IUE-701-73-015

A BRIEF DESCRIPTION OF THE INTERNATIONAL ULTRAVIOLET EXPLORER

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FOREWORD

The International Ultraviolet Explorer, or IUE, formerly known as the Small Astronomy Satellite (SAS-D), was first considered late in 1969 as a result of recommendations made by the NASA Astronomy Mission Board in their publication of a document, A Long-Range Program in Space Astronomy, which recommended an integrated space astronomy plan for the 1970's. Various programs were identified for UV astronomy such as the OAO and LST. By the end of 1969, however, it appeared unlikely that it would be possible for NASA to launch OAO-type spacecraft after OAO-C. As a result, it was recommended that an Explorer-class satellite should be investigated to see if it could meet the needs of a UV astronomy program. The Astrophysics Research Unit of the United Kingdom's Science Research Council had already conducted a study for ESRO, known as the UVAS study, concerning a 45 cm telescope with an echelle spectrograph. As a result of this study and the recommendations by the Astronomy Mission Board for an Explorer-class satellite, Goddard Space Flight Center conducted an "in-house" Phase A Study during the summer of 1970. Because the objective of the study was a system able to operate primarily as a guest observer facility, Goddard established an Astronomy Working Group to provide continuing scientific guidance. The original members of the Working Group were selected for their experience in developing space astronomy instrumentation and because of their interest in using Explorer-class satellites for astronomical observations. As the design of the satellite becomes fixed, the composition of the Working Group is being changed to reflect an increasing emphasis on how the satellite should operate as an astronomical observatory. The current members of the Working Group are:

A. Boggess	Goddard Space Flight Center
E. Böhm-Vitense	University of Washington
P. Conti	Joint Institute for Laboratory Astrophysics
W. Fastie	Johns Hopkins University
H. Gursky	Smithsonian Astrophysical Observatory
M. Hack	Trieste Observatory
L. Houziaux	University of Mons

E. Jenkins	Princeton University
J. Oke	Hale Observatories
T. Owen	State University of New York, Stony Brook
M. Plavec	University of California at Los Angeles
B. Savage	University of Wisconsin
A. Underhill (Chairman)	Goddard Space Flight Center
R. Wilson	University College London

As implied by its name, IUE is an international undertaking. The satellite and optical instrumentation are to be provided by the Goddard Space Flight Center. The television cameras to be used as detectors will be provided by the United Kingdom Space Research Council. ESRO is to supply solar paddles for the satellite and will construct a European control center. This cooperation is to continue after launch, when two-thirds of the observing time will be directed from a control center at Goddard Space Flight Center and one-third of the time the satellite will be operated from the European control center near Madrid.

This summary describes the satellite and instrumentation that are defined by the IUE System Design Report. It is intended to give the information on the satellite's performance and operation that is needed by a potential user in order to formulate his observing program. A more detailed observing handbook will be written when the characteristics of the flight instrument have been measured.

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THE SYSTEM CONCEPT

The basic concept underlying the design of the International Ultraviolet Explorer is that of an ultraviolet astronomical observatory intended primarily for use as an international research facility. Astronomers should be able to come to this observatory and carry out their own observing programs without going through tedious training courses in the specialized techniques of operating a telescope in earth orbit. For a low orbit, special techniques become necessary not only because of the relatively complicated observing environment resulting from the orbital geometry but also because this environment changes so rapidly. The observer has little opportunity to evaluate and take advantage of particular observing situations as they arise. Rather he must rely on pre-planned automatic sequences that are often only indirectly responsive to the scientific requirements of the observation.

Many of these complications become less severe at higher altitudes and, in the special case of a synchronous orbit, the problems and techniques of telescope operation become remarkably similar to those at ground observatories which are already familiar to every observing astronomer. The choice of a synchronous orbit is then an important ingredient in achieving the objective of a guest observatory where the observers can concentrate on astronomy rather than become experts in satellite orbital operations. The synchronous orbit does restrict the weight and, therefore, the size of the telescope that can be used. However, in the IUE this restriction has been counterbalanced by the relatively efficient design of the telescope instrumentation.

