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THE HOPKINS ULTRAVIOLET TELESCOPE

A new capability in ultraviolet astronomy will be realized in 1986 when the Hopkins Ultraviolet Telescope is carried aloft by the space shuttle. Designed to measure far ultraviolet and extreme ultraviolet radiation from a broad range of astronomical objects, this telescope will complement the Space Telescope's observations of the same objects at longer wavelengths. Its first shuttle mission is timed to coincide with the passage of Halley's Comet through the earth's neighborhood. Observations of the comet, as well as of stars, interstellar matter, supernova remnants, galaxies, and quasars, will be made at previously unexplored wavelengths.

INTRODUCTION

The Hopkins Ultraviolet Telescope (HUT) is a 90-centimeter-diameter instrument that will be used aboard the space shuttle, beginning in 1986, to carry out spectroscopic studies of a wide variety of interesting astronomical objects, ranging from Halley's Comet and the planets of our solar system to distant galaxies and quasars. HUT has been designed to study both the far ultraviolet spectra (912 to 1800 angstroms) of all of these objects and the extreme ultraviolet spectra (450 to 912 angstroms) of a subset of them. It will be far more sensitive to the longer ultraviolet wavelengths in its band than any previous telescope, and it will be the first orbiting telescope to provide a detailed look at many astronomical objects in a broad band of wavelengths shorter than 1200 angstroms. Observation of Halley's Comet from the shuttle is illustrated in Fig. 1.

The telescope is a joint project of The Johns Hopkins University's Department of Physics and Astronomy and APL's Space Department, resulting from a proposal submitted to the National Aeronautics and Space Administration (NASA) in 1978.[1] Preliminary design studies were begun in 1979,[2] leading to the development of flight hardware during 1982-84. HUT is currently undergoing integration, testing, and qualification with delivery to NASA's Kennedy Space Center scheduled for March 1985 in order to begin shuttle integration leading to an initial flight in March 1986. At least two more missions, each of 7 to 10 days duration, are planned in 1986 and 1987.

HUT is the largest of three ultraviolet telescopes that together will make up the ASTRO Observatory aboard the shuttle. The other two are an ultraviolet spectropolarimeter being developed by the University of Wisconsin and an ultraviolet camera being developed by NASA's Goddard Space Flight Center. The three complementary ultraviolet telescopes, two visible-light cameras, and several optical star trackers (Fig. 2) are mounted together on a single structure that, in turn, is mounted on the instrument pointing system provided to NASA by the European Space Agency as a part of the Spacelab equipment. The telescopes are accurately coaligned and designed to operate jointly, thereby efficiently providing a very broad range of information on all the astronomical objects to be studied.

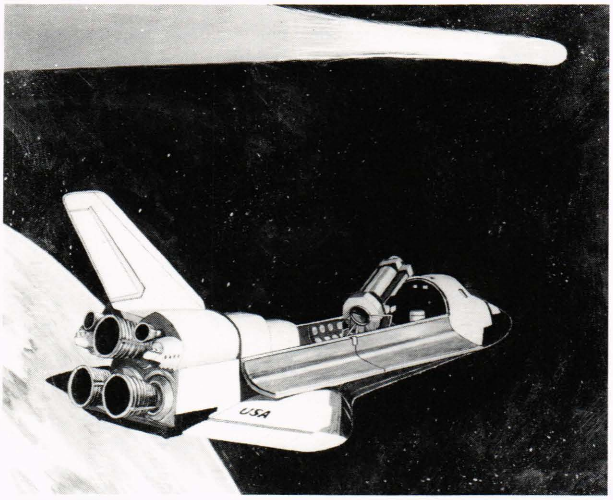

Figure 1—The ASTRO observatory on board the shuttle. The ASTRO Observatory will be carried aloft by the space shuttle on 7- to 10-day missions beginning in 1986. On the first mission, Halley's Comet will be a prime target for study.

The ASTRO Observatory has been designed to operate under the direct control of an astronomer who will fly aboard the shuttle as a payload specialist. One astronomer from each of the three instrument development teams has been chosen to begin training for that role. Two of them will fly on each mission in order to provide 24-hour operation of the observatory, while the third will serve as a backup. Samuel T. Durrance of the Department of Physics and Astronomy has been chosen as Hopkins' first man in space. The flight crew will also include two mission specialists—scientist-astronauts who are trained to operate all of the Spacelab subsystems.

HUT will provide real-time engineering data, ultraviolet spectral data, and information on the pointing

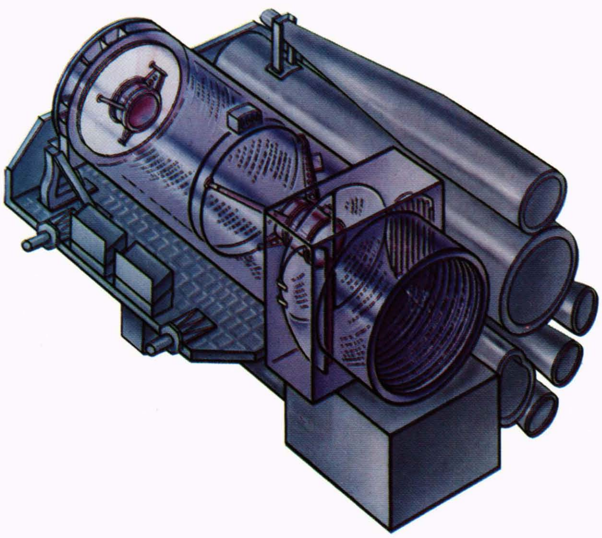

Figure 2—The ASTRO cruciform layout. HUT is the largest of three ultraviolet telescopes mounted on a single pointing platform and operated simultaneously. The payload also includes a wide-field visible light camera for studies of Halley's Comet and several optical star trackers.

direction to the payload specialist on the shuttle's aft flight deck. Whenever possible, all these data will also be presented in near real time to the ground operations team located at the Payload Operations Control Center at Marshall Space Flight Center. The payload specialist will use this information to acquire the targets of interest and to configure HUT and the other instruments to carry out each observation. Analysis of the data obtained in near real time on the ground will allow revisions of planned observational strategies in order to improve the scientific value of the results obtained during each mission.

