigger than Earth, a dense, hot ember, a **white dwarf**. Astronomers predict that most stars may end their lives as white dwarfs, so it is important to study these stellar remains. White dwarfs emit most of their radiation in the ultraviolet, and one of Astro's main goals is to locate and examine them in detail.

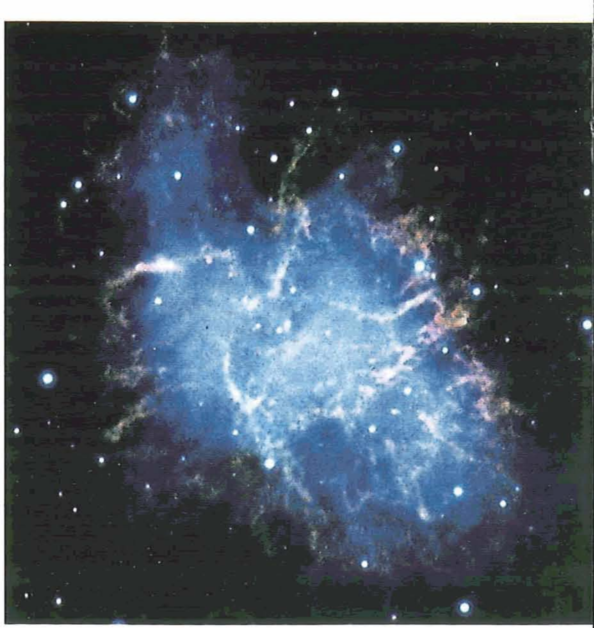
The Ring Nebula is a planetary nebula. Early telescope observers thought that these nebulae resembled formative planetary systems, but we now know that they contain material ejected from stars.



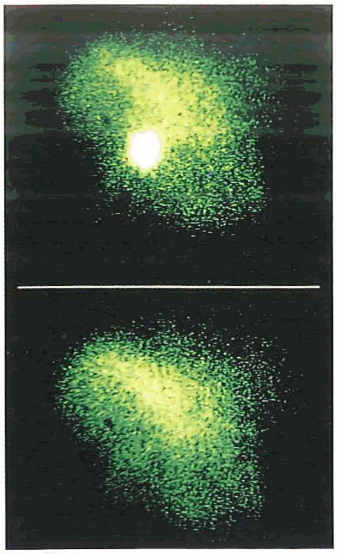
Stars with 10 to 100 times more mass than the sun burn hydrogen rapidly until their cores collapse and they explode as **supernovae**, among the most powerful events in the Universe. These stars are initially very hot and emit mostly ultraviolet radiation. Astro instruments will locate **hot, massive stars** of all ages so that astronomers can study these phases of stellar evolution.

Astro will view the recent explosion, Supernova 1987A, which spewed stellar debris into space. Supernovae forge new elements, most of which are swept away in expanding shells of gas and debris heated by the shock waves from the blast. Astro will look for **supernova remnants** which remain visible for thousands of years after a stellar death. Astro's ultraviolet and X-ray telescopes will provide information on element abundances, the physical conditions in the expanding gas, and the structure of the interstellar medium.

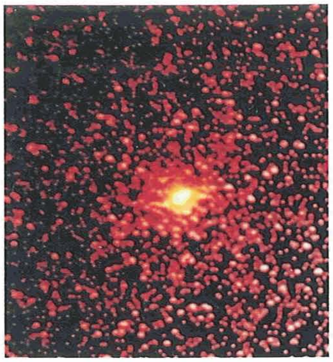
After a supernova explosion, the stellar core sometimes collapses into a **neutron star**, the densest and tiniest of known stars, with mass comparable to the sun compacted into an area the size of a large city.



Crab Nebula: remnant of a supernova



These X-ray images of the Crab Nebula show a pulsar, the surviving core of an exploded star. Just as the beam from a lighthouse appears to wink, this pulsar blinks on (upper) and off (lower) 33 times per second.



An invisible object associated with a visible star in the constellation Cygnus may be a black hole. The X-rays that produced this Cygnus X-1 image may be from matter falling into the black hole.

Matter can become so dense that a sugar cube of neutron star material could weigh a billion tons. Sometimes neutron stars are **pulsars** that emit beacons of radiation and appear to blink on and off as many as hundreds of times per second because they spin so rapidly. Scientists have theorized that some stars may collapse so far that they become **black holes**, objects so dense and gravitationally strong that neither matter nor light escapes. Ultraviolet radiation and X-rays are thought to be produced as hot, whirling matter is drawn into a black hole.

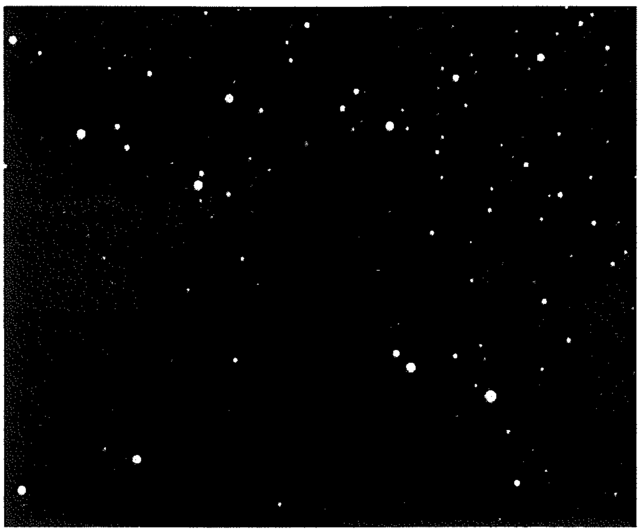
Few stars live in isolation; most are found in pairs or groups. Some stellar companions orbit each other and often pass so close that mass is transferred from one star to the other, producing large amounts of UV and X-ray radiation. These **binary star systems** may consist of various combinations of stars including white dwarfs, neutron stars, and black holes.

Stars may congregate in **star clusters** with anywhere from a few to millions of members. Often, there are so many stars in the core of a cluster that it is impossible to detect the visible light from individual stars. Because they shine brightly in the UV, Astro will be able to isolate the hot stars within clusters. The clusters are excellent laboratories for studying stellar evolution because the stars residing there formed from the same material at nearly the same time. However, within a single cluster, stars of different masses evolve at different rates. We can study stellar evolution by looking at clusters of different ages. Each cluster of a given age gives us a snapshot of what is happening as a function of stellar mass. By examining young clusters (less than 1 million years old) and comparing them to old clusters (10 million years old), we can piece together what happens over a long time.

The space between stars is not completely empty but is

Globular star cluster M13

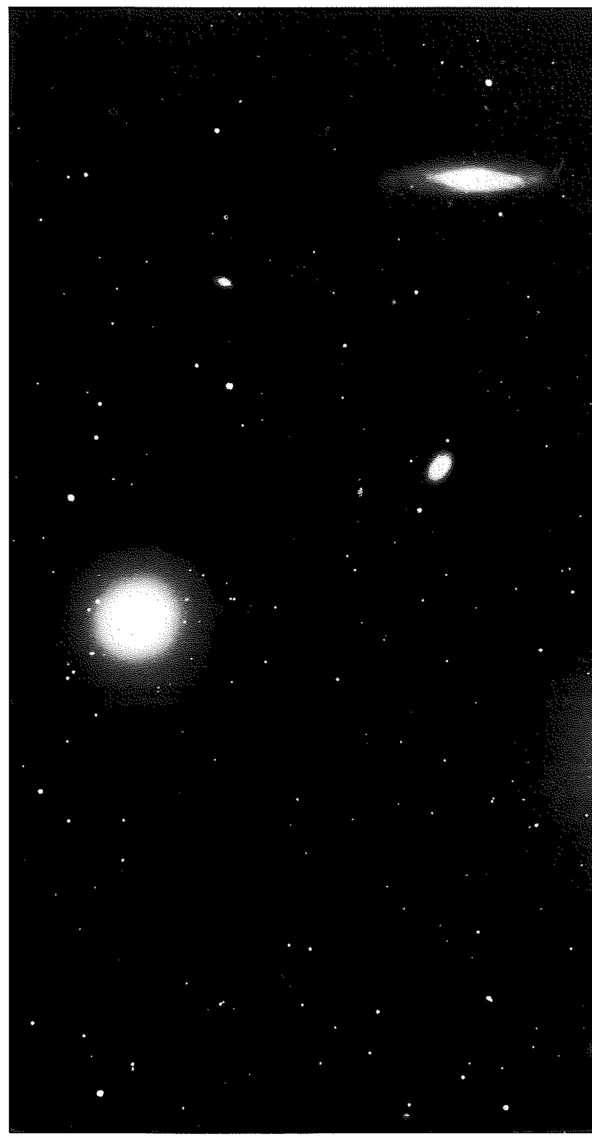
filled with dust and gas, some of which will condense to become future stars and planets. This **interstellar medium** is composed chiefly of hydrogen with traces of heavier elements and has a typical density of 1 atom per thimbleful of space. Astro will be able to measure the properties of this material more accurately by studying how it affects the light from distant stars. For the most part, the interstellar medium is relatively cool, but temperatures and densities vary by factors of a million. Dense clouds with 10 to 10,000 atoms and molecules per cubic centimeter and very low temperatures exist as well as hot, low-density cavities (million degree temperatures, 1 ion per 1,000 cubic centimeters). Dense clouds of dust that surround stars and scatter and reflect colorful light are called **reflection nebulae**. These are often illuminated by hot, young stars in stellar nurseries hidden in the clouds. Ultraviolet observations will reveal the features of stars hidden by the dust as well as the size and composition of the dust grains.



The interstellar medium contains dark clouds, like the Horsehead Nebula, that absorb starlight.

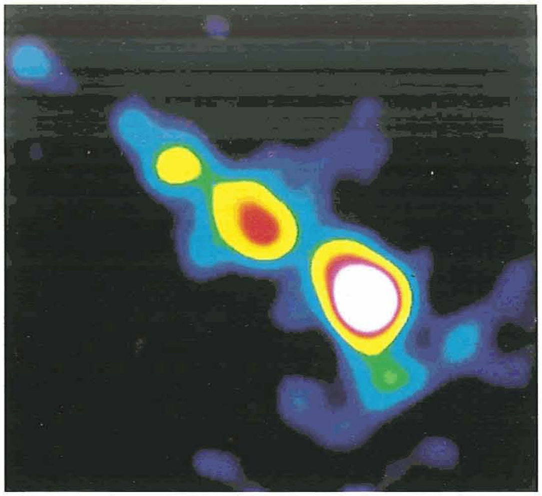
Beyond the Milky Way are at least a hundred billion more **galaxies**, many with hundreds of billions of stars. They contain most of the visible matter in the Universe. The galaxies form **clusters of galaxies** that have tens to thousands of members. X-ray and ultraviolet emission will allow us to study the hottest, most active regions of these galaxies as well as the **intergalactic medium**, the hot gas between the galaxies in a cluster. Galaxies have a variety of shapes and sizes: gigantic spirals like our Milky Way, egg-shaped ellipticals, and irregular shapes with no preferred form. Astro will survey the different types of galaxies and study their evolution. The nearby galaxies will appear as they were millions of years ago, and Astro will see the most distant ones as they were billions of years ago. By comparing these galaxies, we can trace the history of the Universe.

Some galaxies are in the process of violent change. Such **active galaxies** have central regions (nuclei) that emit huge amounts of energy; their ultraviolet and X-ray emission may help us identify their source of power. Both the ultraviolet and X-ray telescopes will detect **quasars**, very distant compact

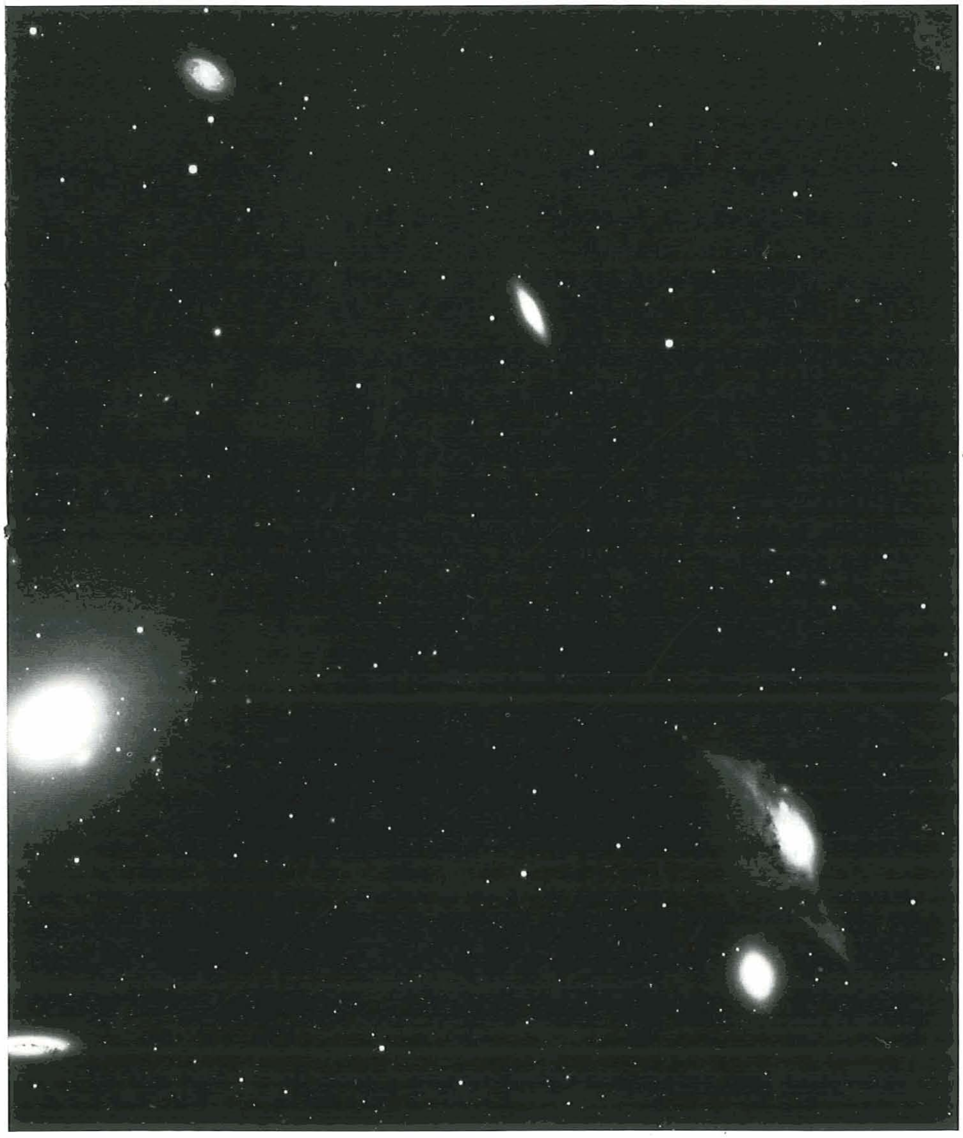


objects that radiate more energy than 100 normal galaxies. Quasars may be the nuclei of ancient active galaxies. Strong X-ray and ultraviolet radiation arising in the central cores of these powerful objects may help us discover what the objects really are.

This is the Universe as we know it today, but many of our ideas are only predictions based on theory and a few observations. We still lack the observations needed to confirm or refute many of our theories. We do not know the exact size of the Universe or its age. We have never definitely seen a black hole, and scientists continue to question the nature of quasars. To understand these mysteries, we need to see the Universe in all its splendor. Astro is part of NASA's strategy to study the Universe across the electromagnetic spectrum, in all wavelengths. ▲



An X-ray image of the active galaxy Centaurus A reveals a central powerhouse that is producing jets of high-energy particles.

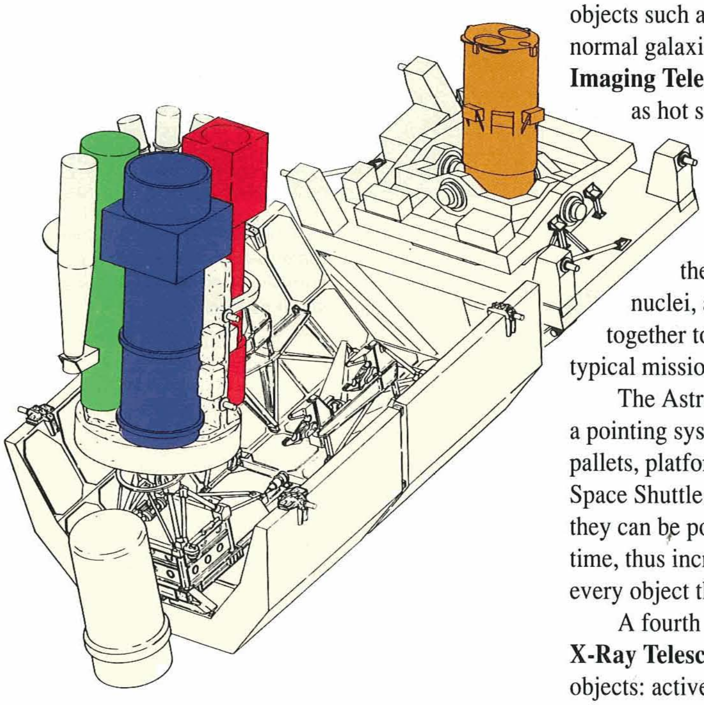


Galaxies with various shapes and sizes form a rich cluster.