The IUE is to contain a 45 cm telescope which will be used exclusively for spectroscopy. The scientific aims of the project have not been altered since the earliest studies of its feasibility. They were summarized in the original feasibility study as follows:

- To obtain high-resolution spectra of stars of all spectral types in order to determine more precisely their physical characteristics

- To study gas streams in and around some binary systems

- To observe at low resolution faint stars, galaxies, and quasars, and to interpret these spectra by reference to high-resolution spectra

- To observe the spectra of planets and comets as these objects become accessible

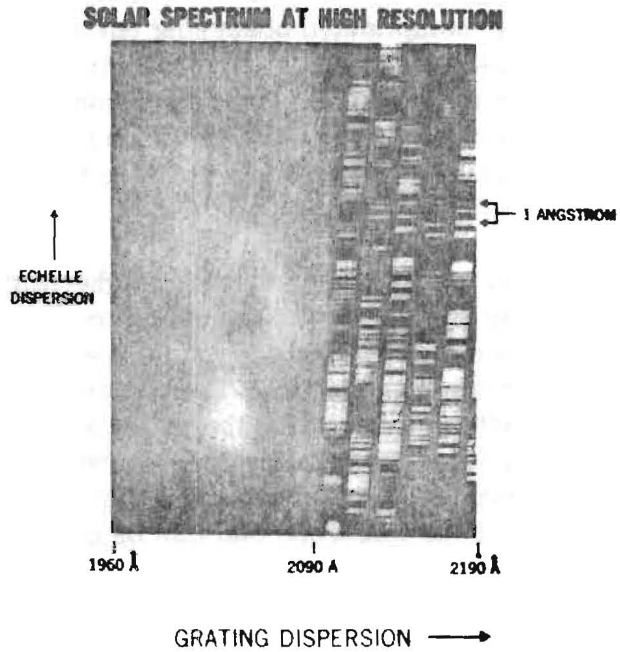

Figure 1. An Echelle Spectrogram of the Sun. (Photograph obtained by R. Wilson, Astrophysics Research Unit, Culham Laboratory from a Skylark rocket fired at Woomera, Australia, April 7, 1970.)

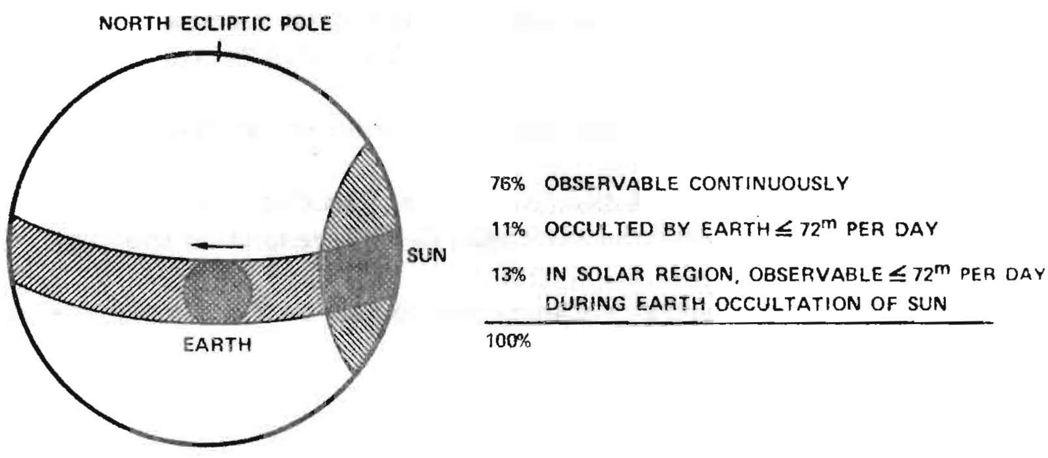

Figure 2. The Celestial Sphere from Synchronous Orbit

- To make repeated observations of objects known or newly found to show variable spectra

- To define more precisely the modifications of starlight caused by interstellar dust and gas.

These scientific aims are predicated on a capability of obtaining both high-resolution spectra (~0.1Å) of bright objects and low-resolution spectra (~6 Å) of fainter objects. Determining the equivalent widths of faint lines used to measure chemical abundance, or the profiles of stronger lines used to study gas motions, requires a spectral resolution of at least 0.2Å; a resolution of 0.1Å or better is desirable. Low-dispersion spectroscopy, on the other hand, serves primarily in the observation of faint sources. Observing programs calling for this capability either do not require high resolution for analysis or they involve sources with intrinsically broad spectral features, and emphasis is placed on limiting magnitude rather than resolving power. The desire to record complete ultraviolet spectra rather than selected spectral regions dictates the use of spectrographs with the capability of recording a spectral image, rather than spectrum scanners.