SCIENTIFIC OBJECTIVES

The far ultraviolet region (less than 2000 angstroms) is a rich one for astronomical spectroscopy because many commonly occurring ionization stages of the most abundant elements have important transitions at these wavelengths. For example, hydrogen, the most abundant element, has its entire Lyman series (transitions between the ground state and any excited state) in the range from 1216 angstroms to the series limit at 912 angstroms. The latter wavelength also provides the short-wavelength limit of the far ultraviolet region. Shorter wavelengths, from 100 to less than 912 angstroms, are referred to as the extreme ultraviolet band. Photons with wavelengths below 912 angstroms cannot normally travel far in the interstellar medium before they are absorbed by neutral atomic hydrogen, which has a high cross section for photoelectric absorption at those wavelengths. On the other hand, photons with wavelengths longer than 912 angstroms can propagate relatively freely throughout vast distances in the interstellar medium, generally being absorbed or scattered only rarely when they occasionally strike solid grains of interstellar dust.

Much of the far ultraviolet region has been explored extensively in the past few years, particularly from the International Ultraviolet Explorer satellite, which was launched in 1978 and is still operating. A rich scientific return has been obtained from this small telescope, which is sensitive to ultraviolet wavelengths longer than 1200 angstroms. HUT has been designed to extend the capabilities of that telescope above 1200 angstroms to study fainter objects and especially to carry out related studies in the unexplored region of 912 to 1200 angstroms. For nearby objects, including the planets and at least several hot white dwarf stars, HUT can also yield very important information in the extreme ultraviolet region of 450 to 912 angstroms. Like the International Ultraviolet Explorer, the spectrographs aboard the Space Telescope will be limited to observations at wavelengths longer than about 1150 angstroms. Thus, HUT will remain an important and unique source of ultraviolet data long after the launch of the Space Telescope, currently planned for mid-1986.

HUT is designed to be broadly useful in studying a wide variety of astronomical objects in order to understand better the physical processes that occur throughout the universe. Because of the very rich store of information associated with the ultraviolet region of the electromagnetic spectrum, HUT will be a valuable tool for many research problems. Table 1 is a partial list of the types of objects and the scientific objectives that HUT will pursue.

INSTRUMENT PERFORMANCE GOALS AND PARAMETERS

In order to study the scientific problems listed in Table 1, HUT was designed for maximum sensitivity at moderate spectral resolution throughout the far ultraviolet region with particular emphasis on the 912 to 1200 angstrom band. In the first-order spectrum, the HUT spectrograph covers the 850 to 1850 angstrom range at a dispersion of 1 angstrom per detector channel (a linear dimension of 25 micrometers) with resolution of 2 angstroms for point sources and 3 to 6 angstroms for diffuse sources, depending on the aperture selected. In the second-order spectrum, the spectrograph range is 425 to 925 angstroms in the unfiltered mode and 425 to 700 angstroms through an aperture that includes an aluminum filter to reject the first-order spectrum. Selectable apertures include 9 and 18 arc-second-diameter circles, and both 9 × 120 and 18 × 120 arc-second slits. The smallest aperture will be used to observe stars and other point sources, while the larger apertures will be used to increase the HUT sensitivity to diffuse sources such as nebulae and galaxies. In a typical 30 minute observation, HUT is expected to be able to observe point sources that have a continuum flux level of about 10^{-14} ergs per square centimeter per second per angstrom. For the case of line emission from diffuse sources, HUT will be able to measure lines with intensities as small as 1 Rayleigh. Figure 3 shows a spectrum of a nitrogen discharge

Table 1—HUT science objectives.

Object Class	*Science Objectives*
Comets	Determine chemical composition; search for new constituents
Planets	Study aurora-producing mechanisms on the outer planets
Nearby hot white dwarfs	Detect extreme ultraviolet radiation and measure absorbing column densities of hydrogen and helium in the local interstellar medium
Very hot white dwarfs	Study atmospheric structure and effective temperatures of the hottest white dwarfs; measure rapid variability in the ultraviolet for pulsating objects
Magnetic white dwarfs	Measure Zeeman splitting of Lyman lines of hydrogen and study radiative transfer in very strong magnetic fields
Cataclysmic variables and X-ray binaries	Study mass transfer and accretion in close binary systems; employ high time resolution to constrain physical processes and geometry
Globular clusters	Study the far ultraviolet light of old stellar populations
Young supernova remnants	Determine abundances of heavy elements generated in supernova explosions
Old supernova remnants	Study the physics of shock waves in the interstellar medium
Interstellar dust	Determine the extinction curve in the far ultraviolet in order to constrain models for dust
Giant elliptical galaxies	Determine the stellar population producing strong ultraviolet flux in these systems; search for nuclear emission lines and the source of their ionization
Seyfert galaxies	Measure ultraviolet continuum and fluxes, velocities, and profiles of emission and absorption lines to constrain models of active galactic nuclei
Low and intermediate red shift quasars	Same as for Seyfert galaxies; search for absorption lines due to intervening matter at low red shifts and compare with absorption as observed at high red shift
High red shift quasars	Detect extreme ultraviolet ionizing radiation directly; search for helium emission and absorption

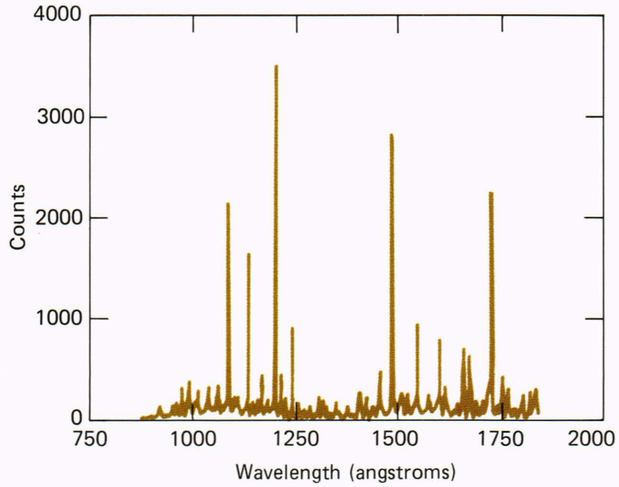

Figure 3—Spectrum of a laboratory calibration source. The data were obtained by the HUT spectrograph from a nitrogen discharge lamp in the ultraviolet calibration facility at Johns Hopkins. The line widths indicate that the resolution of the spectrograph will be approximately 3 angstroms.

lamp obtained with the HUT spectrograph and detector in the vacuum ultraviolet calibration facility of the Hopkins Department of Physics and Astronomy.