The Astro Observatory

The Astro Observatory is a carefully selected set of telescopes and instruments uniquely designed to address specific questions in UV and X-ray astronomy, yet well-suited for joint observations. In fact, the advantage of using them together is the basis for the Astro Observatory.

The Astro Observatory has three UV-sensitive instruments: the **Hopkins Ultraviolet Telescope (HUT)** for studying spectra of faint astronomical objects such as quasars, active galactic nuclei, and normal galaxies in the far ultraviolet; the **Ultraviolet Imaging Telescope (UIT)** for imaging objects such as hot stars and galaxies in broad ultraviolet wavelength bands and with a wide field of view; and the **Wisconsin Ultraviolet Photo-Polarimeter Experiment (WUPPE)** for studying the polarization of hot stars, galactic nuclei, and quasars. These instruments work together to make 200 to 300 observations during a typical mission.



The Astro Observatory

- *HUT*
- *UIT*
- *WUPPE*
- *BBXRT*

The Astro ultraviolet telescopes are mounted on a pointing system that is attached to two Spacelab pallets, platforms carried in the payload bay of the Space Shuttle. The telescopes are coaligned so that they can be pointed in the same direction at the same time, thus increasing the scientific data return on every object that is observed.

A fourth Astro instrument, the **Broad Band X-Ray Telescope (BBXRT)**, views high-energy objects: active galaxies, quasars, and supernovae. This telescope is mounted on a separate pointing system secured by a support structure in the payload bay. For joint observations, it can be aligned with the UV telescopes to see the same objects, but it also can be pointed in other directions to view other X-ray sources. This instrument makes 200 to 300 observations per mission.

Unlike free-flying satellites that are launched and left in space, the Astro payload is designed to be reusable and may be reflown on additional Shuttle missions. Since the UV telescopes and the X-ray telescope are mounted on different support structures, they can be reflown together or separately. Prototypes of the instruments have been successfully tested and flown on sounding rockets. The first flight of these telescopes together makes Astro-1 a mission without precedent. The Astro Observatory can simultaneously obtain UV imagery, spectroscopy, and polarimetry data as well as X-ray spectroscopy on the same object. No other observatory has ever accomplished this feat.

HUT looks for elements formed in stellar explosions such as this one that occurred in Cygnus.

Probing the Far and Extreme Ultraviolet: The Hopkins Ultraviolet Telescope

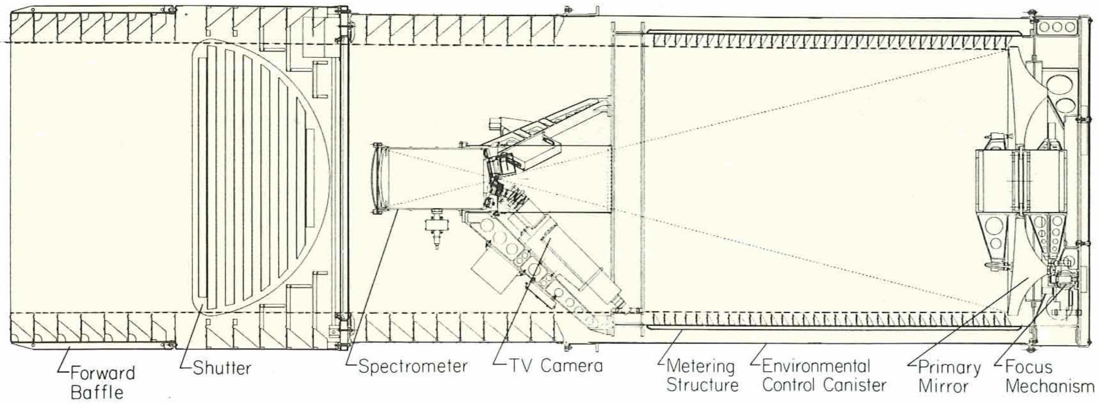
To study an object's spectrum, radiation must be separated into its component wavelengths. The strengths of various wavelengths tell us how much of certain elements are present; the ratio of the spectral lines reveals a source's temperature and density; and the shape of the spectrum shows the physical processes occurring in a source.

The Hopkins Ultraviolet Telescope (HUT) was designed and built by members of the Center for Astrophysical Sciences and the Applied Physics Laboratory of The Johns Hopkins University in Baltimore, Maryland. It consists of a 90-centimeter (36-inch) f/2 mirror that focuses incoming light from a celestial source on the aperture of a prime focus spectrograph. The telescope and spectrograph are optimized for the little-explored 900 Å to 1,200 Å region, but the instrument is versatile enough to cover most of the EUV and FUV spectral range from 425 Å to 1,850 Å.

Many technical challenges were overcome to produce an instrument with these characteristics. One property of UV radiation is that at shorter wavelengths photons are energetic enough to interact with mirrors and are absorbed rather than reflected by the mirror's surface. Usually this effect can be counteracted by overcoating the mirror with a substance that helps maintain its UV reflectivity. A major innovation of the HUT instrument is a coating of the rare element iridium, which remains reflective down to about 400 Å and permits spectroscopy in much of the EUV and FUV range.

Another challenge overcome by the HUT spectrograph is one of logistics — keeping the sensitive instrument free from contamination during ground operations. The electronic detector in the instrument is coated with a cesium iodide compound that allows it to "see" incoming UV photons. The detector must never come in contact with normal air (water vapor, in particular) because this would destroy its UV sensitivity. This is not a problem in the near-vacuum of space, but to prevent damage during assembly and testing the HUT spectrograph and detector have to be maintained in a near-vacuum, or during brief transition periods in a dry nitrogen atmosphere. Once the spectrograph is sealed, vacuum pumps are used to evacuate and maintain the spectrograph at a vacuum level of about 1/100,000,000th of an atmosphere.

With its significantly extended wavelength coverage and greater sensitivity than previous instruments, HUT can scrutinize a variety of targets. For example, the brightest quasars have been observed by the International Ultraviolet Explorer satellite, but exposures are very long, the wavelength coverage is restricted to greater than about 1,200 Å, and the quality of the resultant spectrum is often quite poor. HUT will observe fainter quasars for shorter periods of time and get better quality spectra with coverage down to the Lyman limit (912 Å).



Principal HUT components

Within our own Galaxy, we cannot probe great distances in the spectral region below the Lyman limit, 912Å. All the photons at these wavelengths have enough energy to ionize atomic hydrogen and are absorbed as they interact with this primary constituent of the interstellar gas. However, a remarkable phenomenon — redshift — can be the basis for studying some extragalactic objects that radiate shortward of the Lyman limit. Most astronomers are convinced that redshift is caused by the expansion of the Universe as a result of the initial Big Bang. Light emitted by distant galaxies arrives at Earth shifted to the red of its original wavelength; the farther away the galaxy, the greater the spectrum is shifted to the red. Hence, redshift is used as a measure of distance to galaxies and related objects. Indeed in the most distant extragalactic objects, radiation orginally emitted at wavelengths shortward of 912Å has shifted toward longer red wavelengths well beyond the Lyman limit of our Galaxy.

Quasars have highly redshifted spectra. Thus, the EUV spectrum of more distant (high redshift) quasars will be shifted into the HUT range, permitting their EUV flux to be measured directly for the first time. Observations of nearby (low redshift) quasars and active galaxies will provide measurements of emission line profiles and weak absorption features with unprecedented accuracy, allowing models for these objects to be tested more effectively.

At Kennedy Space Center, technicians prepare HUT for the mission.

Active galaxies have very bright centers surrounded by clouds of hot gas. It is speculated that black holes may lie in these galactic nuclei and in quasars, but many questions about physical conditions in these objects are unanswered. By looking into the central regions of such objects, investigators may be able to determine what is really there, how dense the hydrogen atmospheres are, how abundant helium is, and how the objects resemble or differ from one another. The nuclei of normal galaxies also have been difficult targets to study; spectra from HUT will be used to examine the stellar populations of these objects, in particular providing information on the hottest stars.

Closer to home, there are many objects in our own Galaxy that are the target of the HUT observations. Very hot objects that emit much of their energy in the 900 Å to 1,200 Å region are of special interest. These include certain binary star systems, pairs of stars mutually attracted by gravity. If the two stars are close enough, some of the larger star's material may be transferred toward its compact companion star, creating an accretion disk of hot, swirling material. On a grander scale, similar processes may be taking place around black holes and the centers of quasars as matter is attracted to them. The light from some binary systems periodically changes because of the dual motion of the stars; some of these systems will be observed several times to measure temporal variations and gain additional information about the binary system and its individual components.

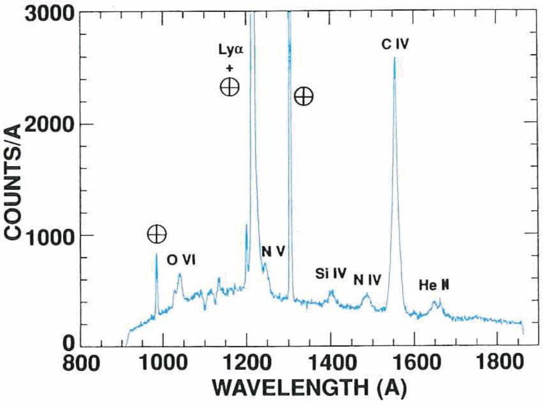
Other very hot stars that emit energy in this range include collapsed stellar remnants, such as the central stars of planetary nebulae, white dwarfs, and neutron stars. Some of the nearest white dwarf stars will be observed in the extreme ultraviolet using HUT to gain information that is currently available for only a few stars.

The large spectrograph apertures on HUT permit observations of extended nebulae such as supernova remnants. Many of these gaseous filaments are so faint and extended that they are difficult targets for other observatories, which are optimized for studying point sources such as stars. Spectra of these nebulae have many emission lines with relative intensities that can be interpreted in terms of temperatures, densities, and chemical composition of the gas. Young supernova remnants are of special interest because in them we see enriched abundances of heavy elements that were made within the pre-supernova star. Presumably, the heavy elements on Earth and in our bodies were created in this manner long ago. Understanding these processes will help answer questions about the chemical evolution of the Milky Way.

The interstellar medium, a thin, dusty gas between stars, scatters and absorbs radiation, dimming or even extinguishing light from distant stars. Thus, the dust makes it difficult or impossible to see

HUT will observe NGC 4151, one of the nearest and brightest active galaxies.

This simulated spectrum from the Hopkins Ultraviolet Telescope shows emissions of oxygen (O VI), hydrogen Lyman alpha (Lyα), nitrogen (N V), silicon (Si IV), nitrogen (N IV), carbon (C IV), and helium (He II) that might be expected from an active galaxy's nucleus. Expected emission lines from the upper atmosphere beyond the Shuttle's orbit are marked ⊕.



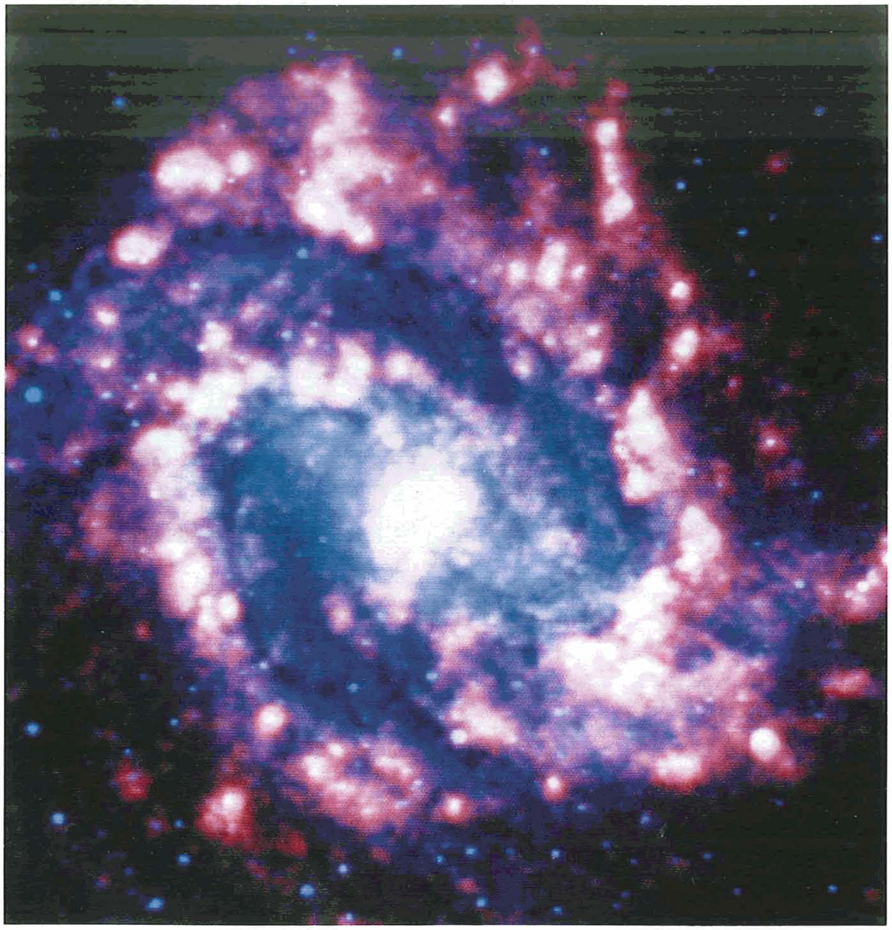
distant celestial objects. It is very important to be able to correct for this interstellar extinction, since almost every object observed by HUT will be affected by it to some extent. Although ultraviolet radiation tends to be scattered and absorbed by interstellar gas and dust more readily than visible light, this effect can be turned into an advantage: it reveals properties of the interstellar medium itself and helps astronomers determine how the dust masks the spectra of different stars.

Within the solar system, the outer planets are of interest to the HUT investigators, especially Jupiter, its moons, and its magnetosphere. Jupiter's moon Io constantly releases ionized material into the surrounding region of space where it interacts with the Jovian magnetic field. The HUT observations address a number of problems related to ion abundances in this plasma (ionized gas), injection mechanisms, and the energy balance between particles and magnetic fields. In addition, FUV and EUV observations of all the outer planets will be made to investigate aurorae and gain insight into the interaction of each planet's magnetosphere with the solar wind.

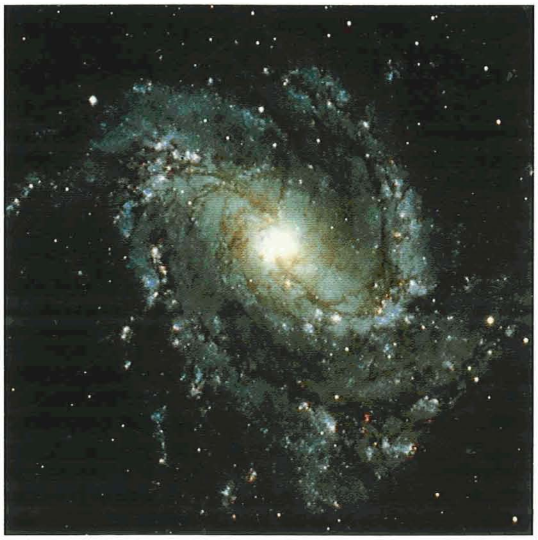
HUT Vital Statistics

Sponsoring Institution:	The Johns Hopkins University Baltimore, Maryland
Principal Investigator:	Arthur F. Davidsen
Project Scientist:	Knox S. Long
Co-Investigators:	
William G. Fastie	Knox S. Long
Paul D. Feldman	H. Warren Moos
Richard C. Henry	
Deputy Project Scientist:	Randy A. Kimble
Assistant Project Scientists:	
William P. Blair	Henry C. Ferguson
Charles W. Bowers	Gerard A. Kriss
Samuel T. Durrance	
Project Management and Engineering:	
Glen H. Fountain	Harold W. Screen
Steven J. Conard	Kevin J. Heffernan
Telescope Optics:	90 cm (36 in.) aperture, f/2 focal ratio iridium-coated paraboloid mirror
Instrument:	Prime Focus Rowland Circle Spectrograph with microchannel plate intensifier and electronic diode array detector
Field of View of Guide TV:	10 arc minutes
Spectral Resolution:	3.0 Å
Wavelength Range:	850 Å to 1,850 Å (First Order) 425 Å to 925 Å (Second Order)
Weight:	789 kg (1,736 lb)
Size:	1.1 m (44 in.) diameter 3.7 m (12.4 ft) length

Arthur F. Davidsen,
HUT Principal Investigator,
The Johns Hopkins University



The spiral galaxy M83 seen in visible light (right) is cluttered with stars. When M83 is imaged in the ultraviolet (above), the cooler stars disappear to reveal the spiral arms more clearly.