An echelle spectrograph has been selected to obtain the high resolution spectra desired for brighter objects. With this type of instrument a high dispersion is easily achieved, and there is an additional advantage that the format of the spectrum can consist of a series of adjacent spectral orders displayed one above another in the raster-like pattern illustrated in Figure 1. This format makes efficient use of the sensitive area of the SEC Vidicon television tubes which will be used to integrate and record the spectrum. Since the echelle spectrograph design contains a high dispersion echelle grating in series with a low dispersion grating, the instrument is easily converted into a low resolution spectrograph by simply inserting a plane mirror in front of the echelle, leaving the low dispersion grating to act alone.

In order to achieve the dispersion required in the high resolution mode, it has been necessary to split the spectrum from 1150 to 3200Å into two ranges, and two exposures are required to record the entire spectrum. Observing efficiency is not significantly affected, however, for the grating blaze angles and other design parameters can be separately optimized for the two spectral ranges, greatly improving the optical efficiency. Two exposures would frequently be required in any case in order to optimally expose both the short and long wavelength portions of the ultraviolet spectrum.

The telescope is to be placed in a synchronous orbit such that it can be in continuous contact with the operations center located at Goddard Space Flight Center. The satellite can also be controlled from a second center near Madrid, and observing time will be shared by the two centers. This arrangement is conceptually different from previous orbiting observatories which communicated with ground stations only intermittently and so had to be self-contained, automated systems that acquired data while not under direct ground control. In the case of IUE, control and performance monitoring will be exercised continually from the ground. The telescope field can be recorded with a television camera and displayed to the observer, who can identify his target star and direct the course of the observation essentially in real time. The "Observatory," therefore, is comprised of the ground control center, where the astronomer views his television monitors, and the optical and electronic instrumentation located at synchronous altitude. The fact that the telescope remains at nearly a constant longitude permits the concept of local sidereal time to regain validity as a tool in planning and carrying out observing programs. The two most significant scientific advantages of the synchronous orbit are that the astronomer has physical access to the observatory where he can directly participate in the telescope control loop and that the observing circumstances develop at the diurnal rate so that plans and real time decisions can be made in an effective and orderly manner.

The Earth will subtend an angle of seventeen degrees as seen by the telescope, and the area of sky available at any given time is much greater than from lower orbits or from the ground. Moreover, the region of the celestial sphere periodically occulted by the Earth is also greatly reduced as indicated in Figure 2. As a result, in most parts of the sky long exposures or the monitoring of variable phenomena need not be periodically interrupted because of earth occultations. The plane of the satellite orbit will be chosen to coincide approximately with the ecliptic so that the sun will be eclipsed by the Earth for about one hour each day. This time may be used to observe inner planets or other objects too close to the sun for ordinary observation.

The most serious concern about the synchronous orbit is that observations must normally be made in full sunlight. Telescope baffle designs have been carefully evaluated, both theoretically and by comparison with flight tested designs, and it is possible to reduce scattered sunlight to a negligible amount. Scattered earthlight is more difficult to control, and the scattered light level may noticeably increase when the telescope is oriented so that earthlight falls inside the telescope tube. Fortunately, the Earth's spectrum contains very little energy below 3000A. With an optics and detector system properly designed to be insensitive to visible wavelengths, the limiting magnitude of the spectrograph will not be appreciably affected by Earth light. The offset guiding system can be influenced by Earth light, however, and near the Earth's limb observations may be restricted to fields containing relatively bright guide stars.