INSTRUMENT DESCRIPTION

Constraints of geometry and heat dissipation on the ASTRO payload required that the HUT instrument be partitioned into a telescope module and an electronics module. Both modules are mounted on the Spacelab instrument pointing system along with the other instruments. In the stowed (launch) condition, the telescope length was limited to 3.8 meters, which would not allow the instrument electronics to be attached to the telescope optics. Thermal analysis of the electronics power dissipation indicated that a larger radiating area than could be accommodated in a unified instrument was required to keep the electronics temperature within reasonable bounds. These two constraints dictated the instrument partitioning. The telescope module contains the optics and the focal plane instrumentation. The electronics module contains the power conditioning and the computer electronics. The ASTRO Observatory is attached to the instrument pointing system by a cruciform structure that acts as an optical bench. As shown in Fig. 2, that structure accommodates an instrument in each of its four quadrants, as well as star cameras for attitude determination and an integrated radiator system that holds several instrument electronics packages (including the HUT electronics module). The instrument pointing system/instrument array and Spacelab avionics (which includes computers, power conditioning and distribution systems, and mass storage devices) are mounted on two pallets attached to the shuttle bay.

The payload and mission specialists operate the ASTRO instruments from the aft flight deck of the shuttle, located behind the commander/pilot console. The crew can observe operations in the bay by looking through two ports. Displays on the aft flight deck allow the crew to monitor the status of the instruments and the scientific data they are obtaining. The mission specialist controls the instrument pointing system and other general Spacelab functions. The payload specialist controls the instruments by means of data entry via the Spacelab computers. Thus, the instruments can be tailored to changing conditions and observation opportunities with little time lost between the onset of some event and the execution of appropriate responses.

A schematic drawing of the HUT telescope module is shown in Fig. 4. The module is 1.0 meter in diameter, 3.8 meters long, and weighs 697 kilograms. The instrument optics are housed inside an aluminum environment-control canister that protects the optics from contamination during ground and launch operations and provides a thermally controlled, optically shielded environment during observations. The entrance aperture of the telescope is defined by the door assembly, which allows operating apertures of 5280, 50, and 1 square centimeters to be selected. Baffles in the environmental control canister and in the 1 meter section forward of the door assembly provide protection from stray light. The telescope module is attached kinematically to the cruciform structure by means of three titanium feet. Titanium was chosen because of its high strength-to-weight ratio and its low thermal conductivity. Thermal isolation of the telescope from the cruciform structure was required to maintain alignment stability between the instruments.

The layout of the electronics module is shown in Fig. 5. The module is 1.0 × 0.3 × 0.3 meters and weighs 52 kilograms. All interfaces to the Spacelab avionics are conditioned by electronics contained within the module. Three direct current voltage converters and an electromagnetic interference filter condition the primary power supplied by the ASTRO power distribution system. The command relay module distributes power from the primary power source and from the converters to the rest of the HUT system. A power inverter supplies 400-hertz, two-phase power to hysteresis synchronous motors located in the telescope module. A heater control unit regulates the temperature in both the telescope and electronics modules. The spectrometer processor and the dedicated experiment processor condition the output of the focal plane instrumentation, control the subsystem functions, and format the system data for transmission to the onboard recorder and to the ground.

HUT is designed to operate in a highly interactive mode with both the payload specialist and the ground operations team. Information and commands flow via the Spacelab/shuttle avionics to the ground and to the instrument; Fig. 6 illustrates the major system interactions. Commands to the instrument from either the ground or the payload specialist are processed by the Spacelab experiment computer and transmitted via the Spacelab remote acquisition unit. The computer provides both discrete and serial commands to the instru-