Ultraviolet Photography: The Ultraviolet Imaging Telescope

For many years, scientists have used balloons, rockets, high-altitude aircraft, satellites, and now the Space Shuttle to get ultraviolet telescopes above Earth's atmosphere. Yet the total time for UV imaging amounts to only a few hours, mostly in the form of 5-minute sounding rocket excursions and short exposures made during manned space missions. In the 20 years that astronomical observations have been made from space, no high-resolution ultraviolet photographs of objects other than the sun have been made. Nonetheless, our brief glimpses of the UV sky have led to important discoveries in spiral galaxies, globular clusters, white dwarf stars, and other areas.

Deep, wide-field imaging is a primary means by which fundamentally new phenomena or astrophysically important examples of known classes of objects will be recognized in the ultraviolet. Part of the Astro Observatory, the Ultraviolet Imaging Telescope (UIT) developed at NASA's Goddard Space Flight Center in Greenbelt, Maryland, is the key instrument for such investigations. UIT is a powerful combination of telescope, image intensifier, and camera.

Images are recorded directly onto a very sensitive astronomical film for later development after the Shuttle lands. UIT has enough film to make 2,000 exposures per flight. A series of 11 different filters allows specific regions of the UV spectrum to be isolated for quantitative energy distribution studies. After development, each image frame is electronically digitized to form 2,048 x 2,048 picture elements or pixels, and then further analysis is done with computers.

UIT has a 38 cm (15 in.) diameter mirror with a f/9 focal ratio and a 40 arc minute field of view. A single frame of 70-mm film images a field somewhat larger than that subtended by the moon, with resolution of about 2 arc seconds. UIT has the largest field of view of any sensitive UV imaging instrument planned for flight in the 1990s. It will photograph nearby galaxies, large clusters of stars, and distant clusters of galaxies.

The wavelength range of UIT covers the ultraviolet spectrum from 1,200 Å to 3,200 Å. A 30-minute exposure (the length of one orbital night) will record a blue star of 25th magnitude, a star about 100 million times fainter than the faintest star visible to the naked eye on a dark, clear night. The UV sensitivity of the instrument favors the detection of hot objects which emit most of their energy in the ultraviolet. Common examples span the evolutionary history of stars: massive stars (O-type) and stars in the final stages of stellar evolution (white dwarfs). Images of numerous relatively cool stars that do not radiate much in the ultraviolet are suppressed, and the UV sources stand out clearly in the photographs.

The potential of ultraviolet imaging is evident in the search for hot stars in the rich, crowded field of a globular cluster. UIT is the first instrument that can take high-resolution UV images of an entire cluster 10 to 20 arc minutes across, about one-half the size of the apparent diameter of the full moon. Since UIT makes longer exposures than previous instruments, fainter objects will be visible in the images. Astronomers can use these images to pinpoint interesting ultraviolet objects throughout the cluster and study their relationships. Such clusters are an ideal laboratory for studying stellar evolution, because all the some 100 thousand to 1 million stars in each cluster were formed at the same time from gas with the same initial chemical composition. However, the mass of stars in a cluster varies, and the stars evolve at different rates determined by their individual masses. The more massive stars shine more brilliantly, use their nuclear fuel supply more rapidly, and age more quickly. The range of stellar masses when a cluster forms determines the cluster's appearance today; therefore, the properties of sample stars in a cluster can be related to their evolutionary history.

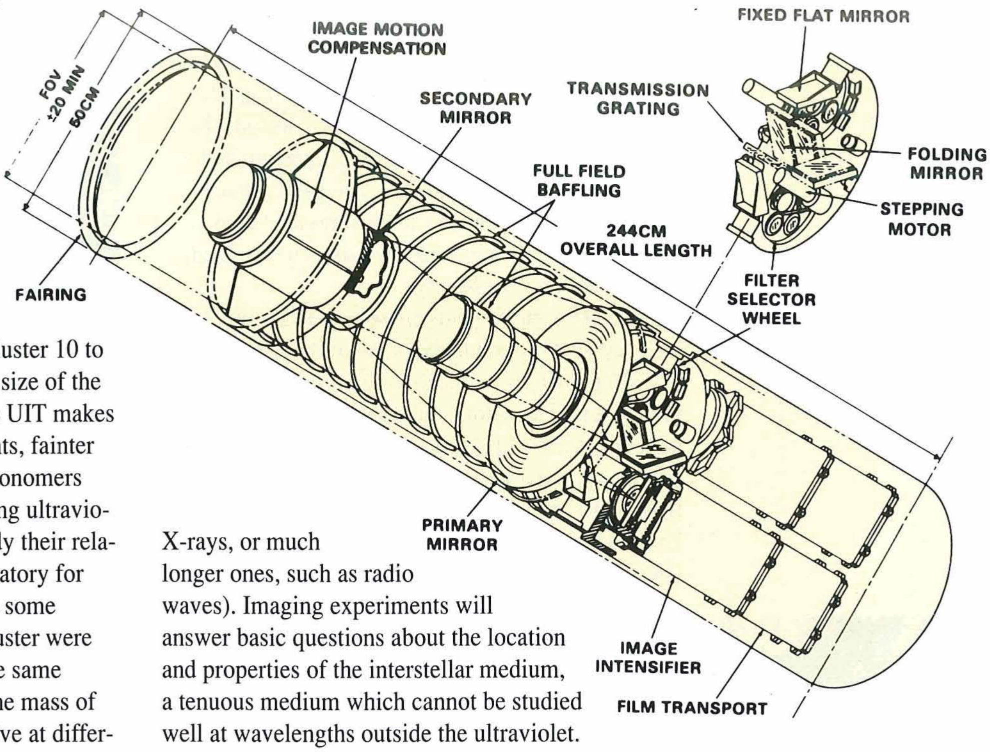
An important prediction of stellar evolution theory is that globular clusters should contain large numbers of hot white dwarf stars. These are the end products of stars like our sun. The brightest white dwarfs in the nearest globular clusters are just on the verge of detection at visual wavelengths with the largest ground-based telescopes equipped with the most sensitive detectors. However, hot white dwarfs emit most of their radiation in the ultraviolet. This property, together with the reduced UV output of the cool stars, makes the white dwarfs easily visible to UIT. Ultraviolet images will provide excellent data on these faint stars. The temperatures, brightnesses, and even the locations of the white dwarfs within the globular cluster will yield vital information about star formation, evolution, and death.

Another important use of UV imagery is for studying the properties and distribution of dust found throughout interstellar space. These particles are microscopic, but they are very effective at blocking the passage of UV radiation (but not electromagnetic radiation of much shorter wavelengths, such as X-rays, or much longer ones, such as radio waves). Imaging experiments will answer basic questions about the location and properties of the interstellar medium, a tenuous medium which cannot be studied well at wavelengths outside the ultraviolet. Scientists wonder whether the dust grains are the same in all galaxies, especially in such strikingly disturbed ones as M82 and NGC 5128. General UV extinction properties as well as the 2,200 Å absorption band signature are used by UIT to probe the interstellar dust.

During the Astro missions, UIT will be able to survey many regions of the ultraviolet sky for the first time. Aside from the exciting possibility of finding unexpected new phenomena, these surveys will help in solving problems where existing telescopes are not sensitive enough. For instance, the UIT survey will help determine the relative numbers of very small, star-forming galaxies. Their hot star populations radiate brightly in the ultraviolet, making these galaxies easier to find with UIT than with visible light telescopes on Earth.

Another goal of the UIT surveys is to identify extremely distant star-forming galaxies in the early phases of their evolution. These galaxies are difficult to identify with ground-based telescopes, but they will have unique signatures on the UIT images because of their large redshifts and the copious amounts of UV radiation emitted from their massive, young stars. Studies with UIT and the other Astro instruments will contribute enormously to our understanding of galaxy formation and evolution.

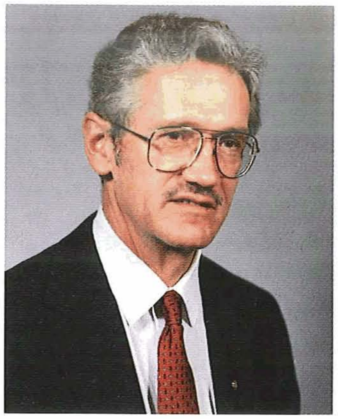
In addition to sources of ordinary thermal radiation (in which the energy spectrum is determined by



UIT components

the temperature of the emitting source), UIT effectively studies the many objects that radiate by "nonthermal" processes, such as synchrotron radiation created by charged particles moving in a magnetic field. Examples of nonthermal emitters include the Crab Nebula (a supernova remnant), quasars, and a related class of objects called active galactic nuclei. These objects are brighter in the ultraviolet than in visible light, and their properties are better studied through ultraviolet imagery.

The UIT target fields are selected carefully to yield the first representative view of the ultraviolet sky. We do not know what strange objects might be found there. That exotic, unexpected phenomena will be found is most likely, for throughout the history of astronomy, important discoveries were made every time a new spectral region was probed deeply. Ultraviolet imagery will give us a unique view of the Universe.



Theodore P. Stecher, UIT Principal Investigator, NASA/Goddard Space Flight Center

UIT is checked out at the Kennedy Space Center.

Hot stars in the globular cluster, M5, affect the energy balance of our entire galaxy and tell us about the rate of new star formation. Astro-1 images will be clearer than this photograph made from a UIT rocket flight because the resolution will be 10 times better.

UIT Vital Statistics

Sponsoring Institution:	NASA/Goddard Space Flight Center (GSFC) Greenbelt, Maryland
Principal Investigator:	Theodore P. Stecher (NASA/GSFC)
Co-Investigators:	Ralph C. Bohlin (Space Telescope Science Institute) Robert W. O'Connell (University of Virginia) Morton S. Roberts (National Radio Astronomy Observatory) Andrew M. Smith (NASA/GSFC)
Supporting Astronomers:	Peter C. Chen Robert H. Cornett Jesse K. Hill Wayne B. Landsman Stephen P. Maran Andrew G. Michalitsianos Susan G. Neff Ronald A. Parise
Project Management Team:	Gerald R. Baker Albert N. Blum Robert W. Fulcher Jack C. Tebay
Telescope Optics:	Ritchey-Chretien (variation of Cassegrain two-mirror system with correction over wide field of view)
Aperture:	38 cm (15 in.)
Focal Ratio:	f/9
Field of View:	40 arc minutes
Angular Resolution:	2 arc seconds
Wavelength Range:	1,200 Å to 3,200 Å
Magnitude Limit:	25
Filters:	2 filter wheels, 6 filters each
Detectors:	Two image intensifiers with 70-mm film, 1,000 frames each; IIaO astronomical film
Exposure Time:	Up to 30 minutes
Weight:	474 kg (1,043 lb)
Size:	81 cm (32 in.) diameter 3.7 m (12.4 ft) length

The Geometry of Stars: The Wisconsin Ultraviolet Photo-Polarimeter Experiment

Any star, except for our sun, is so distant that we see only a point of light; we cannot see any surface details. Our clues to the shape and structure, or geometry, of the emitting source lie in the spectral signatures of its radiation. If that radiation is polarized, it can tell us something about the source's geometry, the physical conditions at the source, and the reflecting surfaces along the radiation's path.

The Wisconsin Ultraviolet Photo-Polarimeter Experiment (WUPPE), developed by the University of Wisconsin, is designed to measure polarization and intensity of ultraviolet radiation from celestial objects. Photometry is the measurement of the intensity of the electric field, while polarization is the measurement of the orientation of the electric field. Light and all types of radiation are electromagnetic waves. If the electric field shows a preferential orientation, the light is said to be polarized. The light from an ordinary light bulb, for example, is unpolarized; if that light is scattered, however, the scattered light tends to be polarized. Polaroid sun glasses reduce glare by rejecting light polarized in directions characteristic of scattering from horizontal surfaces.

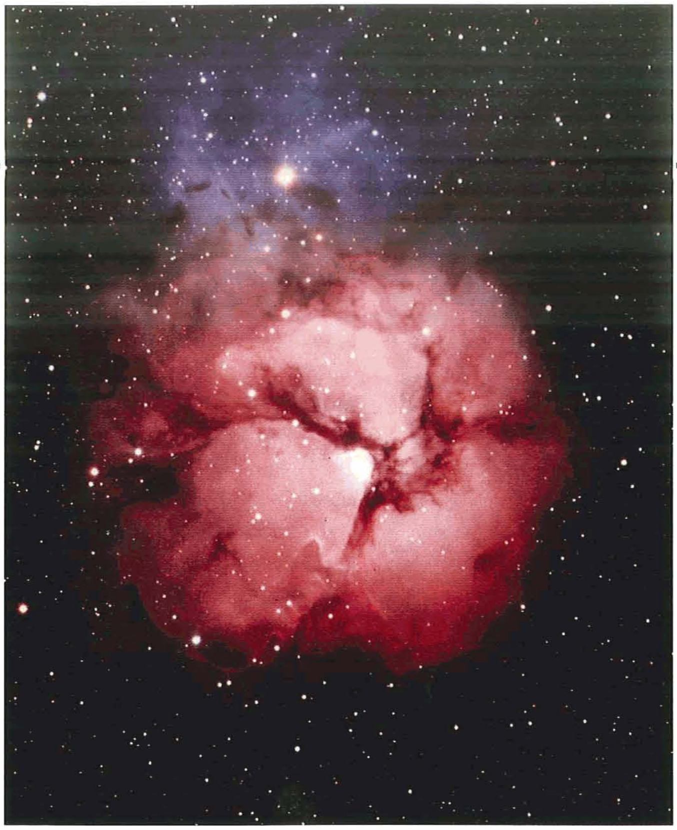
In the UV spectrum, both photometry and polarization are extremely difficult measurements to achieve with the high degree of precision required for astronomical studies. To develop an instrument that could make these delicate measurements required an unusually innovative and advanced technical effort. Thus, the WUPPE investigation is pioneering, a foray with a new technique into uncharted territory.

To date virtually no observations of polarization of astronomical sources in the ultraviolet have been carried out. WUPPE measures the polarization by splitting a beam of radiation into two perpendicular planes of polarization, passing the beams through a spectrometer, and focusing the beams on two separate array detectors.

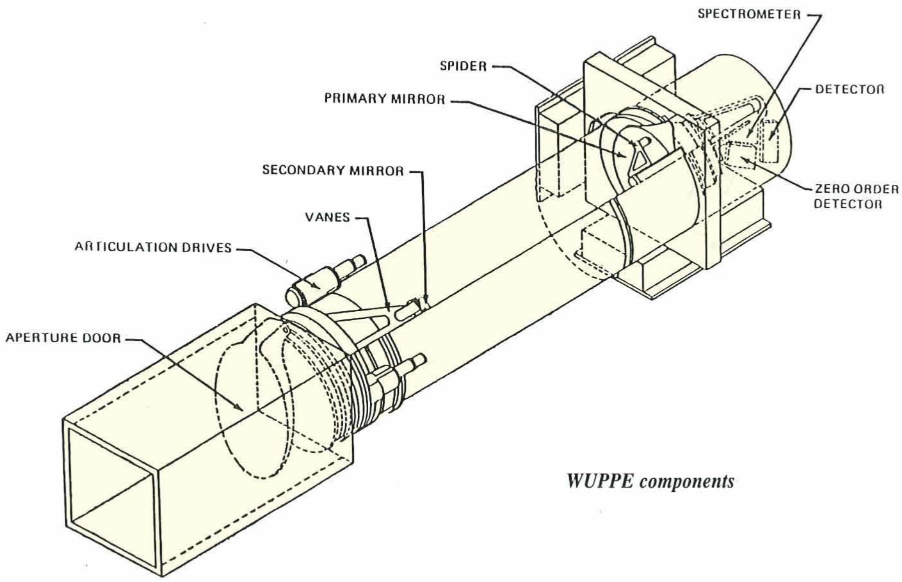
The targets of WUPPE investigations are primarily known objects, in our Galaxy and beyond, for which comparative data exist in other wavelengths. Like the Hopkins Ultraviolet Telescope, WUPPE also makes spectroscopic observations of hot stars, galactic nuclei, and quasars; since it covers longer UV wavelengths from 1,400 Å to 3,200 Å, the two instruments complement each other nicely.