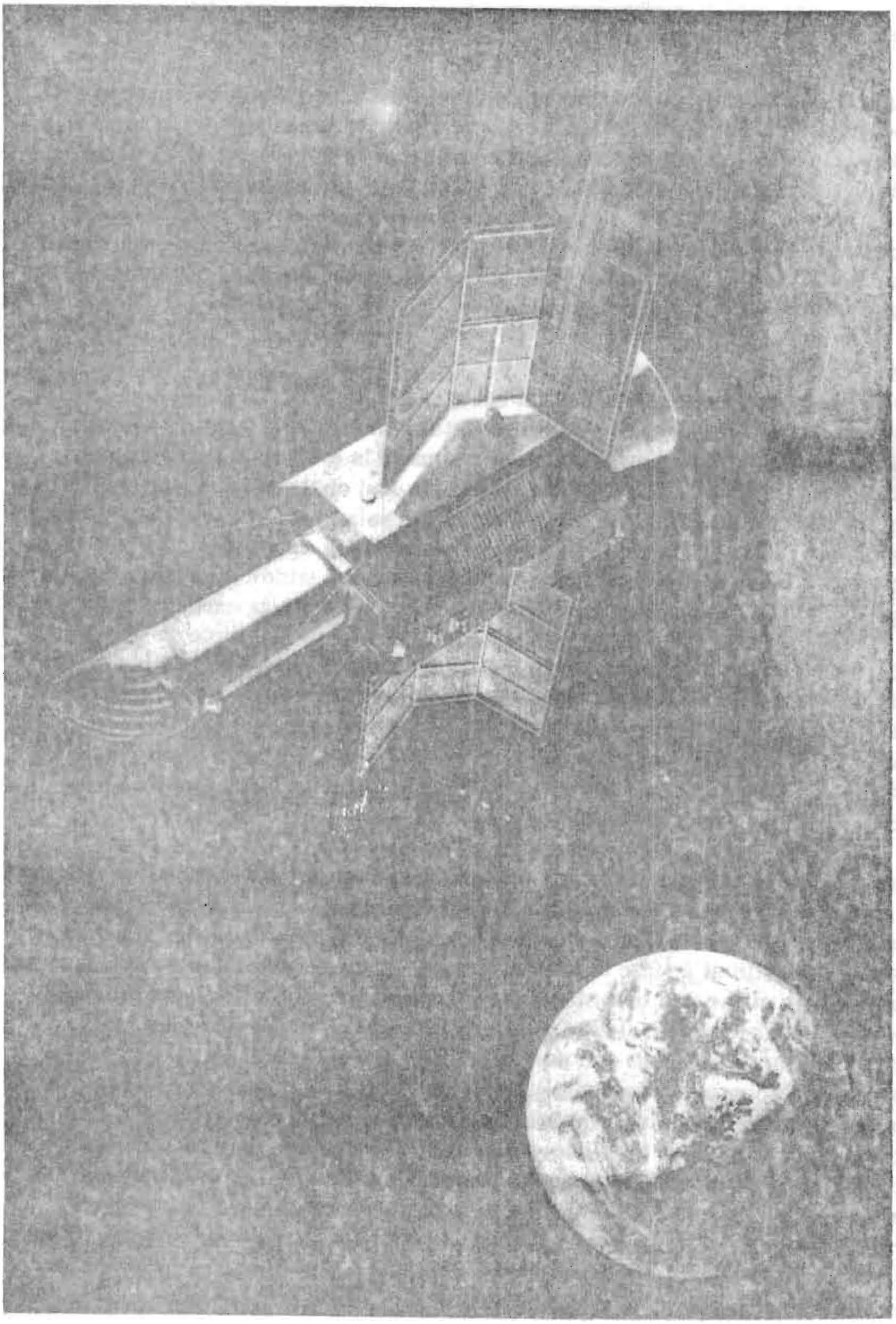

Figure 3. IUE in Orbit

THE IUE SPACECRAFT

Figure 3 shows an artist's conception of the satellite's appearance in orbit. The spectrographs are installed in a central cavity in the octagonal structure. The telescope tube extends forward and terminates in a hood cut at 43 degrees to baffle out sunlight. Solar paddles extending from the spacecraft body provide power. Thermal louvers are located on the shaded side of the body to control temperature. The fourth stage motor used to put the spacecraft in synchronous orbit is located to the rear, as are the small gas thrusters used to maintain station and to dump excess angular momentum.

The overall characteristics of the IUE satellite are listed in Table 1. The spacecraft body houses three principal subsystems in addition to the telescope and its instrumentation. They are power, stabilization and control, and communications and data handling. The power source is a solar array which energizes the satellite directly during sunlit periods and charges batteries that provide power when the satellite is in shadow. The solar paddles are fixed to the spacecraft body but, as may be seen in Figure 3, their surface is convex toward the sun so that adequate power can be generated over a wide range of telescope pointings. The average power consumption of the satellite is expected to be 185 watts, and the arrays are able to exceed this amount for all pointings greater than 43° from the sun. Since the satellite is not designed to point closer to the sun than 43° when in sunlight, a power negative condition (i.e., discharging batteries) occurs only during eclipse. The arrays contain solar cells only on their convex side. In addition, the thermal design is predicated on one side of the spacecraft being hot and the other side cold, so the position angle of the telescope must remain fixed with respect to the sun.