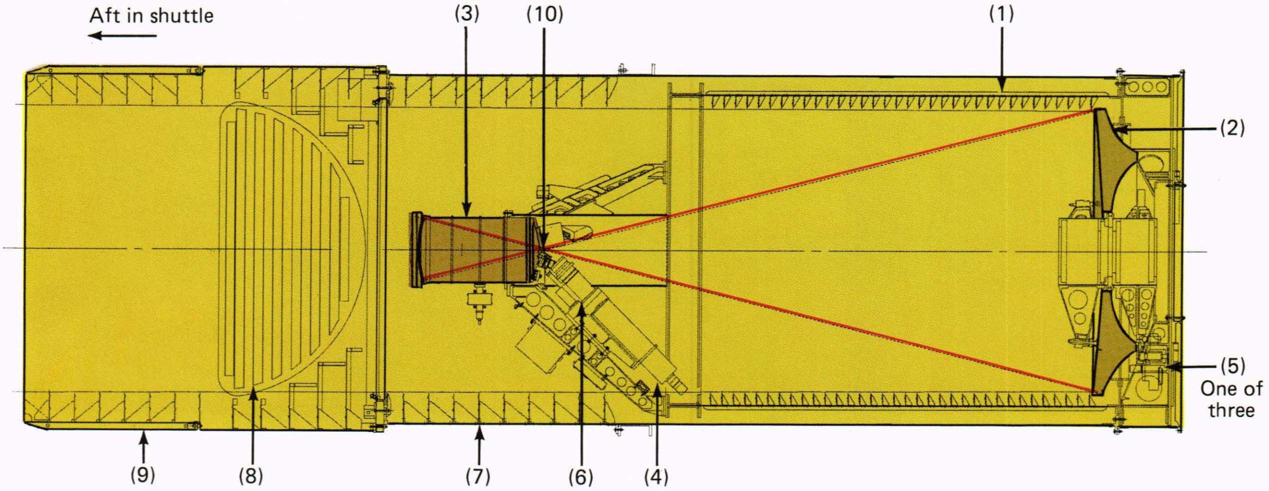

Figure 4—Schematic drawing of the HUT telescope module. The telescope's metering structure (1) holds the primary mirror (2) relative to the focal plane instruments, the spectrograph (3), and the television camera (4). Three focus mechanisms (5) allow the primary mirror to be adjusted in flight with a precision of 0.3 micrometer. The television camera will allow the crew and ground investigators to review the 10 arc-minute telescope field of view with a spatial resolution of 1 arc-second. A filter-wheel mechanism (6) allows adjustment of the television camera's sensitivity to observe objects as bright as Halley's Comet and as faint as a 17 visual magnitude star. The telescope is protected from contamination by the environmental control canister (7). Doors on the canister (8) are opened during orbit to allow observation. Baffles located in the forward section (9) and in the canister prevent stray light from striking the spectrograph aperture (10). A mechanism allows the spectrograph aperture to be selected from eight options by the investigators.

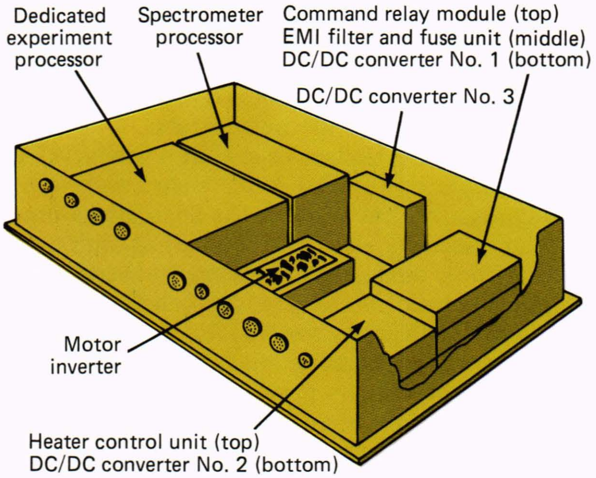

Figure 5—The HUT electronics module, which contains the majority of the system electronics, is attached, via a thermal radiator, to the ASTRO cruciform structure. The heat generated by the module (approximately 140 watts) is conducted through the base plate of the module to the radiator. All electrical interfaces to the Spacelab avionics are through four of the connectors shown. The remaining connectors are for connections to the telescope module.

ment. Most discrete commands drive relays located in the command relay module to switch primary power to subsystems within HUT. The serial commands are loaded into the experiment's dedicated experiment processor and provide configuration data and timing information necessary to operate the experiment. Discrete outputs, serial data, and video data are transmitted to the aft flight deck to allow the payload specialist to monitor the instrument status. A high-rate multiplexer data stream created by the dedicated experiment computer transmits scientific, engineering, and video data to the ground. During the mission, telemetry ground support equipment located at Marshall Space Flight Center will analyze the multiplexer data stream and display the information for use by the instrument science team in real time.

OPTICAL SYSTEM

The primary constituents of the telescope module are the telescope optics and the metering structure that holds them rigidly with respect to one another and to the other instruments via the cruciform structure. As shown in Fig. 4, the optics include a 0.9 meter diameter