Many of the objects that WUPPE studies are nonthermal. Light from thermal objects is unpolarized because atoms and electrons move in random directions as they emit radiation. However, radiation emitted by nonthermal objects can be polarized, and the degree of polarization is often determined by the structure of the emitting object. For example, large, uniform magnetic fields organize free electrons so that they radiate polarized light. The degree of linear or circular polarization of the light depends on how fast the electrons are moving, the structure of the magnetic field, and the viewing angle of the observer.

Very strong magnetic fields, many millions of times stronger than Earth's, polarize radiation. From the nature of the spectrum and the polarization, we are able to know about these magnetic fields. It is interesting that for many astronomical sources the



The Trifid Nebula is divided by dark lanes of dust that polarize light.



WUPPE components

WUPPE is prepared for the Astro-1 mission.

polarization increases rapidly at the shortest wavelengths observable from the ground. Does the polarization continue to increase in the ultraviolet? Different theories make different predictions in answer to this question, and WUPPE provides a new way to test these theories.

White dwarfs figure prominently in the Astro observing program, while substantial effort also is directed to a variety of synchrotron sources such as those found in radio galaxies. It seems that the larger the magnetic field of white dwarfs, the farther into the UV their polarized radiation extends. Thus, WUPPE studies stars possessing larger magnetic fields than stars viewed from the ground. Circularly polarized light has been detected from some magnetic white dwarfs, such as the very faint star AM Her in the constellation Hercules. Judged by the characteristics of their radiation, quasars also seem to have strange geometries and strong magnetic fields. The WUPPE instrument is unique in its ability to detect both linear and circular polarization simultaneously. It is thus well-suited for the examination of intense magnetic fields in compact objects, both faint and bright.

Light is also scattered and polarized by the interstellar medium. Very small elongated grains of dust aligned by weak interstellar magnetic fields absorb and scatter radiation. Both the transmitted as well as the scattered light is polarized by the dust grains. Careful studies of the scattered and transmitted radiation will help us determine the size, shape, and type of dust grains. Interstellar scattering is much greater in the ultraviolet, and smaller grains can be studied in the ultraviolet than in the visible spectra. Astro scientists are eager to observe stars obscured by interstellar dust and to study reflection nebulae illuminated by the light of nearby stars. To learn about this dust is to learn about the sites of new star formation.

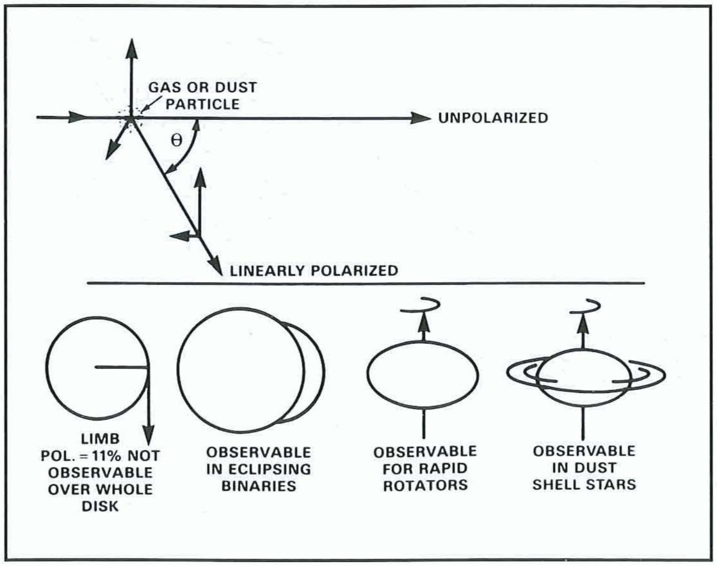
Scientists are interested in the overall geometry of the interstellar medium, which varies from region to region, and the nature of the polarizing material itself. The total extinction of wavelengths by this dust is much higher in the UV and displays large variations. With improved insight into the dusty clouds that blanket space, scientists may better understand the origin and evolution of our Galaxy and others.

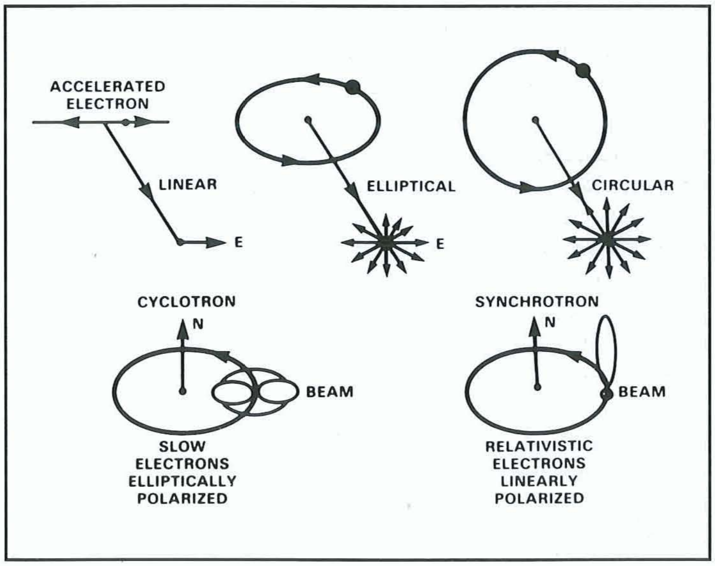
One interesting feature of the interstellar dust is the 2,200 Å "extinction bump," at which the absorption of UV radiation increases markedly. It has been suggested that this relatively narrow and well-defined spectral feature is due to small grains of graphite. If this is so, then polarization is not expected to increase even though the extinction increases. WUPPE will look for polarization in this part of the UV spectrum. If graphite is responsible for absorbing the radiation, we then have a new way to study the composition of dust in interstellar clouds.

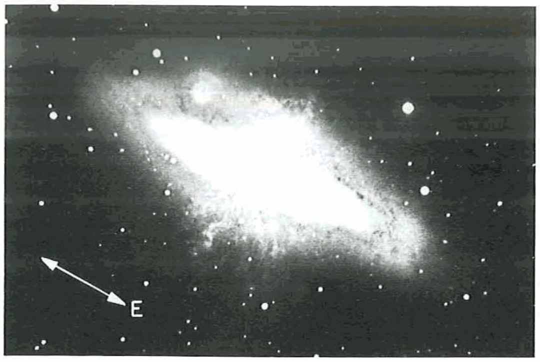
The presence of interstellar dust in other galaxies is a subject of these polarization studies, but nearby solar system objects also offer some fascinating puzzles. Asteroids and comets polarize scattered sunlight. Both types of objects are thought to have formed during the early evolution of the solar system. Asteroids have been subjected to the radiation and

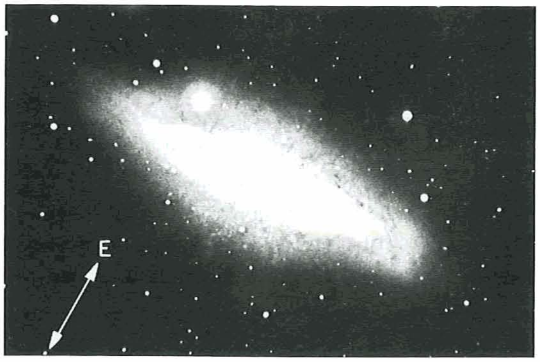
Lower left: Scattered radiation is polarized in a plane determined by the angle of the scattering. Polarization provides clues to the shape and structure of some stars.

Lower right: The polarized radiation emitted by electrons moving around a magnetic field will show the direction of that field.







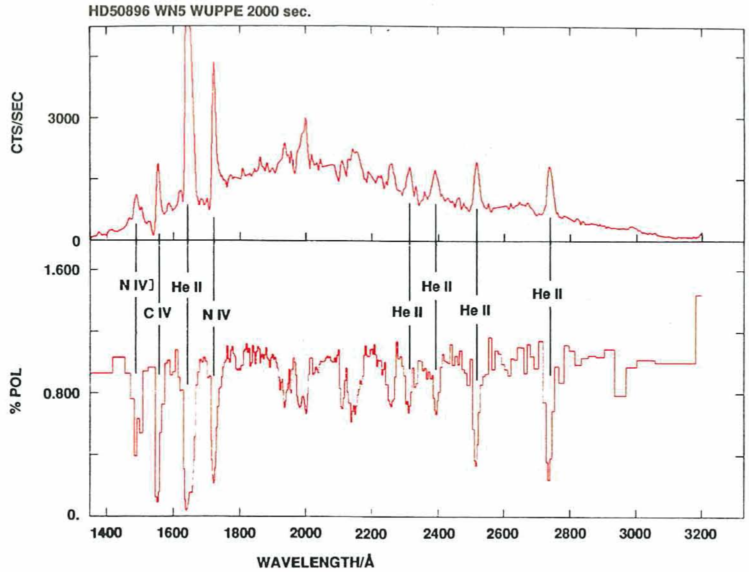


In these two views of the M82 galaxy, the polarization of blue visible light brings out gaseous filaments. Scientists want to see if polarization continues in the ultraviolet and reveals more invisible structures. The arrows indicate the direction of the electric field.

particles emitted from the sun while comets have spent most of their lives far from the sun and thus are believed to consist of primordial matter. A comparison of the polarization properties of asteroids and comets will lead to new insight about their nature and perhaps the history of the solar system.

Some stars and star systems emit polarized radiation. We think this indicates that the geometry of the radiative source is nonspherical: perhaps the star is spinning so fast that it is slightly flat; perhaps radiation is scattered by electrons in the distorted atmospheres of hot stars; or perhaps the star is actually a binary star system so close that one member may be eclipsed by the other. Stars, other than our sun, are so distant that we cannot directly see their structure. However, from the intrinsically polarized radiation of a star, scientists may be able to deduce information about its hidden geometry.

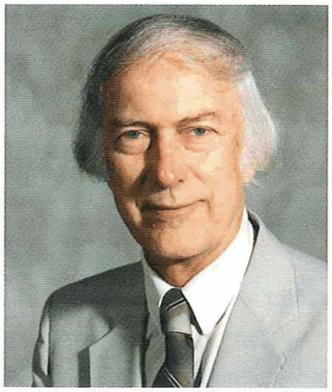
No one has observed the polarization of ultraviolet radiation from stars, nebulae, and galaxies before. We will be seeing a totally new facet of the Universe, and we are prepared for discovery.



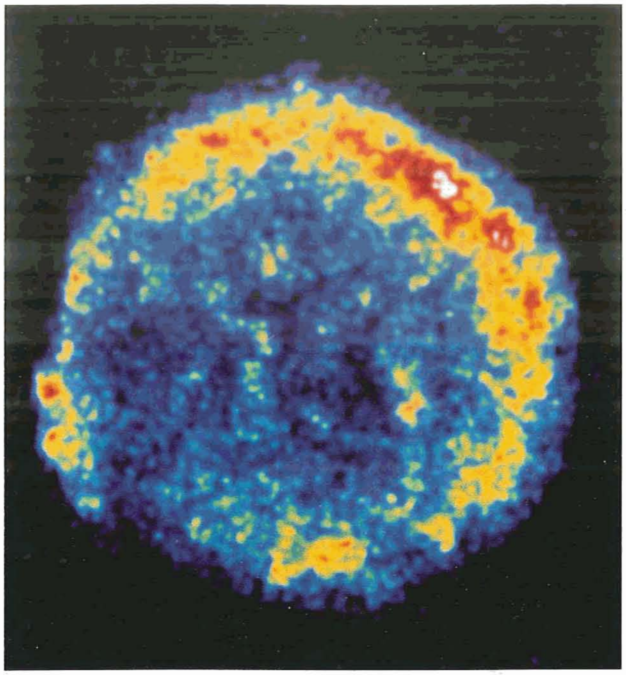
WUPPE scientists decipher complex data to understand various kinds of objects.

WUPPE Vital Statistics

Sponsoring Institution:	University of Wisconsin Madison, Wisconsin
Principal Investigator:	Arthur D. Code
Co-Principal Investigator:	Kenneth H. Nordsieck
Co-Investigator:	Christopher M. Anderson
Project Scientists:	Karen S. Bjorkman Andrew Y. S. Cheng Antonio Mario Magalhaes Regina E. Schulte-Ladbeck MaryJane Taylor
Project Manager:	Donald E. Michalski
Project Team:	Cathleen A. Accettura Allisanne Apple Samuel J. Gabelt Thomas E. Jones John K. Lemke Marilyn R. Meade Mark A. Nook Richard H. Pfeifer Laurie B. Ptaschinski Helena P. Renz Kathy J. Stittleburg Neal E. Wolfe Michael J. Wolff
Telescope Optics:	Cassegrain (two-mirror) system, f/10 focal ratio
Instrument:	Spectropolarimeter with dual electronic diode array detectors
Primary Mirror Size:	50 cm (20 in.) diameter 1,800 cm^2 (279 $in.^2$) area
Field of View:	3.3 x 4.4 arc minutes
Spectral Resolution:	6 Å
Wavelength Range:	1,400 Å to 3,200 Å
Magnitude Limit:	16
Weight:	446 kg (981 lb)
Size:	70 cm (28 in.) diameter 3.7 m (12.4 ft) length



Arthur D. Code, WUPPE Principal Investigator, University of Wisconsin



The supernova witnessed by Danish astronomer Tycho Brahe in 1572 has left this spherical shell of hot gas imaged in X-rays.

X-Ray Spectroscopy: The Broad Band X-Ray Telescope

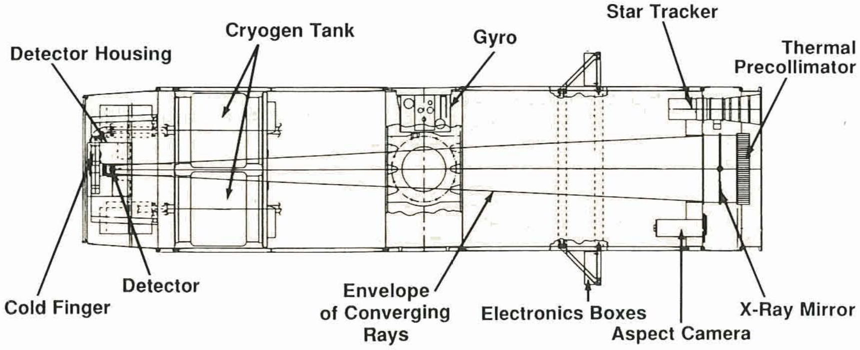
The Broad Band X-Ray Telescope (BBXRT) will provide astronomers with the first high-quality spectra of many of the X-ray sources discovered with the High Energy Astronomy Observatory 2, better known as the Einstein Observatory. BBXRT, developed at NASA's Goddard Space Flight Center in Greenbelt, Maryland, uses mirrors and advanced solid-state detectors as spectrometers to measure the energy of individual X-ray photons. These energies produce a spectrum that reveals the chemistry, structure, and dynamics of a source.

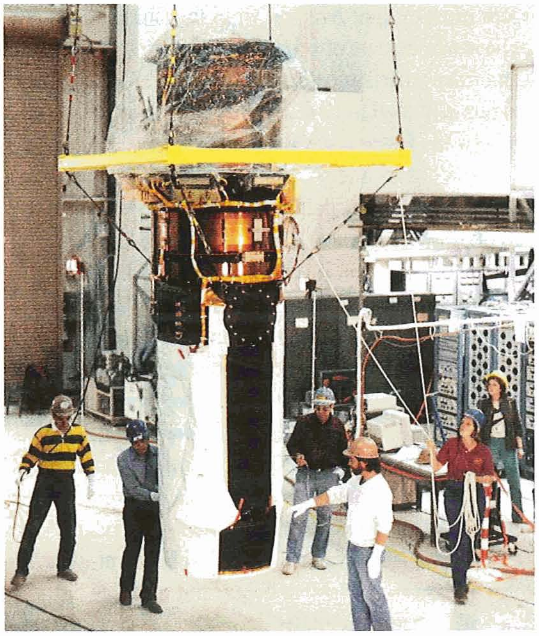
X-ray telescopes are difficult to construct because X-ray photons are so energetic that they penetrate mirrors and eventually are absorbed. A mirror surface reflects X-rays only if it is very smooth and the photons strike it at a very shallow angle. Because such small grazing angles are needed, the reflectors must be very long to intercept many of the incident X-rays. Since even shallower angles are required to detect higher energy X-rays, telescopes effective at high energies need very large reflecting surfaces. Traditionally, X-ray telescopes have used massive, finely polished reflectors that were expensive to construct and did not efficiently use the available aperture. The mirror technology developed for BBXRT consists of very thin pieces of gold-coated aluminum foil that require no polishing and can be nested very closely together to reflect a large fraction of the X-rays entering the telescope. Because its reflecting surfaces can be made so easily, BBXRT can afford to have mirrors using the very shallow grazing angles necessary to reflect high-energy photons. In fact, BBXRT is one of the first telescopes to observe astronomical targets that emit X-rays above approximately 4 thousand electron volts (keV).