The stabilization and control subsystem consists of a set of reaction wheels, which slew the spacecraft or stabilize it while pointing at a star, and a set of gyroscopes, which control the slews and pointing. Slews are executed sequentially about one axis at a time at a rate of 4 to 5 degrees per minute, and the positional error at the end of a slew sequence is to be less than 2 arc minutes. The momentum wheels will slowly accumulate angular momentum due to external torques on the spacecraft and due to noise in the wheels themselves, and this excess energy must occasionally be dumped by firing small hydrazine jets. Angular momentum dumps will be initiated manually at scheduled times; they are expected to occur less than once per day. The amount of hydrazine on board ultimately limits the useful lifetime of the spacecraft; it will be launched with at least a five year supply. The long life goal raises questions about wheel and gyro reliability. Four momentum wheels will be flown, one in each of the three control axes plus a fourth oriented at 45° with respect to the pitch and yaw wheels. With this configuration, the fourth wheel can act as a back-up to either

TABLE 1

IUE Parameters	
Body Diameter	142 cm
Overall Length	422 cm
Spacecraft Weight	275 kgm
Scientific Instrument Weight	107 kgm
Apogee Motor Weight	286 kgm
Total Weight	668 kgm
Launch Vehicle	Delta 2914
Life	3 to 5 years
Orbit	Geosynchronous, 28° inclination
Power Required	185 w average
Array Capability (Beginning of Life)	407 w max; 242 w 45° and 180° from sun
Batteries (2)	12-AH NiCad Cells (17 each)
Telemetry	2.5 to 40 kb/s with fixed and reprogrammable formats
Command	PCM/FSK/AM, 1200 b/s

the pitch or yaw wheel with the aid of coordinate transform information from the spacecraft's on-board computer. Because the telescope is less sensitive to errors in roll orientation, the hydrazine jets can control roll directly in case the roll momentum wheel fails. The gyro package also contains redundancy for long life. The inertial reference unit consists of six non-orthogonal gyros, oriented such that any three of them can provide three-axis control information with the aid of the spacecraft computer. Ground computers can be substituted for the on-board computer if necessary. When guiding on a stellar target, the spacecraft is expected to maintain ± 1 arc second pointing accuracy. Fine guidance is achieved by use of an offset star tracker looking at an off-axis star in the telescope field. With guide stars brighter than 12^m, the tracker can control the momentum wheels directly. When fainter guide stars must be used, direct control comes from the gyros which are periodically updated with information from the star tracker. Guide stars as faint as 14^m can be used with this mode of operation.

The communications and data handling subsystem accepts commands from the ground and transmits scientific data, pointing information, and engineering status. This subsystem also contains the spacecraft computer which is used for performing attitude control law calculations and some other functions whose timing is too critical to depend on the reliability of the ground data link. The spacecraft can accept ground commands at 1200 bits per second through either an S-band or VHF receiver. Commands may also be issued by the on-board computer, and the execution rate of commands from both sources can be 50 per second. Data is sent to the ground via an S-band transmitter operating at 40,000 bits per second. Each data sample is transformed into an 8 bit data word and transferred to a serial data bit stream. The telemetry is divided into frames 128 words long and, during readout of scientific data, 96 words per frame are devoted to scientific data. The television tube readout is clocked by the telemetry and arranged in a fixed frame format so that, if noise is introduced during data transmission, it should appear as fixed pattern noise in the final image and should be removable. An entire spectrograph image will occupy 6144 successive frames of telemetry, requiring 2.7 minutes to transmit to ground.

The on-board computer is a modularized device consisting of a processor module, which contains the central processor unit and input/output circuitry, and random access memory modules, each containing 4096 eighteen bit words. Two processor modules will be included for redundancy and four memory modules will be flown. The computer will be used for all stabilization and control calculations and will also be convenient for controlling various operational sequences. However, the ground control computer is functionally equivalent to the on-board computer and, in practice, the observational programs should be independent of the computer configuration.

THE SCIENTIFIC INSTRUMENT

The IUE Scientific Instrument consists of three assemblies: the Optical Unit, shown in Figure 4, and two electronics boxes mounted on a spacecraft equipment shelf. The complete Scientific Instrument including electronics is to weigh 107 kgm. The Optical Unit, which includes the sunshade, telescope, spectrographs, and detectors, is 301 cm long and 66 cm at its largest diameter. Other pertinent characteristics of the instrument are listed in Table 2.