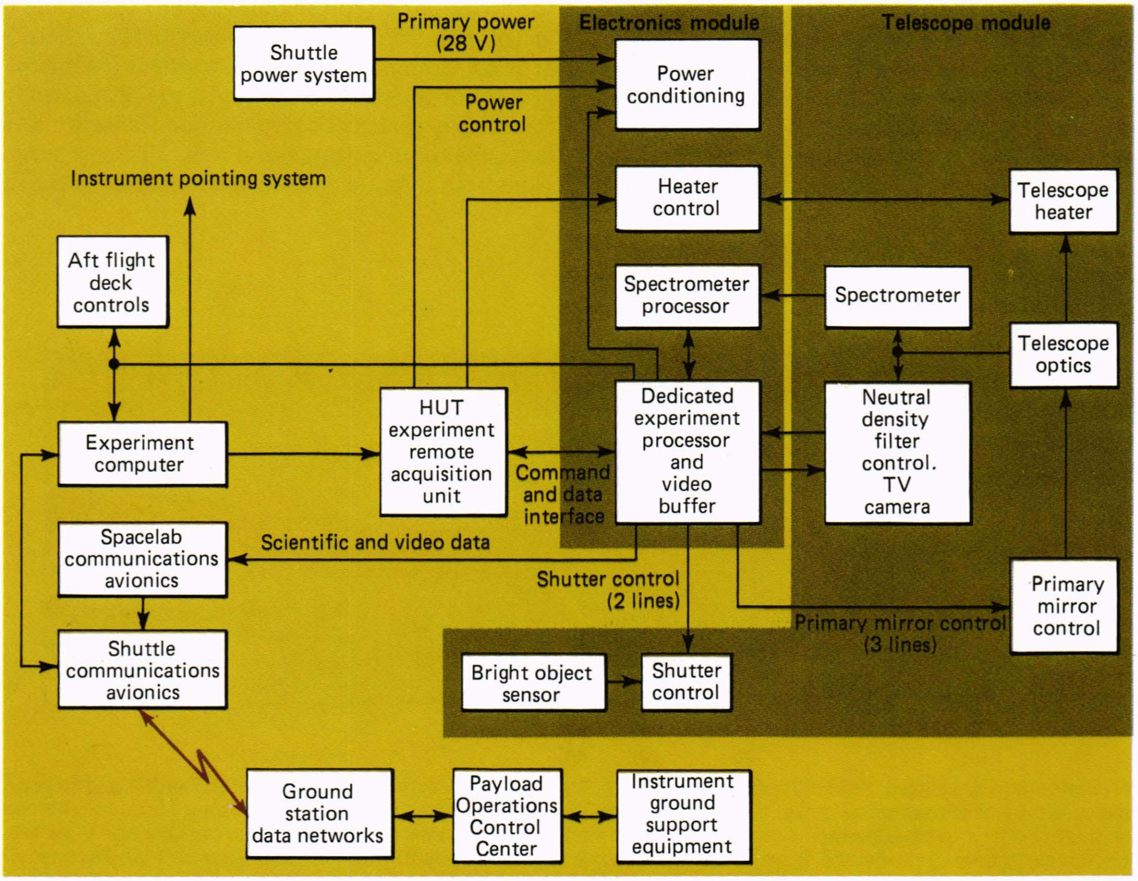

Figure 6—Block diagram of the HUT and its interfaces with the shuttle controls. Commands generated by the shuttle crew or by the investigators at the Marshall Space Flight Center are used by the processor to actuate the various subsystem elements. Science and engineering data are collected by the processor for display on the shuttle aft flight deck and on the telemetry ground support equipment for real-time analysis.

primary mirror, a Rowland spectrograph located at the focal plane of the primary mirror, and a silicon-intensified target television camera that allows the focal plane images to be viewed by the payload specialist and the ground science team. The baffling within the metering structure (in the forward part of the environmental control canister and forward of the canister doors) is also an important part of the optical system.

The primary mirror is a parabola whose focal length is 1.8 meters. The mirror's surface is coated with iridium, which has a reflectivity of 20 percent in the far ultraviolet region. The image quality of the mirror is approximately 1 arc-second at the focal plane. Three motorized mechanisms allow the mirror focus and pointing position to be adjusted within the telescope by moving the mirror ±0.3 millimeter relative to the metering structure and spectrograph. Each mechanism can be individually controlled with a resolution of 0.3 micrometer, allowing pointing control to within about 1 arc-second over a range of several arc-minutes. The control range (1 to 2 arc-minutes) is limited by the coma introduced by off-axis pointing of the parabola.

The metering structure is fabricated from Invar 36® alloy because of its extremely low coefficient of expansion and its long-term stability. Other materials such as carbon composites were rejected because of cost. Dimensional tolerance and stability of the primary mirror with respect to the spectrograph were basic requirements for the metering structure. Mirror translation greater than 4 micrometers along the optic axis or 8 micrometers perpendicular to that axis would produce an unacceptable image. These alignment requirements, even with a thermally stable material such as Invar®, imposed temperature gradient requirements of less than 7°C along the optical axis and 4°C across the telescope. In addition, a restriction of transferring less than 15 watts across the interface between the telescope and the cruciform structure was imposed by alignment requirements of the cruciform structure itself.

To meet the thermal requirements, a control system that monitors 14 elements of the telescope structure and maintains their temperatures by means of heaters was incorporated into the telescope design. The control temperatures can be changed by command to maintain them above the ambient environment.

The telescope is required to operate at viewing angles as close as 45° from the sun and 20° from the sunlit earth limb. Circular baffles in the section forward of the canister doors, in the forward section of the environmental control canister, and in the metering cylinder itself reduce the stray light reaching the spectrograph aperture. In addition, a cylindrical baffle surrounds the aperture and the entrance to the television optics, limiting ray sources that might strike the focal plane to the surface of the mirror and the mirror clamp structure. The baffle system is expected to allow observation of sources as faint as 17 visual magnitude.

Although the instrument pointing system will be programmed never to bring the telescope aperture within 45° of the sun, bright-object sensors have been built into the HUT system as a safety measure. The effect of the sun illuminating the interior of the environmental control canister would be to raise the internal temperature quickly to unacceptable levels. The two sensors are opposite each other at the entrance to the telescope aperture and are composed of a fused silica lens assembly and an immersed diode that is sensitive to optical light. The optics in each are slightly altered in such a way that the output current of one changes markedly when the sun comes within 42° of the optical axis and the output of the other changes when the lit earth limb comes within 20° of the optical axis. The currents are detected and used by the dedicated experiment processor to close the canister doors automatically when the sun is detected and to insert a neutral density filter in the optical path of the television camera when the lit earth is detected.

SPECTROMETER SYSTEM

The spectrograph is the heart of the HUT. It is the primary science sensor, counting and classifying with respect to wavelength each photon it detects. The spectrograph is illustrated in Fig. 7. Light from an object, reflected from the primary mirror, passes through the spectrograph aperture and falls on the diffraction grating, which is ruled with 400 lines per millimeter. The grating disperses and refocuses the light on the detector, with wavelengths ranging from 850 to 1850 angstroms spread along a 25 millimeter-long strip. Initial calibration of the spectrograph indicates that aberra-

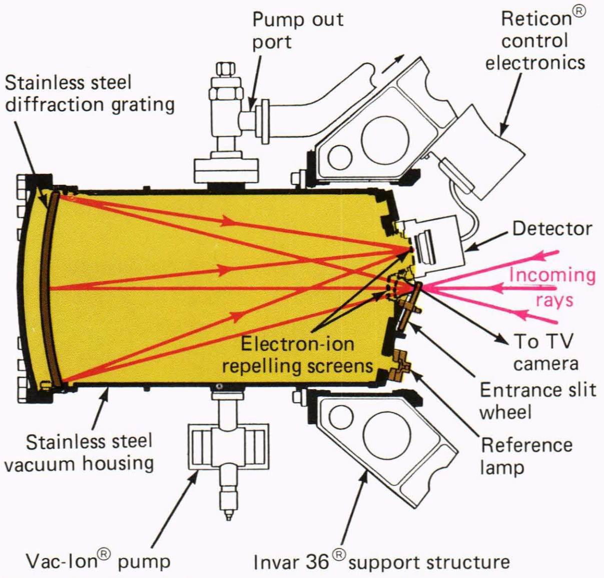

Figure 7—The HUT spectrograph is enclosed in an evacuated stainless steel housing to protect the open window detector. In orbit, the entrance slit wheel is moved to open the aperture. The incoming light is reflected by the diffraction grating and is focused onto the detector. Light that does not fall on the aperture is reflected into the television camera reimaging lens. The pumps, which are operated when the aperture is closed, maintain a vacuum of about 10^{-7} torr. The reference lamp can be used to provide a signal of known signature to the detector to test the system. The external line valve allows the spectrograph vacuum to be maintained by an external pump for long storage periods between flights.

tions of the grating produce a limiting resolution of 2 angstroms.