Two identical telescopes are used to focus X-rays onto solid-state spectrometers which measure photon energy in electron volts. The use of two telescopes doubles the number of photons that are detected and also provides redundancy in case of a failure. Each telescope has a radius of 20 cm and a focal length of 3.8 m. The instrument has an effective area many times larger than that of the Einstein Observatory at energies less than 4 keV and also has substantial area in the 4 to 10 keV band where the Einstein Observatory had no response.

The BBXRT spectrometers are substantially improved versions of the solid-state detector that was flown aboard the Einstein Observatory. They detect nearly 100% of the incident X-rays over a broad energy range from approximately 0.3 to 12 keV. The spectral resolution is two times better, which facilitates identification of spectral features. BBXRT has sufficient spectral resolution to distinguish features due to individual elements such as oxygen, silicon, sulfur, calcium, and iron. The non-X-ray background of the detector has been reduced by a factor of about 100, which means that fainter targets can be detected, increasing by about 1,000 the number of potential

BBXRT components





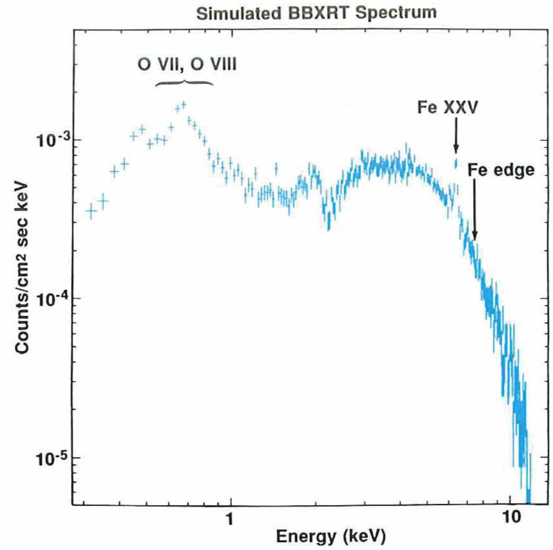
BBXRT is prepared for launch.

X-ray sources that can be detected by BBXRT. Finally, each detector has been segmented into five pixels so that low-resolution imaging of extended X-ray sources is possible.

One of the great triumphs of the Einstein Observatory was the revelation of the incredible variety of astronomical objects that are X-ray sources. For many of these sources, BBXRT provides astronomers with their first opportunity to detect broad-band X-ray spectra, which reveal the physical processes taking place in an object. BBXRT also provides the first chance to investigate detailed features due to iron, which occur in the 6 to 9 keV energy band. Quite strong iron features are commonly produced by the high-energy phenomena that occur in X-ray sources. Since BBXRT has the spectral resolution to distinguish different features, important information about the X-ray emitting region can be revealed. The Astro flight will provide opportunities to examine variations in the spectra of the sources. These variations are important clues about the structure of sources, most of which are so distant they appear point-like even with the finest telescopes.

BBXRT will be used to study a variety of sources, but a major goal is to increase our understanding of active galactic nuclei and quasars. Many astronomers believe that active galactic nuclei and quasars are actually very similar objects that contain an extremely luminous source at the nucleus of an otherwise relatively normal galaxy. The central source in quasars is so luminous that the host galaxy is difficult to detect. Their great luminosity, strong optical emission lines, and redshifts indicate that quasars are the most distant objects ever seen. The mechanism producing the luminosity of the central source is not known for certain, but most theories suggest that matter is being consumed by a black hole weighing about a billion times as much as the sun. X-rays are expected to be emitted very near the central engine of these objects. Astronomers will examine X-ray spectra and their variations to understand the phenomena at the very heart of quasars.

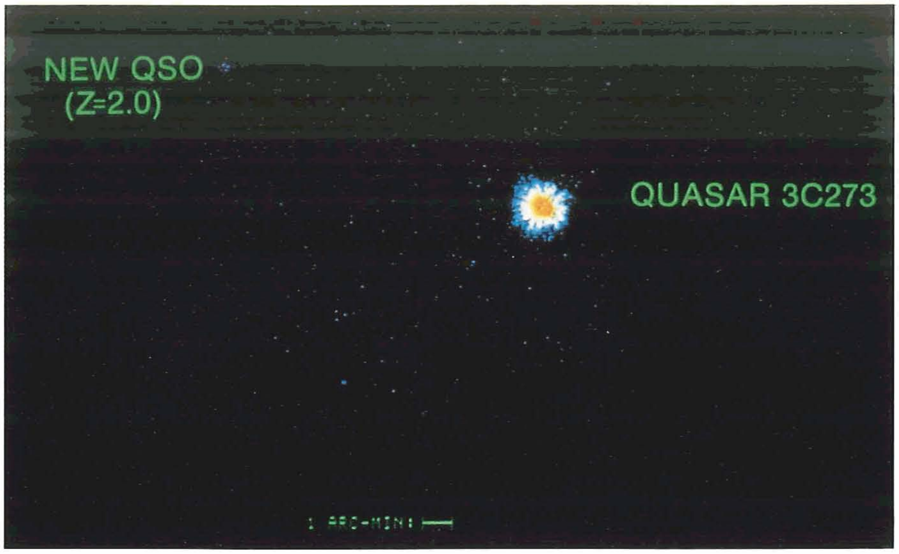
Optical studies show that quasars have changed over cosmological time scales; near the beginning of the Universe they were far more numerous than they are today. BBXRT will be used to examine very distant (and thus very young) quasars to see if their X-ray emission is different from relatively nearby quasars. Some astronomers think that the evolution of quasars could explain most of the unresolved X-ray background. The X-ray spectrum of quasars is only poorly known at present, but is apparently quite different from that necessary to explain the X-ray background. This suggests that there may be other exotic X-ray sources still to be discovered. BBXRT will examine the spectral evolution of quasars to test the suggestion that they may be substantial contributors to the X-ray background.



This histogram represents an anticipated BBXRT spectrum from the active galaxy NGC 4151. Emission lines from oxygen (O VII, O VIII) and iron (Fe XXV and Fe edge) are shown.

Investigators are interested in clusters of galaxies, congregations of tens or thousands of galaxies grouped together within a few million light-years of each other. When viewed in visible light, emissions from individual galaxies are dominant, but X-rays come mainly from hot gas between the galaxies. In fact, theories and observations indicate that there should be about as much matter in the hot gas as in the galaxies, but all this material has not been seen yet. BBXRT observations will enable scientists to calculate the total mass of a cluster and deduce the amount of "dark" matter. BBXRT spectra of plasma in the clusters will reveal how much iron they contain and how evenly it is distributed. Then, scientists can determine the temperature and luminosity of ionized gas in different locations of a cluster and estimate its mass. BBXRT also studies galactic evolution by comparing distant (younger) clusters to those of nearer (older) clusters.

BBXRT studies active galaxies such as Centaurus A.



This X-ray image (upper photo) shows the hot emissions from the center of Quasar 3C 273 about 3 billion light-years away. The cluster of blue dots (upper left) is another quasar at an estimated distance of 10 billion light-years. In the visible image of Quasar 3C 273 (lower photo), a jet of ejected material is seen.

BBXRT observes stellar sources in the Milky Way. Most of the bright X-ray sources in our Galaxy are binary stars in which a normal star orbits a very dense companion such as a neutron star, a white dwarf, or maybe an elusive black hole. As the gravitational pull of the dense companion draws material from the other star, the material is heated to very high temperatures and emits X-rays. By tracking the energy of these X-rays, BBXRT can observe how material is transferred.

Although normal stars release much more ultraviolet radiation, they are also X-ray sources. Some of the first X-rays were detected from our own sun. These X-rays are due to high-temperature ionized gas in the corona or outer atmosphere of stars. The sun's corona is completely masked by the bright, visible light from the solar surface and is seen only during eclipses or by special instruments. Relatively little is known about the X-ray spectra of other stellar coronae; BBXRT measurements of temperatures and element abundance will provide critical information for our understanding of stellar physics.

A star's death, a supernova, heats the region of the galaxy near the explosion so that it glows in X-rays. Scientists believe that heavy elements such as iron are manufactured and dispersed into the interstellar medium by supernovae. The blast or shock wave that propagates into the interstellar medium may produce energetic cosmic ray particles that travel on endless journeys throughout the Universe and instigate the formation of new stars. BBXRT detects young supernova remnants (less than 10,000 years old) which are still relatively hot. Elements will be identified, and the shock wave's movement and structure will be examined. BBXRT observations may reveal new supernova remnants for detailed study. ▲

BBXRT Vital Statistics

Sponsoring Institution:	NASA/Goddard Space Flight Center (GSFC) Greenbelt, Maryland
Principal Investigator:	Peter J. Serlemitsos (NASA/GSFC)
Co-Investigators:	Elihu A. Boldt Stephen S. Holt Richard L. Kelley Francis E. Marshall Richard F. Mushotzky Robert Petre Jean H. Swank Andrew E. Szymkowiak
Project Management Team:	Gary F. Banks Charles A. Glasser
Lead Engineers:	Robert G. Baker John A. Balla James A. Bass Francis B. Birsa Gregory S. Greer John G. Hagopian David A. Lindauer Michael E. Schein Joseph P. Schepis Peter K. Shu George E. Winkert
Telescope Optics:	2 coaligned X-ray telescopes with cooled segmented lithium-drifted silicon solid-state detectors in the focal planes
Focal Length:	3.8 m (12.5 ft) each, detection area 4 mm (0.16 in.) diameter pixel
Focal Plane Scale:	0.9 arc minutes per mm
Field of View:	4.5 arc minutes (central element) 17 arc minutes (overall)
Energy Band:	0.3 to 12 keV
Effective Area:	765 cm^2 at 1.5 keV, 300 cm^2 at 7 keV
Energy Resolution:	0.09 keV at 1 keV, 0.15 keV at 6 keV
Weight:	680.4 kg (1,500 lb)
Size:	101.6 cm (40 in.) diameter 421.6 cm (166 in.) length

Peter J. Serlemitsos, BBXRT Principal Investigator, NASA/Goddard Space Flight Center

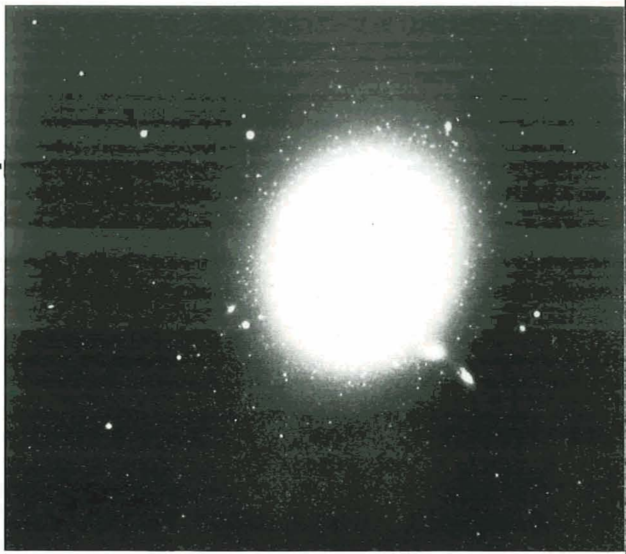
Simultaneous Observations: Sharing Scientific Data

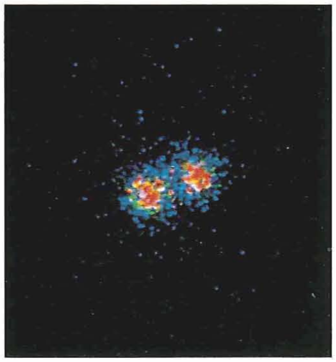
The Astro instruments provide new techniques for studying astronomical objects at ultraviolet and X-ray wavelengths. Although each instrument was developed with specific science goals in mind, much additional information can be gleaned by combining their operations.

Many astronomical objects selected for study by the Astro Observatory are of keen interest to most or all of the instrument teams. Simultaneous observations will bring together much new information that can be compared to reveal new physical relationships. For example, studying the M87 galaxy with all the Astro instruments may help us understand why this galaxy emits energetic jets of radiation and may uncover evidence of a supermassive black hole at its center. While UV spectra and X-ray images have been made of this interesting galaxy, Astro instruments will take the first ultraviolet photographs and obtain the most detailed UV and X-ray spectra yet made of M87.

Astro will obtain the first comprehensive set of simultaneous observations of active galactic nuclei at UV and X-ray wavelengths. These data will help astronomers comprehend the relationship among various kinds of active galactic centers and characterize their properties as a function of luminosities and redshifts. Of special interest is NGC 4151, one of the nearest and brightest Seyfert galaxies. Data from each telescope will help scientists unravel the structure of the galaxy which may be partially obscured by clouds of gas.

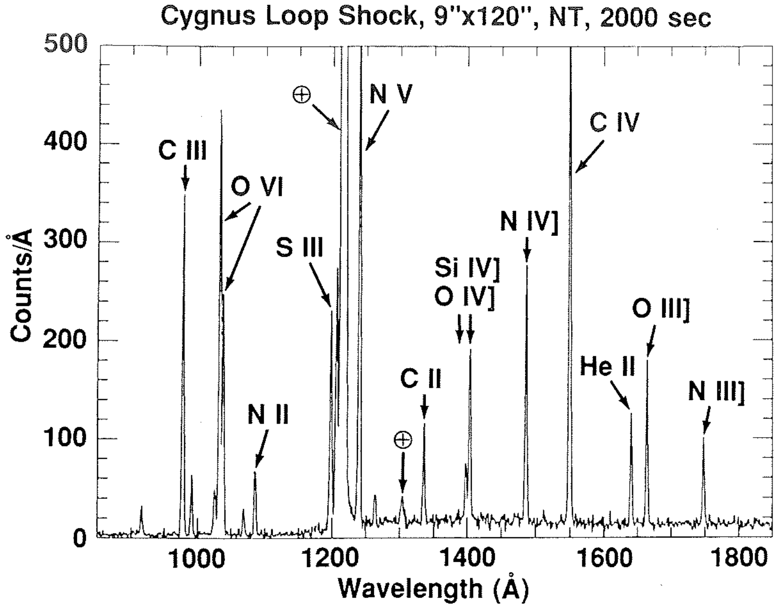
Astro will provide unique observations of nearby galaxies, such as M83, which are called starburst galaxies because of increased star formation seen there. Astronomers do not know why galaxies have a sudden burst of star formation, but this process may be triggered by the gravity of a neighbor galaxy or it may result from processes similar to those in active galaxies. Astro may help clarify the relation of the



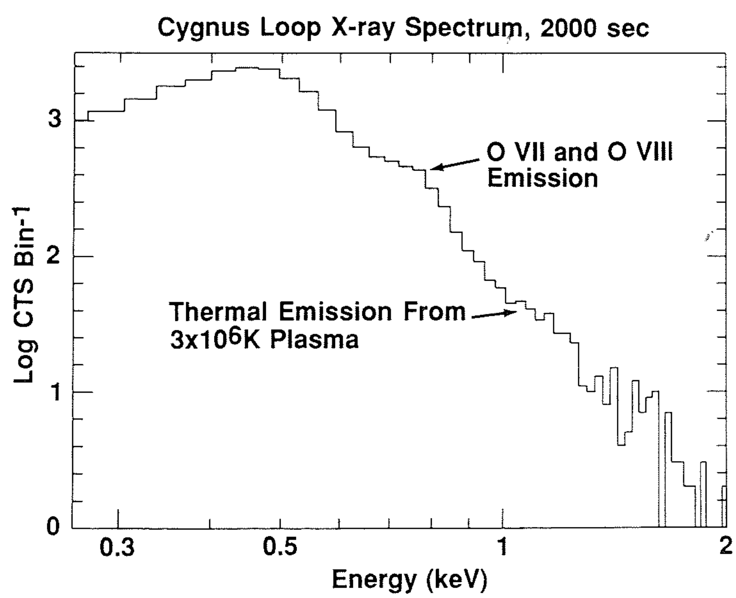


The giant elliptical galaxy M87 in Virgo has a mysterious jet that is a strong radio source (top, visible image). This galaxy also emits strong X-rays that may be associated with a supermassive black hole at the galaxy's core (bottom, X-ray image). Astro will make the first ultraviolet image of this unusual galaxy.

Images such as this one of a portion of the Cygnus Loop uncover the complex ionization structure of the gaseous filaments found in supernova remnants. The emission of oxygen III is green, hydrogen alpha shines in bright red, and the light of sulfur II is blue. White areas are bright from the light of all three ions.