TABLE 2

Scientific Instrument Parameters

Telescope		
Figure	Ritchey Chretien	
Aperture	45 cm	
Primary Focal Ratio	f/2.8	
Effective Focal Ratio	f/15	
Plate Scale	30.5 arcsec/mm	
Image Quality	1 arc sec	
Acquisition Field	10 arc min diameter	
Spectrographs		
Type	Echelle	
Entrance Apertures	3 arc sec circle or 10 x 20 arc sec ellipse	
Detectors	SEC Vidicon Cameras	
High Dispersion	Short λ	Long λ
Range	1192 - 1924 Å	1893 - 3031Å
Resolving Power	10^4	1.5×10^4
Low Dispersion		
Range	1135 - 2085Å	1800 - 3255 Å
Resolution	6Å	6Å

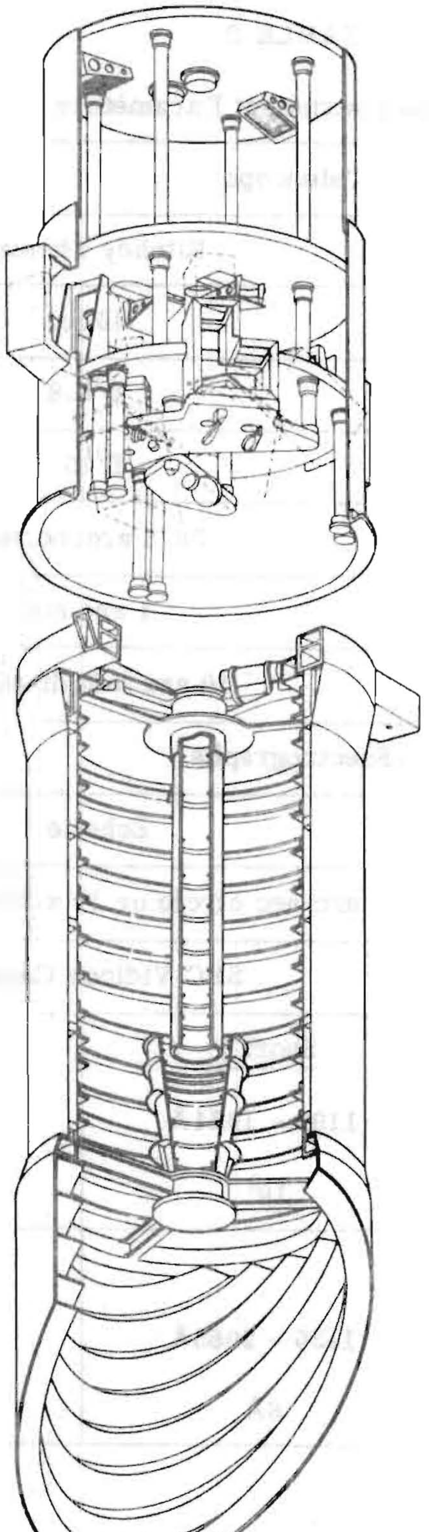

Figure 4. The Scientific Instrument

The telescope is an f/15 Cassegrain telescope with a Ritchey Chretien figure. The primary is 45 cm in diameter and is made of beryllium, coated with a layer of low stress electro-less nickel which receives the optical polish. The secondary has an 8 cm aperture and is fabricated of ULE quartz to minimize the telescope's sensitivity to temperature changes near the front end of the tube. The telescope can be focussed by moving the secondary through a range of 750 μm in 7.5 μm steps, and the structure will be well enough stabilized mechanically and thermally so that proper focus can be maintained with that range of adjustment on the secondary. A shutter is installed just behind the primary mirror in order to protect the instrumentation in case the telescope should inadvertently be pointed toward the sun. The shutter can be closed either upon ground command or automatically by a diode, mounted on the back of the secondary, which can sense the presence of sunlight inside the telescope tube. With this shutter, the scientific instrument should be able to survive a direct pointing at the sun, but would require many hours to regain its thermal balance. Irradiation by the Moon or sunlit Earth will not damage the instrumentation.