The resolution of the spectrograph is further reduced by the size of the entrance aperture. The size of the appropriate aperture depends on the geometry of the object observed and the expected motion of the object in the focal plane that results from pointing error. Jitter on the order of 1 to 2 arc-seconds (one standard deviation) is expected from simulations of the pointing system. The pointing jitter has forced a minimum aperture of 75 micrometers (9 arc-seconds) to be selected. Other apertures of up to 1 millimeter (2 arc-minutes) can be selected by means of a slit-wheel mechanism that positions one of seven apertures at the center of the focal plane. The eighth position of the mechanism is a blank to seal the spectrograph in order to protect it from contamination when it is not in operation. The front surface of the aperture wheel is mirrored to reflect light near the aperture into the television camera system.

The spectrograph detector[3] consists of two microchannel plates in a chevron configuration, followed by a green phosphor intensifier that is coupled by fiber optics to a 1024-channel self-scanning Reticon® photodiode array. The microchannel plates have 12-micrometer pores with a length-to-diameter ratio of 80 to 1. A cesium iodide coating is deposited directly onto the microchannel plate surface. Photons strike the detector at points along a narrow strip, depending on their individual wavelength. Interactions with the cesium iodide coating produce photoelectrons that are amplified 10^7 times by the plates without losing their spatial position. A programmable high-voltage power supply of about 3000 volts supplies the accelerating potential for the plates. A second programmable supply of about 8000 volts provides the accelerating potential between the plates and the P-20 phosphor. The fiber optics bundle electrically decouples the photodiode array, which converts optical information into electrical signals for processing.

Individual ultraviolet photons are converted to a pulse of visible light that illuminates 20 to 30 photodiodes in the array. Each pulse is processed by the system electronics to provide a single count at a computed wavelength that corresponds to the centroid of the pulse. The photodiode array is read at the rate of about 10^6 samples per second. The amplitude of each photodiode output is converted into a 6-bit digital word by the detector control electronics and transmitted to the spectrometer processor. The pulse amplitude and pulse width of each photon-generated event have a characteristic distribution of values that allows them to be discriminated from certain noise pulses. This discrimination is implemented by the spectrometer processor. The incoming data stream must first pass a pulse height discriminator that removes all words that fall outside a selected window, a process that eliminates most nonphoton events and compresses the data stream so that it will contain only those words that have meaningful data. The words—with their address, which retains the detector spatial (and therefore wavelength) information—are then processed to determine the width of each event. Those events that are either too wide or too narrow are discarded, and the ones remaining are passed through a centroiding algorithm. The centroid of each event corresponds to the wavelength of the detected photon.

The processor stores each event in a histogram and, for objects of low count rate, can resolve to the nearest millisecond the times at which photons arrive. The processor can compute the centroid of each event up to a rate of 8000 per second to form histograms and can downlink events with millisecond time resolution for rates up to 500 photons per second. If events occur at higher rates because of an extremely bright source or because of some form of noise in the detector, the discrimination circuitry or the centroiding algorithm can be modified by command. The types of commands include: a reduction in the number of diodes that are processed in the array, changes in the pulse-height and pulse-width discrimination levels, and operation in a data mode that allows unprocessed data to be sent to the ground for later analysis.

If analysis of raw data indicates a detector problem resulting from the shuttle environment, from contamination of the detector, or from a change in characteristics because of aging, the system could then be appropriately reconfigured by command. For example, to eliminate "hot spots" in the detector, segments of the diode array can be rejected.

TELEVISION CAMERA SYSTEM

The television camera system serves two functions. The more important is to provide a way to acquire targets and to measure the pointing error of the telescope. Secondarily, it can provide limited scientific data at visible wavelengths. Operation of the telescope requires the observation of the target (if visible) and nearby guide stars. The payload specialist will use that information to adjust the pointing system in order to force the target into the spectrograph aperture. During the observation, the guide stars will be used to compute drift of the telescope pointing. To ensure, with a reasonable level of confidence, that at least two stars are observable in the telescope field of view, the camera system must be able to detect stars as faint as 15 visual magnitude.

The camera system consists of the silicon-intensified target camera, a filter-wheel mechanism, and a reimaging lens system. The lens system produces an $f/4$ beam imaged onto the camera photocathode and corrects for the coma of the parabola. The filter wheel has eight positions, four of which contain visible-light color filters to provide images of Halley's Comet in narrow bands that are associated with dust and with ions. Three positions contain neutral density filters to attenuate image intensity when very bright stars or planets are observed. The main position contains a clear filter for maximum sensitivity. After a commandable integration period, the camera target is read out into a video memory in the dedicated experiment processor. The processor converts the intermittent camera signal to a standard 2:1 interlaced, 30-frame-per-second signal for distribution to the aft flight deck monitor; computes pointing errors; and transmits a composite frame via the high-rate multiplexer data stream to the ground-based team at the rate of approximately one frame every 20 seconds.

The basic camera sensitivity range is controlled by the camera imaging tube high voltage and the integration time. The sensitivity range is further increased by the neutral density filters. This allows the system to detect stellar objects between +17 and −4 visual magnitude. The spatial resolution is limited by the line resolution of the camera over the 10 arc-minute field of view. This translates into a resolution of approximately 2 arc-seconds.