This simulated spectrum shows what HUT might observe in a bright Cygnus Loop filament. The intensities of elements are expected to vary dramatically from one filament to another as different physical conditions are encountered.

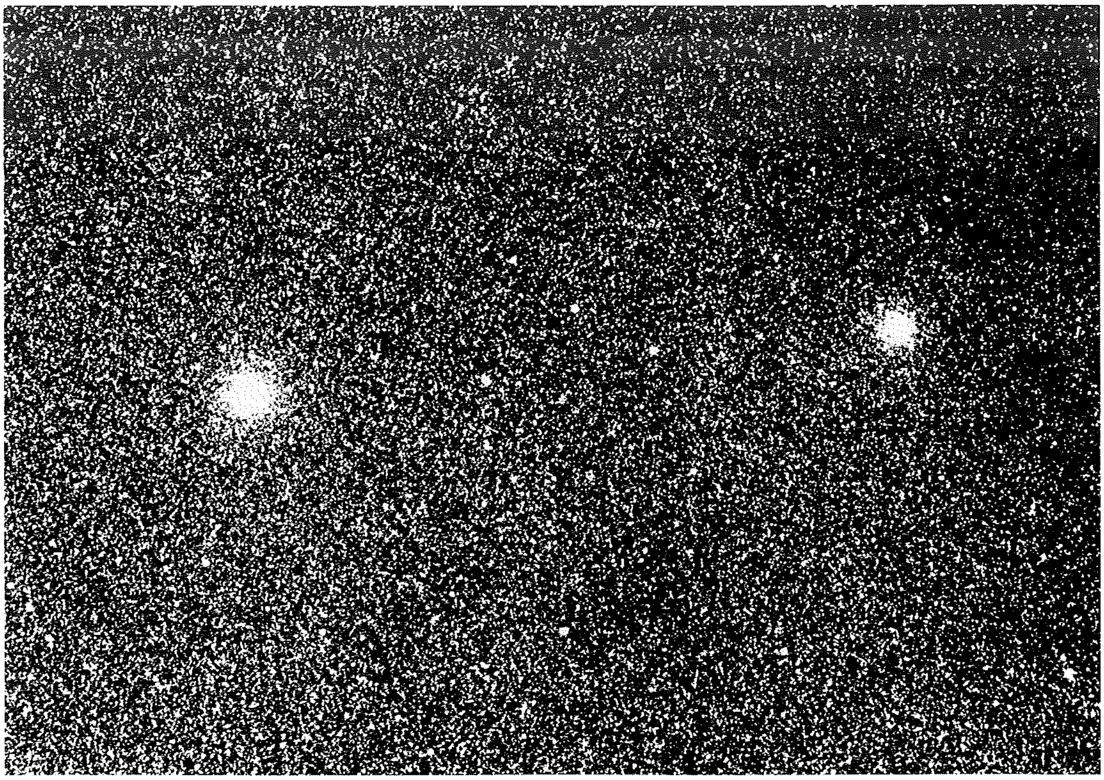


This simulated BBXRT spectrum is dominated by ions associated with an expected 3 million degree Kelvin plasma. X-ray emission will indicate the hottest regions of supernova remnants.

increased star formation to galaxy interaction or active galactic nuclei.

Multiple observations are scheduled at specific times to study stars and other sources that vary in intensity, size, and structure. For example, in eclipsing binary systems, as stars orbit around each other, first one star and then the other will be blocked from view. In this case, carefully timed spectroscopic and polarimetric data recorded simultaneously by HUT, WUPPE, and BBXRT will provide new insight into the structure of the individual stars and the gas flows between them. Astro will observe the binary system, AM Herculis, in which a strong magnetic field funnels material from a red dwarf to a white dwarf's surface near its magnetic poles. This system is characterized by a high degree of polarization, intense X-ray emission, and excited ultraviolet emission lines. The individual telescopes are well-suited to probe the radiation source contributing to the energy of AM Herculis. Since Astro will observe this binary system simultaneously in a wide range of wavelengths and for several phases of the system, a unique set of data will be available for comparison with models of its complex geometry and physics.

All the instruments will work together to study supernova remnants, the expanding gaseous nebulae created after stellar explosions. As the blast moves through the interstellar regions, gas is swept up and heated to millions of degrees. By observing supernova remnants such as the Cygnus Loop, Astro will provide new insight into the physical conditions and chemical abundances in the interstellar medium. Over a period of time, the gas cools and emits strong emission lines in the UV and optical regions. Many supernova remnants in our Galaxy are large in angular size. Hence, while UIT images a large portion of a remnant's filamentary structure in the ultraviolet, HUT, WUPPE, and BBXRT can simultaneously obtain UV and X-ray spectroscopic data of a specific filament or region. When combined, these data will provide a unique opportunity for unravelling the physics of stellar explosions.



More than a million stars are visible in these two globular star clusters near the center of our Galaxy. The Ultraviolet Imaging Telescope will identify interesting sources that can be studied in greater detail by the Hubble Space Telescope.

The Astro Observatory and the Hubble Space Telescope

Soon, NASA plans to deploy the Hubble Space Telescope (HST), a large free-flying observatory that will examine the Universe for 15 years or longer. HST observes the Universe in infrared, visible, and ultraviolet radiation, covering some of the same spectral regions as the Astro Observatory. The capabilities of the two observatories are different and complement each other well.

UIT, which photographs a circular field area somewhat larger than the apparent diameter of the full moon, is very well-suited for photographing a nearby cluster of stars or a nearby galaxy and pinpointing interesting ultraviolet sources. HST covers an area about 170 times smaller, its resolution is much higher, and it studies visible as well as ultraviolet wavelengths; it examines much more distant individual sources in great detail. Surprisingly, little imagery is available at UV wavelengths, so UIT's survey of relatively large portions of the sky will be useful for identifying ultraviolet sources that can be scrutinized more closely by HST and other observatories.

HUT and WUPPE are both ultraviolet spectroscopic instruments, and HST also is capable of high resolution UV and visible spectroscopy. While HUT's wavelength coverage does overlap with HST, its primary capability lies at more energetic wavelengths below 1,200 Å, a region inaccessible to HST. Almost nothing other than the brightest stars has been observed in this critical region, and spectra in this region will be unique.

WUPPE also makes sensitive polarization and spectroscopy measurements at ultraviolet wavelengths. This capability is available on HST, but the size of the spectrograph apertures is very different. The smaller apertures on the HST instruments are optimized for admitting the light of individual stars. WUPPE and HUT have much larger apertures, permitting them to observe many faint, extended sources such as galaxies or galactic nebulae that cannot be observed efficiently with HST. For spectra of large objects that are closer to our Galaxy, HUT and WUPPE will be many times more sensitive than HST, while for distant quasars or other very faint stellar objects, using HST will be advantageous.

There is no other large X-ray telescope operating at this time. BBXRT together with the Roentgen satellite (ROSAT), a cooperative Federal Republic of Germany/U.S. mission to be launched in early 1990, will supply the X-ray data on targets that HST is studying at other wavelengths. X-ray spectral measurements performed with BBXRT will be particularly valuable since quasars are a primary target for both it and HST.

The star Sanduleak -69°202 is normally not visible from Earth, but in this image made 51 days after it exploded, SN 1987A stands out in the Large Magellanic Cloud. The Tarantula Nebula, one of the brightest objects in the Large Magellanic Cloud, shines above and to the left of the explosion.

Supernova 1987A (SN 1987A): The Death of a Star

On the morning of February 24, 1987, light from the first stellar explosion to be observed by the naked eye in nearly 400 years reached Earth. This explosion was the brightest supernova seen since the year 1604, before the invention of the telescope. The supernova, formally named SN 1987A as the first supernova discovery of that year, is located 170,000 light-years away in the Large Magellanic Cloud, our nearest neighbor galaxy. Astronomers worldwide celebrated news of the discovery; the lucky ones, those in the Southern Hemisphere where the supernova could be viewed, rushed to see it.

A flurry of activity began as astronomers called on every available resource to study the supernova. The International Ultraviolet Explorer satellite made the first ultraviolet measurements of the explosion within hours of the discovery. Its observations indicated that the initial burst of high-energy radiation, mostly ultraviolet and X-rays, was already fading as the temperature of the supernova fell rapidly. Ultraviolet detectors aboard Voyager 2, on its way to Neptune, also focused on the supernova; the Solar Max satellite, observing the sun, was reprogrammed to seek gamma rays from the exploding star; and the newly launched Japanese X-ray satellite Ginga was ordered into operation sooner than planned to detect any early X-rays from the event.

Meanwhile, ground observatories in Chile, South Africa, and Australia were producing the first spectra and receiving the first radio waves from SN 1987A. During the months of scrutiny that followed, emissions across the full electromagnetic spectrum were detected from the supernova.

Yet, the secrets of SN 1987A are far from being understood. As the debris from the exploded star sweeps out into space at speeds up to one-ninth the speed of light and collides with gas expelled by the star hundreds of centuries earlier, instruments at ground observatories and aboard high-altitude balloons and satellites continue to probe its mysteries. The Astro mission will build on these investigations, focusing its large, sensitive ultraviolet and X-ray telescopes on the Large Magellanic Cloud in a coordinated campaign to study the supernova.

SN 1987A is not currently a strong source of ultraviolet and X-ray radiation, but it is expected to become one. The timescale for this aspect of the supernova's evolution is not well known. Even if SN 1987A is faint in ultraviolet and X-ray radiation when Astro flies, some indirect information can be obtained.

The "flash" of light from the supernova excited and ionized nearby gas which can be observed and analyzed. Since this is the gas lost from the star before it exploded, its structure and chemical composition will tell us more about the precursor star.

BBXRT will measure the supernova's X-ray energies to reveal the mechanisms producing X-rays and to identify individual chemical elements that were created during the explosion. This instrument will look, in particular, for the processes that produced the soft X-rays detected earlier than expected by the Ginga satellite. BBXRT spectra may reveal evidence of a pulsar at the center of the explosion.

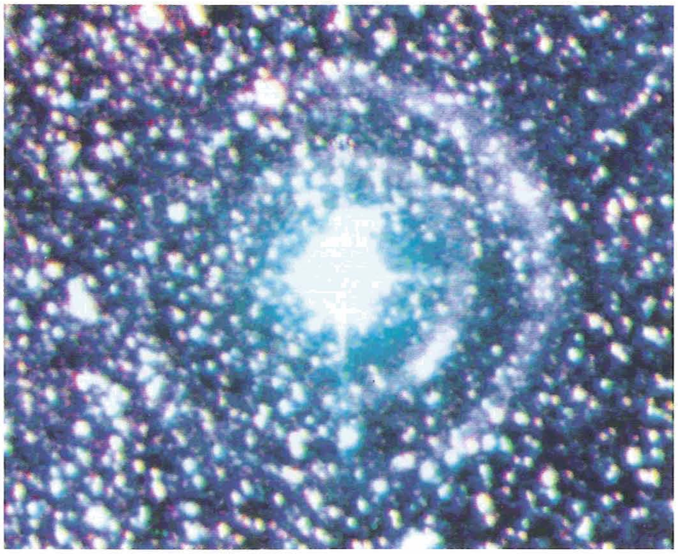
SN 1987A is teaching us about the evolution of stars, about the intergalactic medium between the Milky Way and the nearby Large Magellanic Cloud, and about the interstellar medium between the stars in our Galaxy. The Astro instruments, making complementary observations of the supernova, seek insight into the high-energy processes involved in this grand display of destruction and creation. We now have our best opportunity yet to study how a massive star died in our own backyard, some 170,000 years ago. ▲

If SN 1987A is shining brightly in both UV and X-rays, the Astro instruments can do a coordinated study of both spectral regions.

Very few supernova remnants have been observed in ultraviolet radiation, and none has been observed in the high-energy range of HUT. Lines in the spectra recorded by HUT will aid in determining temperatures, densities, and the chemical composition of SN 1987A.

WUPPE will gather information about the structure and evolution of the asymmetric shell of ionized gas and dust created as stellar debris was flung in unequal amounts in different directions. This shell polarizes radiation from the supernova, and from these observations, the geometry of the supernova and its magnetic fields can be determined.

UIT will search for echoes of the ultraviolet radiation pulse associated with the early outburst of SN 1987A; light reflected by the interstellar dust and gas in the neighborhood of a supernova has never been seen in the ultraviolet. UIT will map and measure the ultraviolet echo to find out how hot and bright the supernova was in its first hours, before it was spotted from Earth. UIT's wide field of view will allow examination of star populations, other supernova remnants, and dust from regions near SN 1987A in the Large Magellanic Cloud. These will provide a better understanding of the star that exploded and of the mechanisms leading to a supernova.

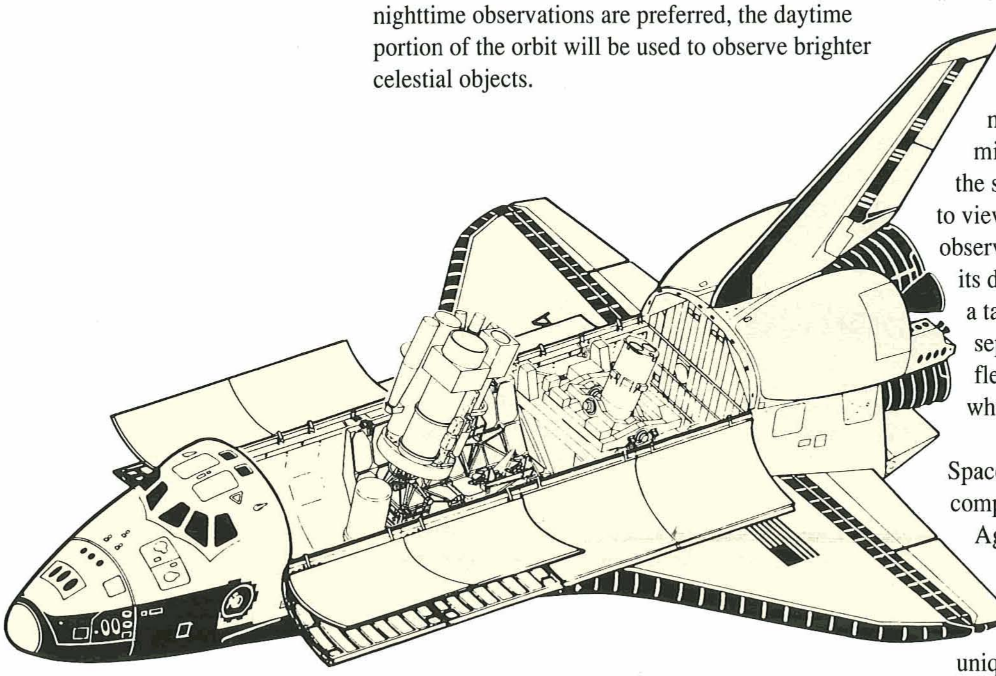


Rings of light from the initial explosion of SN 1987A are being reflected by interstellar dust.

Astro Observatory Operations

The first Astro mission (Astro-1) will last 9 to 11 days and orbit Earth at an altitude of 354 kilometers (220 statute miles) at a 28.5 ° inclination to the equator. Kennedy Space Center in Florida is the launch site for Astro-1.

Preferred launch times for Astro missions result in long orbital nights and minimum passage through the South Atlantic Anomaly, a region of intense particle radiation that affects the detectors. While nighttime observations are preferred, the daytime portion of the orbit will be used to observe brighter celestial objects.



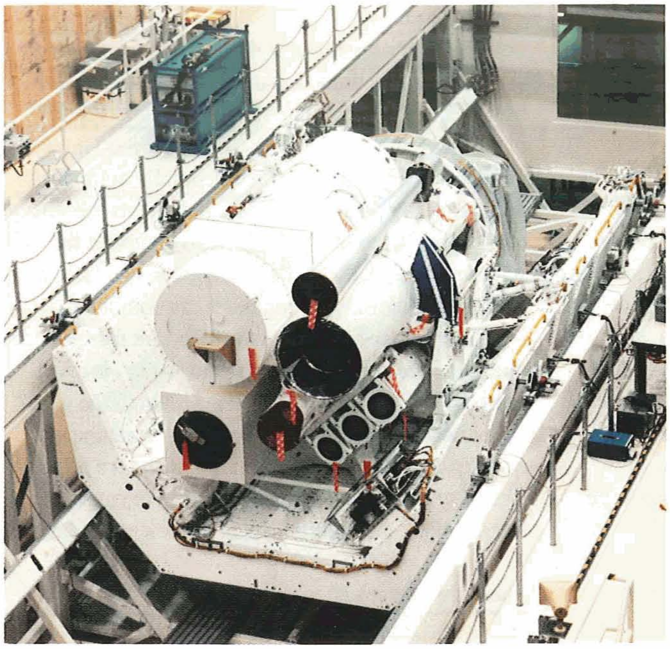
Astro-1 Payload in the Space Shuttle

Mission Design

Astro-1 is the first Shuttle mission dedicated to a single scientific discipline: astrophysics. The Astro Observatory comprises two payloads: three ultraviolet telescopes mounted on the Instrument Pointing System (IPS) and one X-ray telescope mounted on the Two-Axis Pointing System (TAPS).