The telescope is carefully baffled, as may be seen in Figure 4, in order to permit observations in the presence of sunlight and earthlight. Since the power system requires that one side of the solar paddles always face the sun, the baffle design is predicated on the assumption that sunlight only strikes one side of the telescope. The forward hood is extended on that side so that the telescope may be pointed as close as 43° to the sun without sunlight entering the telescope tube. Furthermore, the forward lip of the hood is fitted with a double diffraction edge so that solar radiation must undergo at least two edge diffractions before it can be scattered into the telescope tube. The internal baffling is designed so that scattered light entering the tube must suffer at least two reflections from diffuse black surfaces before it can strike a telescope mirror, from which it must be diffusely scattered to enter the field of view. Scattered sunlight is not expected to be of any concern as long as the 43° pointing restriction is observed.

Radiation from the Earth is more difficult to exclude than solar radiation. Unlike the sun, whose direction is fixed, the Earth is a 17° diameter object which exhibits phases and moves along the ecliptic at the diurnal rate. The baffles in the forward hood are angled so that radiation striking them is reflected forward, out of the telescope. As a result, little Earthlight can enter the telescope tube for pointing directions more than 90° from the Earth's limb, allowing normal observations to be possible. Under these restrictions every point outside the forbidden zone around the sun is observable for at least eleven continuous hours a day. The internal baffling inside the telescope tube is good enough to allow spectroscopic exposures to be made with the Earth as close as 30° to the pointing direction. However, the background in the offset tracker may increase so that observations would be restricted to fields containing guide stars

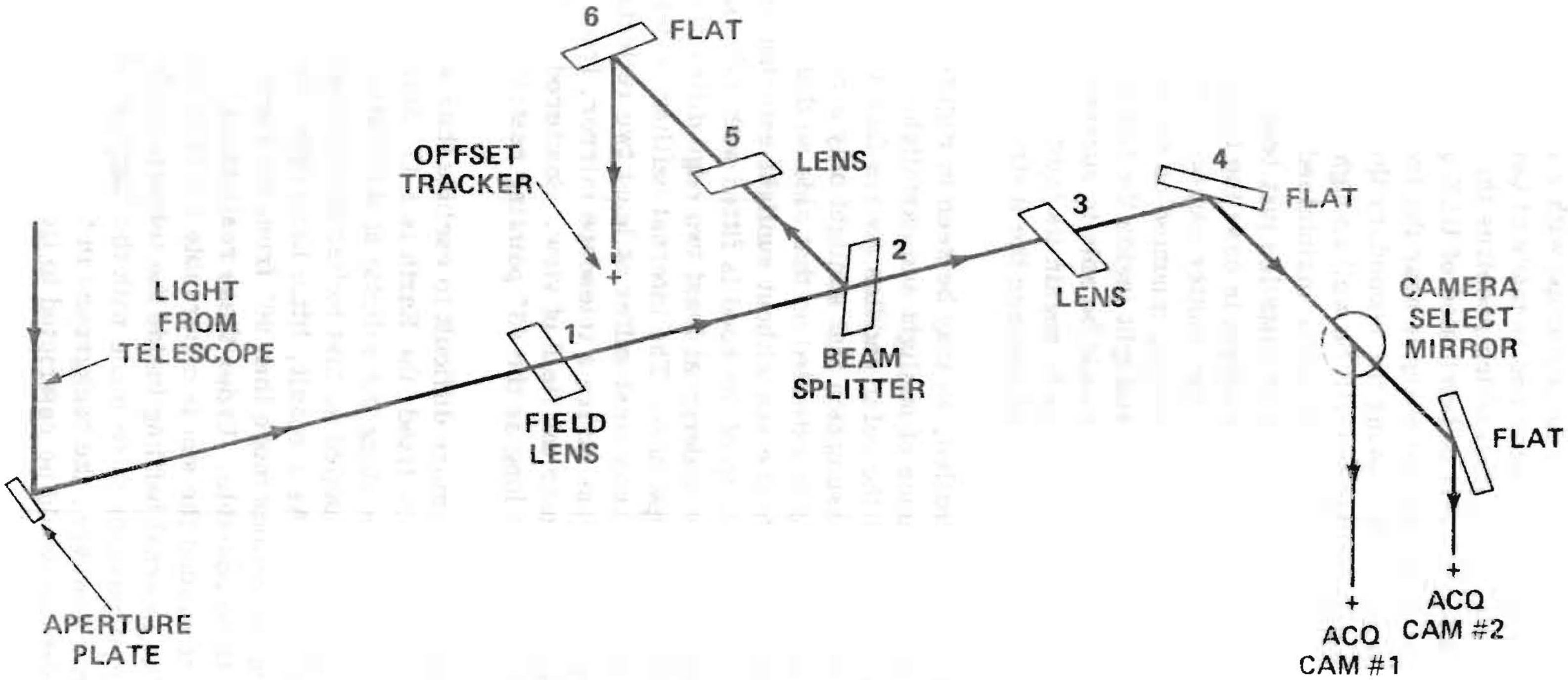

Figure 5. Schematic Arrangement of the Acquisition Camera and Offset Tracker Optics

brighter than about 9^m. Under these circumstances, every point outside the solar forbidden zone is observable for at least eighteen continuous hours a day.