The camera sensitivity and spatial stability are affected by such environmental factors as temperature and the ambient magnetic field. Measurements of the camera's temperature sensitivity indicate that, at temperatures above 10°C, photocathode noise will limit sensitivity to sources brighter than 17 visual magnitude and at temperatures above 30°C to sources brighter than 15 visual magnitude. Because the camera uses a magnetic focus and deflection system, changes in the ambient magnetic field will cause a shift in the apparent position of star images in the focal plane. This is especially pertinent since the Invar® metering structure produces induced fields of several gauss in the vicinity of the camera. To minimize the effect, a Mumetal® shield was fabricated for the camera. The shield attenuated magnetic-induced effects so that shifts of approximately 2 arc-seconds or less were induced by fields as large as 2.5 gauss.

DEDICATED EXPERIMENT PROCESSOR

The dedicated experiment processor is the brain of the HUT flight instrumentation. Figure 8 illustrates its interfaces in greater detail. The processor provides nearly all of the flight instrumentation command and telemetry interfaces with the Spacelab command and data management subsystem. Within the flight instrumentation, the processor interfaces with the television camera system, spectrometer system, primary mirror control system, environmental control canister, aperture control system, power conditioning system, and heater control system.

The functions of the processor include:

1. Receiving and interpreting command messages

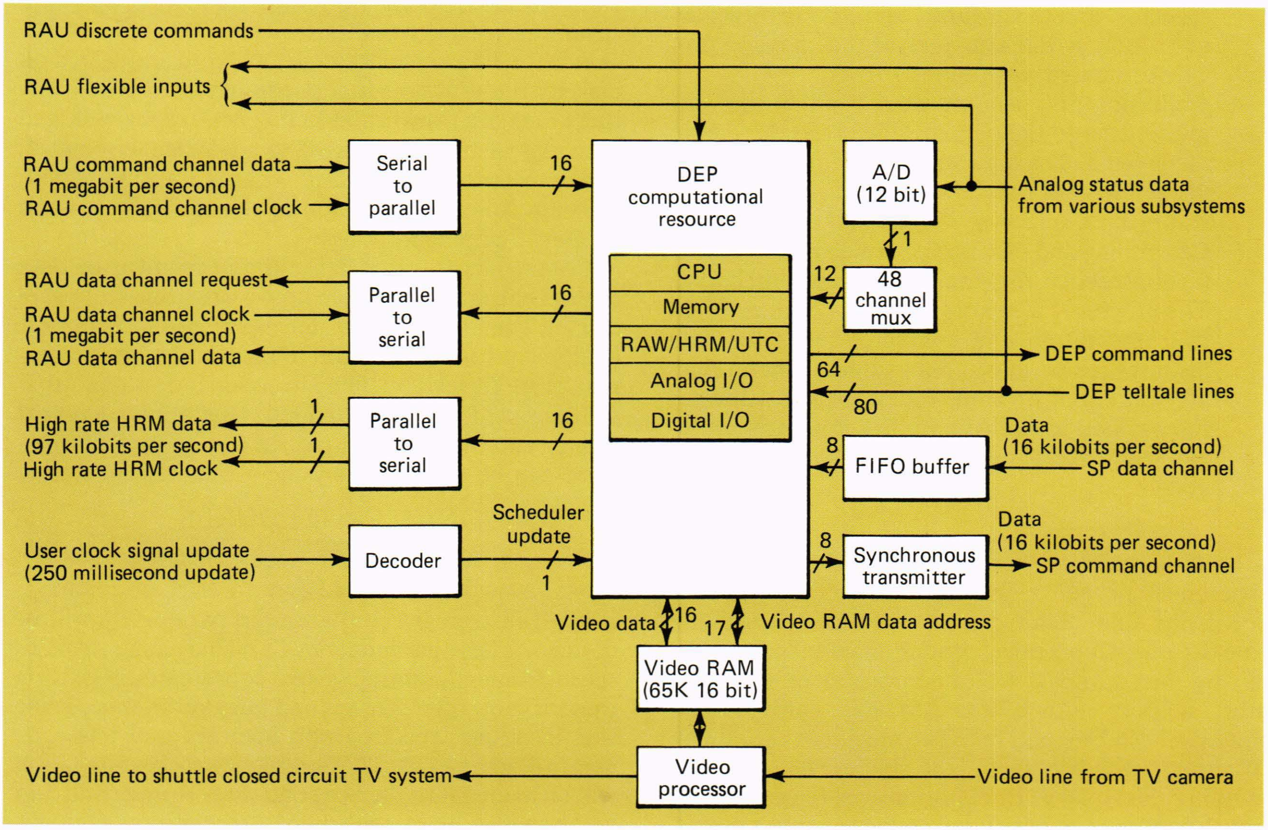

Figure 8—The dedicated experiment processor (DEP) receives serial data messages, which are tne primary control information passed to the system, from the remote acquisition unit (RAU). The processor uses this information to control the telescope via the processor command lines and spectrometer processor (SP) command channel. Engineering status information is collected by the processor telltale lines and by analog status monitors. (A small subset is also sent directly to the RAU for monitoring purposes when the dedicated experiment processor is off.) The science and pointing system data are received via the spectrometer processor data channel and the television camera video line. These data are transmitted, after formatting, via the RAU serial data and closed-circuit television system on the aft flight deck. The data are also transmitted to the ground via the high-rate multiplexer (HRM) data stream.

issued by the Spacelab experiment computer and received via the remote acquisition unit. These command messages provide the means through which the dedicated experiment processor and its interfaces are configured. For example, these messages control the telescope's focusing and pointing system, filter-wheel mechanism, slit-wheel mechanism, camera control, detector, and spectrometer processor system.

2. Creating and sending data messages issued by the dedicated experiment processor and sent via the remote acquisition unit. These data messages provide the means by which the processor requests services from the experiment computer and provides the payload specialist with telescope pointing information and experiment data.
3. Maintaining and analyzing video image data. The processor controls the television camera system that provides the payload specialist and the ground team with images of the telescope's field of view. The images are stored in the processor's video memory and transmitted to the monitor on the aft flight deck and to the ground via the high-rate multiplexer data stream. The processor will manipulate the digitized form of the image to provide guide marks to be used by the payload specialist and the ground team during target acquisitions. It will also analyze the image to provide estimated positioning errors.
4. Collecting and sending data via the high-rate multiplexer to the onboard tape recorder and to the ground. The data stream contains processed ultraviolet spectral data, flight instrumentation status data, and video image data.
5. Controlling and monitoring nondedicated experiment processor flight instrumentation functions. The processor monitors the status of most flight instrumentation and compares telemetry data against predetermined limit values. When values are found out of limit, the processor will warn the payload specialist and, in some cases, automatically take action to prevent damage to a subsystem.