Each telescope was independently designed, but all work together as elements of a single observatory. The pointing systems provide stable platforms that allow the ultraviolet and X-ray telescopes to observe the same target. In planning the mission goals, Astro investigators optimized the number of observations and increased the science data return by pointing the instruments to view celestial targets simultaneously. The joint observations allow each investigator team to multiply its data when all four instruments acquire and view a target at the same time. However, having two separate pointing systems gives investigators the flexibility to point the UV telescopes at one target while the X-ray telescope is aimed at another.

The ultraviolet telescopes are supported by Spacelab equipment. Spacelab is a set of modular components developed by the European Space Agency (ESA) and managed by the NASA/Marshall Space Flight Center (MSFC). For each Spacelab payload, specific standardized parts are combined to create a unique design. To scan the sky and locate interesting celestial objects, the Astro ultraviolet instruments need a stable platform and a precise pointing system. Thus, two Spacelab pallets and the IPS were assembled as the basis for the ultraviolet telescope configuration. The unpressurized pallets are anchored in the Shuttle payload bay, and a pressurized cylindrical container called the igloo, located at the head of the two pallets, houses subsystems that provide such services as power, telemetry, and commands to the instruments.

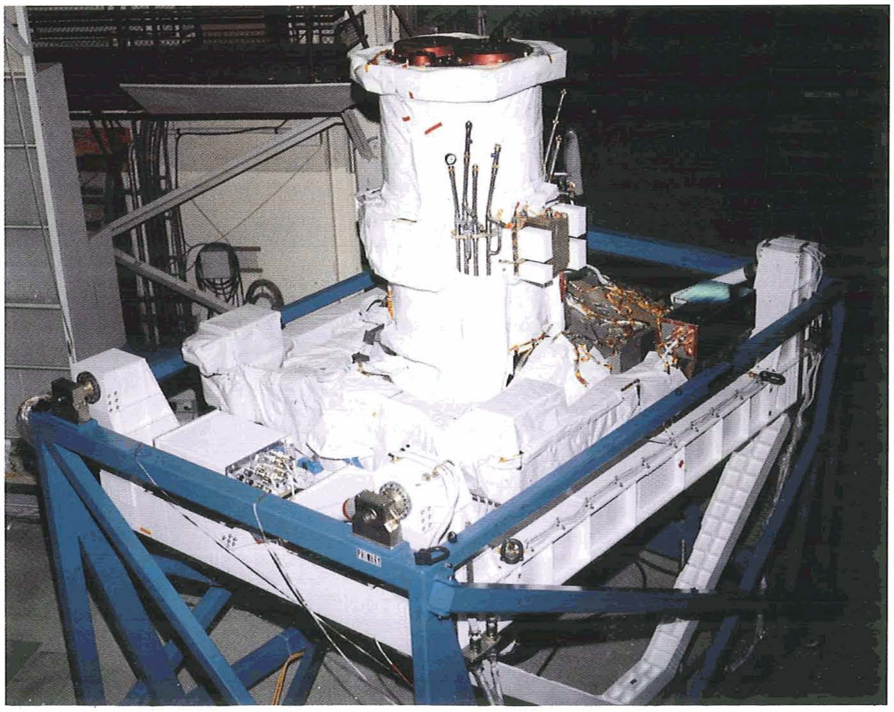


The Astro ultraviolet telescopes are mounted on the Instrument Pointing System which is attached to two Spacelab pallets.

The IPS, a gimballed support structure that can be pointed in various directions, is attached to the pallets. The three ultraviolet telescopes are mounted and precisely coaligned on a common structure, called the cruciform, that is attached to the pointing system. An image motion compensation system was developed by MSFC to provide improved pointing stability. A gyro stabilizer senses the motion of the cruciform which could disrupt UIT and WUPPE pointing stability. It sends information to the image motion compensation electronics system where pointing commands are computed and sent to the telescopes' secondary mirrors which make automatic adjustments to improve stability. A star tracker, designed by the NASA/Jet Propulsion Laboratory, fixes on bright stars with well-known locations and sends this information to the electronics system which corrects errors caused by gyro drift and sends new commands to the telescopes' mirrors. The secondary mirrors automatically adjust to keep pointed at the target.

The X-ray telescope and the TAPS, developed at the NASA/Goddard Space Flight Center (GSFC), were designed for multiple missions. This payload will be anchored in a support structure placed just behind the UV telescopes in the Shuttle payload bay. BBXRT is attached directly to the TAPS inner gimbal frame. The TAPS will move BBXRT in a forward/aft direction (pitch) relative to the payload bay or from side to side (roll) relative to the payload bay. A star tracker uses bright stars as a reference to position the TAPS for an observation, and gyros keep the TAPS on a target. As the gyros drift, the star tracker periodically recalculates and resets the TAPS position.

Since all the Astro Observatory instruments and components are reusable, they can be flown again separately, in concert, or with other astronomical instruments. For quick turnaround, the ultraviolet telescopes can remain integrated on the IPS, and the X-ray telescope can remain intact on the TAPS. Future Astro flights will deepen the scientific knowledge gained on the first pioneering mission.



The Astro X-ray telescope is attached to the Two-Axis Pointing System which is anchored to a support structure.

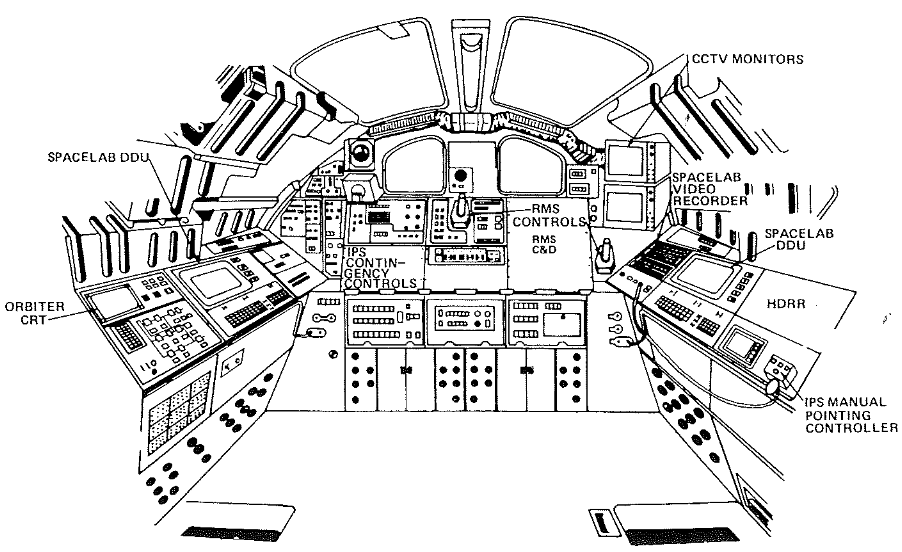
Planning the Observations

Each Astro mission is expected to last a little over a week. Since time in space is precious, it is absolutely imperative that the sequence of Astro observations is scheduled efficiently.

Planning observations is a complex undertaking, and many interrelated factors must be considered. Planning begins by selecting a list of potential astronomical targets for a given mission. Many parameters must be considered: the brightness of each source, the target's visibility for the assumed launch date and orbit, the visibility of the object during the "day" or the "night" portion of the orbit, and the importance of the observation to the overall scientific goals of the mission. Some targets have special observing constraints; for example, some variable stars need to be observed during certain stellar phases.

Once an initial target list is in hand, the detailed timeline of observations is defined. Computers are used to increase the speed of the elaborate calculations needed to determine the location and visibility of each object during specific Astro orbits. The planning process, however, cannot be totally automated because many decisions require judgments too difficult to program into a computer. To complete the science timeline, the skills of computers and knowledgeable scientists and engineers are combined.

The master timeline is the blueprint for the Astro mission; it contains all the UV and X-ray observations as well as crew operations. Although the guiding philosophy is to follow the master timeline, investigators can replan observations to take advantage of unexpected discoveries during the mission. For example, they might decide to view an interesting



The Shuttle's aft flight deck is the control room for the Astro Observatory.

Planning Observations

Science Considerations:

- Which targets are visible during each orbit?
- Which targets have the highest science priorities?
- Does the target need to be observed on the "night" or "day" side of orbit?
- How long must an object be observed by each instrument?
- Should the object be observed by both the UV and X-ray telescopes?

Pointing Considerations:

- Minimize time moving from one object to the next to increase observing time.
- Check to see if instruments can point in the direction of the source.
- Modify maneuvers to maximize contact with NASA communications so that more data can be transferred to the ground.
- Schedule pointing around other planned activities (crew change of shift, Shuttle maneuvers and water dumps, etc.) which may impact the timing of slews between targets.
- Maintain thermal control of the Shuttle.
- Manage the Shuttle's propellant.

Other Considerations:

- No observations:
  - during Shuttle passage through the South Atlantic Anomaly where the intensity of high-energy particles could interfere with data or damage the instruments;
  - in the direction of Shuttle movement where an atmospheric oxygen wind could damage the X-ray telescope's mirrors;
  - when the Shuttle releases excess water that can damage the instruments;
  - during crew handovers, roughly 10 minutes every 12 hours.

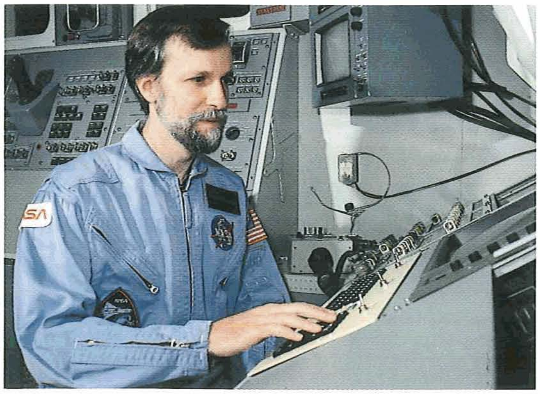
target a second time and shorten or eliminate another scheduled observation. The timeline also may have to be recalculated due to unexpected events such as a launch delay. Even short delays of a few hours affect the visibility of targets. To plan in advance for such contingencies, the timeline is evaluated before the mission to decide how it might be redesigned to meet different flight conditions yet still satisfy the mission's scientific objectives.

Operating the Telescopes

On every Shuttle mission, crew time is a valuable asset that must be shared by experiments and used efficiently. The Astro Observatory instrument operations complement each other nicely because the UV telescopes are operated around the clock by an onboard crew, while the X-ray telescope is controlled completely by remote ground-based operators.

The Astro ultraviolet telescopes and IPS are controlled from the aft flight deck, a work area located at the rear of the Space Shuttle cockpit. This is the primary workstation for the Astro crew members who are in charge of performing the scientific investigations. From here, a payload specialist and a mission specialist can monitor the instruments and command them to precise viewing positions. The aft flight deck has two dedicated Spacelab keyboard and display units, one for controlling the IPS and the other for operating the scientific instruments. To aid in target identification, this work area includes two closed-circuit television monitors: one displays the HUT data and star fields, and the other displays the WUPPE data and star fields.

A typical Astro observation proceeds as follows. Two teams of crew members work 12-hour shifts.



C. Dr. Kenneth H. Nordsieck

A. Dr. Samuel T. Durrance

Astro payload specialists practice operating the ultraviolet telescopes in a mockup of the Shuttle aft flight deck. (A-C)

Instrument Pointing System (IPS)

Single Observation Cycle:

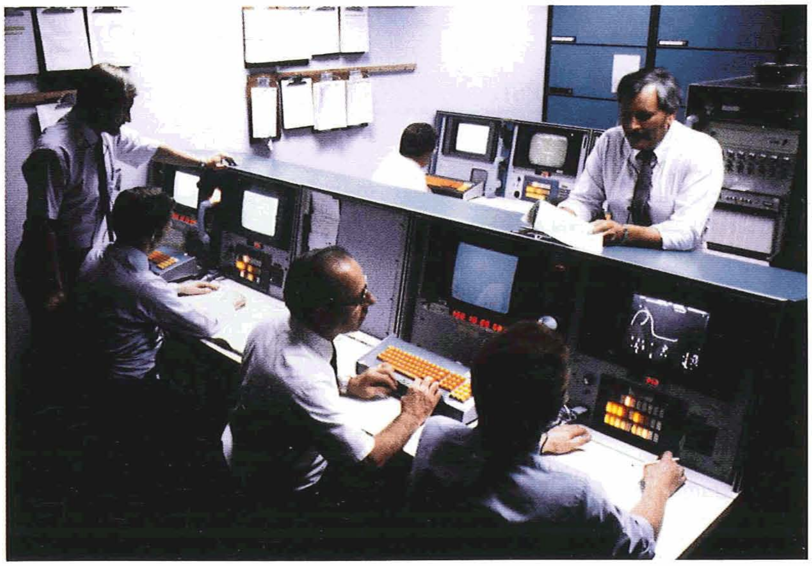
- Crew reviews and, if necessary, modifies pre-launch observation parameters.
- MS inputs right ascension and declination data into IPS.
- PS commands instruments to safe configuration for maneuver to target.
- Pilot maneuvers Shuttle to observation position.
- MS moves IPS so that observation target is in the HUT and WUPPE fields of view.
- PS reconfigures instruments for upcoming observation.
- PS turns instruments on and identifies star field on guide TV.
- MS or PS adjusts IPS to place the target in the HUT aperture, if necessary.
- PS initiates the HUT, WUPPE, and UIT data acquisition.
- PS or MS monitors IPS pointing in the HUT and WUPPE acquisition cameras.
- PS evaluates spectrum of object to verify that it has expected shape and the observing time was sufficient for good data acquisition.
- Science teams evaluate quick-look data and discuss it with crew, if necessary.
- Crew reviews the next target in the mission plan.

MS = Mission Specialist
PS = Payload Specialist

B. Dr. Ronald A. Parise

Each team consists of the commander or pilot, one or two mission specialists, and a payload specialist. The commander or pilot maneuvers the Shuttle to point the payload bay in the general direction of the astronomical object to be observed. A mission specialist commands the pointing system to aim the telescopes toward the target; he also acquires guide stars to help the pointing system maintain stability despite orbiter thruster firings. A payload specialist reconfigures each instrument for the upcoming observation, identifies the celestial target on the guide TV, and provides any necessary pointing corrections for placing the object in the spectrograph apertures. He then starts the instrument observation sequences and monitors the data being recorded. Because the target acquisition and operational workload is high, the payload and mission specialists work together to perform these complicated operations and evaluate the quality of observations.

The X-ray telescope requires little attention from the crew. A crew member turns on the BBXRT and the TAPS at the beginning of operations and turns them off when the operations conclude, but the telescope is operated from the ground. After the telescope is activated, NASA personnel can "talk" to the telescope via computer. First they will activate power and heaters and check out the TAPS pointing system alignment. Before science operations begin, stored commands are loaded into the BBXRT computer system. Then, when the astronauts position the Shuttle in the general direction of the source, the TAPS automatically points the BBXRT at the object. Since the Shuttle can be oriented in only one direction at a time, X-ray observations must be coordinated carefully with UV observations.



Personnel will operate the BBXRT from a remote POCC at Goddard Space Flight Center.

Two-Axis Pointing System (TAPS)

Single Observation Cycle:

- The BBXRT instrument team in the GSFC Payload Operations Control Center (POCC) loads stored commands to perform scientific data-taking operations.
- Astronauts position the Shuttle in the orientation required for the telescope to see the target.
- TAPS moves BBXRT so that target is in detector's central pixel.
- BBXRT begins to acquire science data.
- The GSFC POCC personnel monitor the BBXRT and TAPS operations and analyze data transmitted from the telescope to the ground.
- The GSFC POCC team prepares for next target acquisition.

The Astro Crew

The Astro Observatory has a unique capability for astronomical studies in the space environment: an expert onboard crew. During the past two decades, space astronomy has evolved from brief rocket flights to remote satellite operations to interactive satellite control and now to direct "hands-on" operations. During Astro missions, the ultraviolet telescopes are operated by payload specialists who are scientists from the instrument teams. Each has helped develop one of the instruments from concept to hardware to operations in space. All the payload specialists have a doctorate in astronomy or physics and actively do scientific research at observatories on the ground or with instruments on rockets or satellites, such as the International Ultraviolet Explorer. Their expertise is knowledge of astronomical observations and instrument operations; they are an essential link between the instruments in space and the investigative teams on the ground.