Both the spectrometer processor and the dedicated experiment processor use the same bit slice central processing unit architecture.[4] Each processing unit consists of a 16-bit microprogrammed machine containing four AM2903 4-bit microprocessor slices and other support chips of the AM2900 family of Advanced Micro Devices, Inc. The machines execute instructions directly from the high-level language FORTH. Sixty-six FORTH primitives (basic instructions) are stored as microinstructions in each processing unit. Each unit can execute approximately 500,000 FORTH primitives per second. This approach has allowed the development and testing of code for the high-speed concurrent processes required by HUT. The design of the HUT processor has been described in detail by Ballard.[4]

TELEMETRY GROUND SUPPORT EQUIPMENT

The telemetry ground support equipment will be used for instrument qualification and to collect and interpret data during each flight at the Payload Operations Control Center at the Marshall Space Flight Center. The support equipment consists of a Digital Equipment Corp. LSI 11 preprocessor, a PDP 11/24 computer, a video storage memory, and other peripheral equipment.

The telemetry data stream encoded by the dedicated experiment processor and transmitted by the shuttle avionics is decommutated by the Payload Operations Control Center system and delivered to the telemetry ground support equipment preprocessor. The preprocessor separates the video data from the primary science (spectra) and housekeeping data. The video data are temporarily stored in the video memory and displayed on a monitor. Selected frames of the video data can be frozen by the system and stored either on hard disk or on tape.

Housekeeping data can be displayed for observation by the HUT team at the control center or monitored by subroutines in the ground support equipment, which will generate alarms if out-of-tolerance conditions occur. Selected frames of these data may also be stored for later analysis.

Science data are continually collected and stored on disk by the ground support equipment. Periodically these data are transferred to magnetic tapes. Selected data may also be transferred to a personal computer, where they may be analyzed without interfering with the data collection function of the telemetry ground support equipment.

Commands to reconfigure the instrument or data tables that are used to set up observation sequences can be generated by the telemetry ground support equipment for transmission to the shuttle. These commands are formed by filling in command "shells" that are accepted by the Payload Operations Control Center and then transmitted. In this way, the instrument can be controlled by the ground-based team.

OPERATIONAL PROCEDURES

For each ASTRO mission, a set of preplanned observations will be prepared and, for each observation, a set of instrument configuration parameters will be defined. These parameters will include such items as the instrument pointing system coordinates, television camera gain, filter settings and integration time, guide star locations, spectrograph aperture and telescope aperture settings, etc. A data file for each observation will be loaded into the Spacelab mass storage unit and will be called up by the payload specialist as each observation is made.

An observation will begin by orienting the shuttle so that the instrument pointing system will operate within an angle of 30° from the z axis (directly out of the shuttle bay). The payload specialist will call up the observation and load the observation parameters into the dedicated experiment processor. The mission specialist will load the pointing parameters into the instrument pointing system and move the observatory telescopes to within a few arc-seconds of the target. The processor will then generate reference marks on the television monitor that will be used by the payload specialist to locate the target and guide the pointing system to bring the target into the spectrometer aperture. During this period, the dedicated experiment processor will also compute pointing errors that the payload specialist can read on a data display. Once the target is acquired, other parameters on the data display will allow him to monitor the photon count rate and compare it to an expected count rate stored in memory. A plot of the spectrum can also be generated by the processor for overlay onto the television monitor. By using these displays, the payload specialist can determine that the observation is proceeding properly.

The entire mission will be controlled by a time-line schedule that will include all planned observations. Included in each observation data set is information on how long the observation is to run. During the observation, the next target may be previewed to acquaint the crew with the next set of planned actions, or a new unplanned target may be inserted into the time line, with the observation parameters either being generated by the payload specialist or provided by the ground operations team. The preplanned observation data sets allow efficient use of the observation time. At the same time, significant flexibility is maintained by allowing the payload specialist or the ground operations team to intervene whenever instrument data indicate that a control parameter requires altering or when a target of opportunity occurs.

STATUS AND PLANS

As of early February 1985, HUT was nearing completion of its qualification testing at Goddard Space Flight Center. All testing is scheduled to be completed by March 1985, when HUT will be delivered to the Kennedy Space Center to begin its integration with the rest of the ASTRO Observatory. Integration, shuttle and Spacelab system tests, and mission simulations will occupy a full year at the Kennedy Space Center, with the first launch of ASTRO scheduled for the second week of March 1986. If all goes according to current plans, HUT and ASTRO will be launched again in late 1986 and a third time in mid-1987. With this series of launches, astrophysicists at Johns Hopkins and elsewhere will get the first detailed look at the far and extreme ultraviolet emission of many objects.

REFERENCES

[1] A. F. Davidsen, W. G. Fastie, P. D. Feldman, R. C. Henry, and H. W. Moos, Johns Hopkins University proposal submitted to NASA for a Spacelab Ultraviolet Telescope (1978).

[2] A. F. Davidsen, W. G. Fastie, P. D. Feldman, G. Hartig, and G. H. Fountain, "Shuttle Pointing of Electro-Optical Experiments," in *Proc. Society of Photo-Optical Instrumentation Engineers* **265**, pp. 375-380 (1981).

[3] K. S. Long, C. W. Bowers, P. D. Tennyson, and A. F. Davidsen, "An Intensified Array Detector for Space Applications," *Advances in Electronics and Electron Optics* (to be published).

[4] B. W. Ballard, "FORTH Direct Execution Processor in the Hopkins Ultraviolet Telescope," *J. FORTH Appl. Res.* **4**, 33-38 (1984).

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