All the science crew members have been trained so that their activities are coordinated to make the best use of precious viewing time. Much of this training took place in the laboratories of the principal investigators (the scientists who designed and developed the Astro UV and X-ray instruments) and in the Payload Crew Training Complex at Marshall Space Flight Center.

The Science Crew

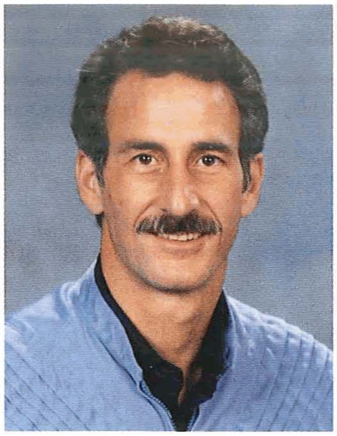
Three scientists — Dr. Samuel T. Durrance, Dr. Kenneth H. Nordsieck, and Dr. Ronald A. Parise — are trained to serve as payload specialists for the Astro Observatory. For Astro-1, Drs. Durrance and Parise will work in orbit while Dr. Nordsieck works in the ground control center. When Astro is reflown, these roles may change. It is very important that the payload specialists be experienced astronomers, because they will make many judgments during the mission that will improve the quality of the scientific data return. Each payload specialist is a member of one of the Astro instrument development teams.

Dr. Durrance is a research scientist in the Department of Physics and Astronomy at The Johns Hopkins University in Baltimore, Maryland, and is an assistant project scientist for the HUT program. He received a Ph.D. in astrogeophysics from the University of Colorado. Dr. Durrance has made International Ultraviolet Explorer satellite observations of Venus, Mars, Jupiter, and other celestial targets.

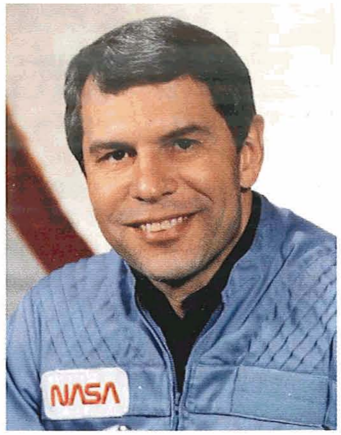
Dr. Nordsieck is a professor at Washburn Observatory at the University of Wisconsin in Madison and is a co-principal investigator for the WUPPE experiment. He received a Ph.D. in physics from the University of California. Dr. Nordsieck specializes in studies of galaxies and space astronomy.

Dr. Parise is a senior scientist in the Space Observatory Systems Operation of Advanced Astronomy Programs, Computer Sciences Corporation in Silver Spring, Maryland, and is a member of the research team responsible for UIT. He received a Ph.D. in astronomy from the University of Florida. Dr. Parise is also doing research using data from the International Ultraviolet Explorer satellite.

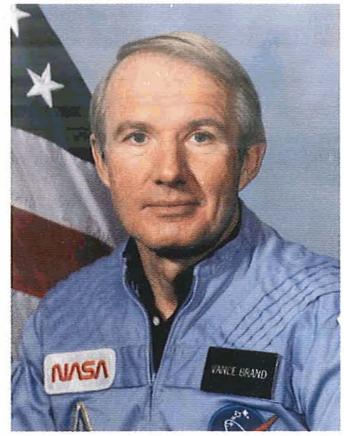
Astro payload specialists (left to right):
Dr. Samuel T. Durrance, Dr. Kenneth H. Nordsieck, and Dr. Ronald A. Parise



Dr. Jeffrey A. Hoffman, Mission Specialist



Dr. Robert A.R. Parker, Mission Specialist



Vance D. Brand, Commander

The NASA mission specialists — Dr. Jeffrey A. Hoffman and Dr. Robert A.R. Parker — are also assets for the Astro-1 mission. They are career astronauts and professional astronomers who have dedicated their careers to developing space astronomy capabilities in the Shuttle environment. Although their main assignment is to operate the Instrument Pointing System and other related Spacelab systems, they are experienced observers who are able to evaluate the science data and operate the science instruments.

Dr. Hoffman has a Ph.D. in astrophysics from Harvard University, and he has designed astronomy payloads for spaceflight and analyzed data from X-ray satellites. His scientific career includes involvement in NASA's High Energy Astronomy Observatory (HEAO) in the 1970s and the Small Astronomy Satellite (SAS-3) programs. During Dr. Hoffman's first flight on Shuttle mission 51-D in 1985, he made a contingency spacewalk to attempt the rescue of a malfunctioning satellite.

Dr. Parker has a Ph.D. in astronomy from the California Institute of Technology. Before he joined NASA, he was an associate professor of astronomy at the University of Wisconsin. As a scientist-astronaut, he served as program scientist for the three manned Skylab missions in the 1970s. On STS-9 (1983), the first Spacelab mission, he performed experiments in many disciplines including astronomy.

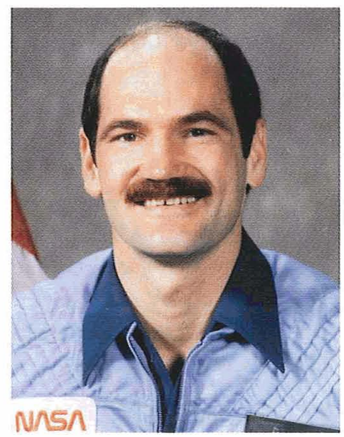
The Flight Crew

The orbiter crew (the commander, the pilot, and a third mission specialist) are highly trained members of NASA's astronaut corps skilled in Shuttle operations. They are responsible for maneuvering the orbiter to specific observation positions two to three times every orbit. The pilot and mission specialist work around the clock in 12-hour shifts with the observatory crew. The commander, who is in charge of ascent, landing, and overall mission progress, works a staggered shift. The flight crew selected for Astro-1 includes commander Vance D. Brand, pilot Guy S. Gardner, and mission specialist John M. (Mike) Lounge.

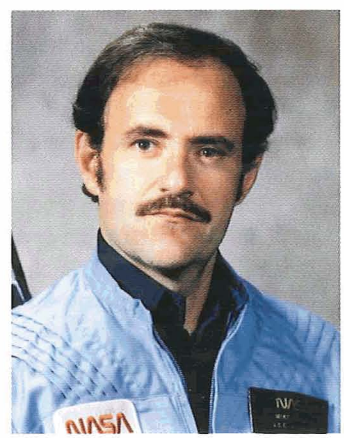
Brand, who will be on his fourth spaceflight, has a B.S. in aeronautical engineering from the University of Colorado and a M.S. in business administration from the University of California at Los Angeles. He was selected as an astronaut in 1966 and served as Apollo command module pilot during the 1975 Apollo-Soyuz Test Project mission, the historic meeting in space between American astronauts and Soviet cosmonauts. Brand was commander of Shuttle mission STS-5 in 1982 when the first commercial satellites were deployed from the Shuttle payload bay. He also commanded the 41-B mission in 1984; during this mission, astronauts checked out the Manned Maneuvering Unit, a jet-powered backpack used to transport them away from the Shuttle during extravehicular activities.

Gardner (Colonel, USAF) has a B.S. in engineering sciences, astronautics, and mathematics from the U.S. Air Force Academy and a M.S. in astronautics from Purdue University. He was selected as an astronaut in 1980. He served as the pilot on Shuttle mission STS-27 in 1988 and has supported several missions from the ground control center.

Lounge will be on his third spaceflight as a mission specialist. He has a B.S. in physics and mathematics from the U.S. Naval Academy and a M.S. in astrogeophysics from the University of Colorado. He became an astronaut in 1981 and supported several missions from the ground. As a mission specialist on mission 51-I in 1985, his duties included deployment of a communications satellite and operation of the robot arm; on mission STS-26 in 1988, he helped deploy a NASA communications satellite and do science experiments.



Colonel Guy S. Gardner, Pilot



John M. (Mike) Lounge, Mission Specialist

The Payload Operations Control Center

The focus of the Astro mission is on activities aboard the Shuttle, yet a large group of scientists and engineers support the Shuttle and payload operations from the ground. Astro is blazing a new path in ground support operations. During past Shuttle flights, the science and engineering teams supporting instruments flown on Spacelab worked in the Payload Operations Control Center (POCC) located next to the Mission Control Center at Johnson Space Center (JSC). Astro-1 will be the first mission directed from a POCC located at Marshall Space Flight Center (MSFC) in Huntsville, Alabama.

The POCC is the nerve center for payload operations during an Astro mission. It is the site of communication between the crew, the mission support team, and the instrument teams. The mission manager and his team will conduct the missions from the MSFC POCC. The POCC receives engineering and science data from the space payloads that help the team make key mission decisions. Throughout the mission, they monitor the health of the UV and X-ray telescopes, IPS, TAPS, the computers, and the many subsystems designed to take care of Astro's needs while on orbit. They prepare and update as necessary the mission timeline, a shift-by-shift schedule of crew activities and procedures.

For this mission, a special team located at a remote POCC at the Goddard Space Flight Center (GSFC) in Greenbelt, Maryland, will operate the TAPS and BBXRT. However, some members of the BBXRT team will be stationed at the MSFC POCC to participate in science planning, and all commands issued to the payload will be coordinated with the mission management team at the MSFC POCC. The GSFC POCC will be linked to the MSFC POCC via voice communication so that teams at both places can confer.

Both POCCs are staffed by teams of scientists and engineers who developed the Astro telescopes. All the ultraviolet astronomy teams are stationed at the MSFC POCC. Each team acts as an integrated group to support its instrument. They monitor the data flowing back from each instrument, evaluate the instrument's performance, and assess the science information revealed by the data. The engineers provide inputs on instrument performance and if necessary recommend alternate methods to maintain optimal performance. The scientists evaluate the quality of data in light of their scientific objectives: Is the object in the spectrograph slit the intended target? Is the spectrum of sufficient quality or should another observation be scheduled later in the mission? Is there an unanticipated spectral feature that requires a slightly different setting for the polarimetry measurements?

The Payload Operations Control Center located at Marshall Space Flight Center

Mission Management

Like other Spacelab missions, the Astro missions are planned, coordinated, and supported by a mission management team. MSFC is responsible for all Astro mission activities.

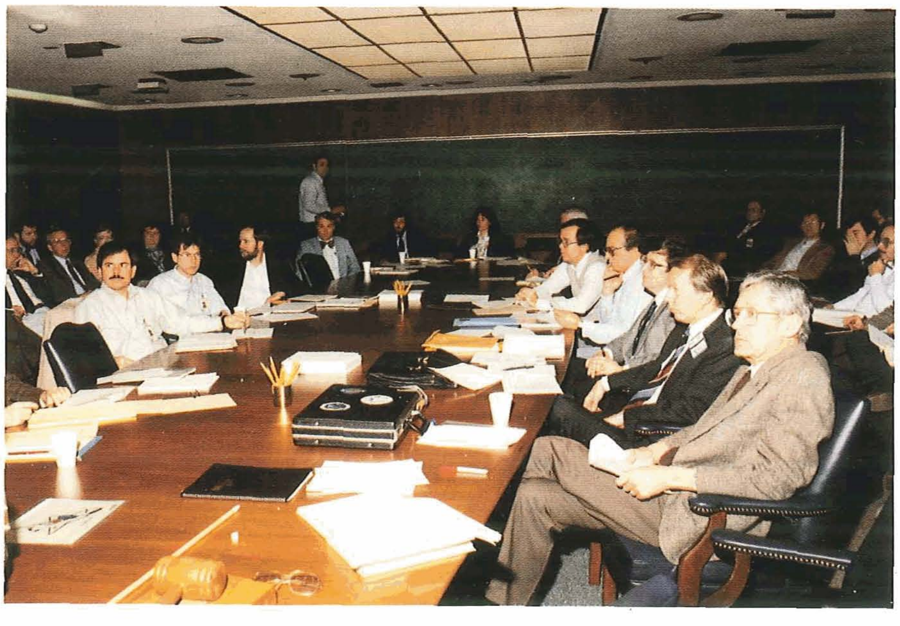
The Astro mission manager, Jack A. Jones, and the MSFC Payload Project Office coordinate all preparations for the missions. For Astro-1, he has worked closely with Frank A. Volpe who is managing the BBXRT effort for GSFC. The mission management team ensures that the mission scenario meets the goals of the investigators, that the requirements of the scientific payload match the Shuttle/Spacelab resources, and that all instruments and systems operate well during flight. This team coordinates activities with other NASA organizations involved in preparing the Shuttle and Spacelab for launch and performing flight operations.

The mission management team also conducts crew training in payload operations and prepares the science teams for their role in the POCC during the mission. The same mission management team is in charge of all science activities during the mission, resolving problems and rescheduling payload operations as necessary.

The Astro Investigator Working Group is composed of the principal investigators who developed and built the instruments. This group helps to develop mission guidelines and to select and train the payload specialists; throughout the flight, the investigators stay in close communication with the onboard crew. The Astro mission scientist, Dr. Theodore R. Gull of GSFC, is chairman of the group, which meets periodically before and during the mission to coordinate activities and planning between the instrument groups and also to interface with the NASA mission management team.

The Astro program manager, who oversees all activities associated with the project, is William T. Huddleston and the program scientist, who oversees Astro science activities, is Dr. Edward J. Weiler; both are from NASA Headquarters. ▲

Astro Investigator Working Group



Mission Management Responsibilities

Mission Planning

Developing mission scenario and design, resource allocations, crew schedule, experiment operations schedule, mission timeline

Hardware Development

Designing, building, assembling, qualifying Spacelab and experiment equipment

Payload Integration

Installing and testing Astro equipment and Spacelab systems, installing Astro Observatory in the Shuttle

Crew Training/Mission Team Training

Training crew in experiment operations, simulating mission activities to train support personnel (the POCC cadre and crew)

Mission Support

Real-time monitoring/problem solving during mission, supporting activities at the MSFC and GSFC Payload Operations Control Centers (POCC) and Huntsville Operations Support Center (HOSC)

Data Acquisition and Data Return

Providing science data to investigators during and after mission

Hardware Disassembly

Returning experiment equipment to investigators after flight

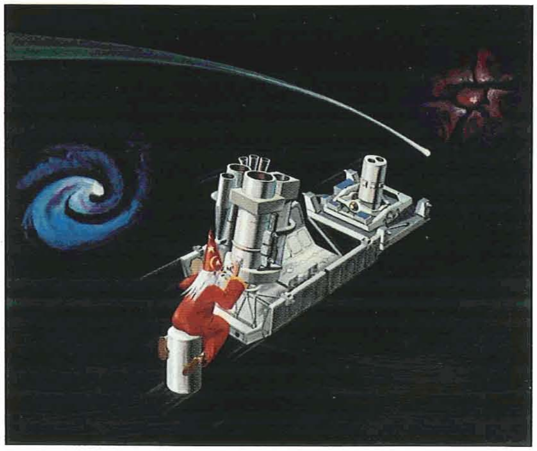
Epilogue

Andromeda Galaxy (M31)

The Astro Observatory is a unique payload that demonstrates how astronomical research can be performed in space in the Shuttle era. Today's space transportation system not only carries large instruments into orbit but also carries the experts who have dedicated their careers to developing the instruments and perfecting their operations. The Astro Observatory is more than a cluster of telescopes launched into space; it includes the crew and investigators and the ground support personnel.

In this respect, Astro operates in a similar manner to ground-based observatories, which serve as hosts for a variety of investigations. NASA expects many scientists to use the Astro Observatory, not by actually occupying the facility as crew members but by proposing investigations, training the crew, and sharing data. The observatory is a valuable scientific resource for the worldwide astronomical community.

The prime purpose of the Astro Observatory is to explore the invisible Universe. We soon will discover what surprises await us there. ▲



Credits

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With appreciation for their contributions to this publication: Jack A. Jones, Eugene W. Urban, and David B. Drachlis, all of NASA/MSFC; Charles J. Pellerin, William T. Huddleston, Edward J. Weiler, and Geoffrey C. Clayton, all of NASA Headquarters; Theodore R. Gull, Theodore P. Stecher, Stephen P. Maran, Frank A. Volpe, Peter J. Serlemitsos, Francis E. Marshall, all of NASA/Goddard Space Flight Center (GSFC); Arthur F. Davidsen, William P. Blair, and Samuel T. Durrance, all of The Johns Hopkins University; Robert W. O'Connell of the University of Virginia; Arthur D. Code, Regina E. Schulte-Ladbeck, Kenneth H. Nordsieck, and Kathy J. Stittleburg, all of the University of Wisconsin; Ronald A. Parise of the Computer Sciences Corporation.

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NASA/MSFC, Huntsville, AL

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