Target identification and fine guidance are accomplished using an acquisition camera and an offset tracker which can view the telescope field surrounding the spectrograph entrance apertures. The field radiation falls upon an optical flat containing the entrance apertures and is reflected into a relay optical system which is shown schematically in Figure 5. The beam splitter reflects 70 percent of the radiation towards the offset tracker, while the remaining 30 percent is focussed on one of the two redundant acquisition television cameras. The relay lenses are designed to provide the largest field possible and still maintain the angular resolution required for each device. As a result, the acquisition cameras, which must be able to measure the angle between the target star and an entrance aperture to within 0.5 arc sec, have 10 arc minute fields of view. The acquisition cameras are white light sensitive, and a nominal one second exposure can reach fourteenth magnitude. The cameras may be used to obtain detailed images of the star field, if desired, but the data transmission time for such an image is 2.7 minutes, just as it is for the spectrograph images. Two alternate readout modes may be employed which allow much faster readout. One is a data compressed mode in which the field is sampled in 2" x 2" steps, and the presence or absence of radiation above a selected threshold is transmitted. This low quality picture should be adequate for most field identification problems and can be transmitted to the ground in only eight seconds. After the approximate positions of the target and guide stars have been determined, a second exposure to measure the exact positions of these stars can be transmitted using the third readout mode. This mode contains a random access feature in which only small areas surrounding the stars of interest are read out. The limited readout requires less than five seconds and can provide accurate positional information in order to calculate the slews necessary to place the target star in the desired entrance aperture. Since the apertures will generally be invisible projected against the dark sky, three small fiducial light sources are embedded in the aperture plate and appear semi-stellar in the acquisition camera images. The positions of the apertures are accurately known with respect to these "artificial stars" so that measurement of the angles between the target star and the "artificial stars" suffice to determine target star position.

After the target star has been identified and maneuvered into the spectrograph entrance aperture, it can no longer be seen by the acquisition camera or offset tracker. Therefore, it is necessary to designate a suitable field star as the guide star. The tracker is then offset to the approximate position of the guide star. The tracker executes a local search, finds the star, and generates the error signals necessary to hold the star in position. The offset tracker is an image dissector with an instantaneous field of 18 arc seconds which can be positioned anywhere within a total field 16 arc minutes in diameter. The tracker,

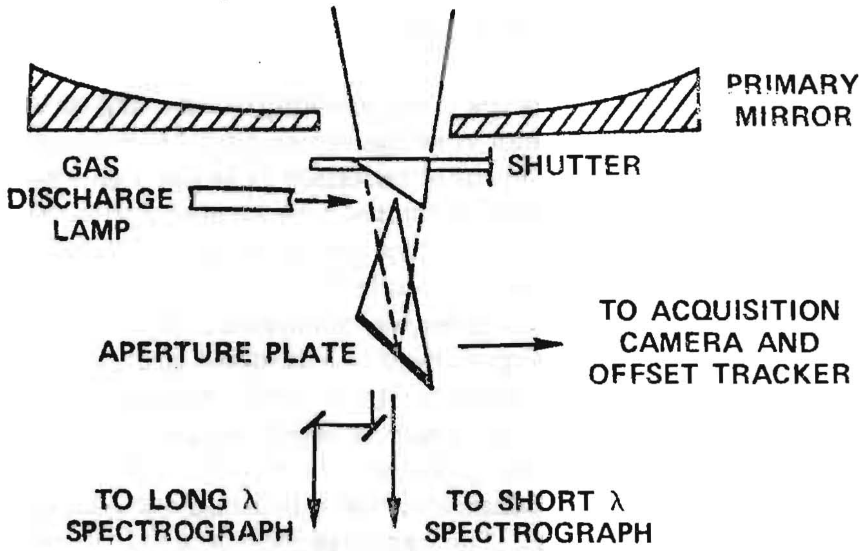

Figure 6. The Telescope Focal Plane

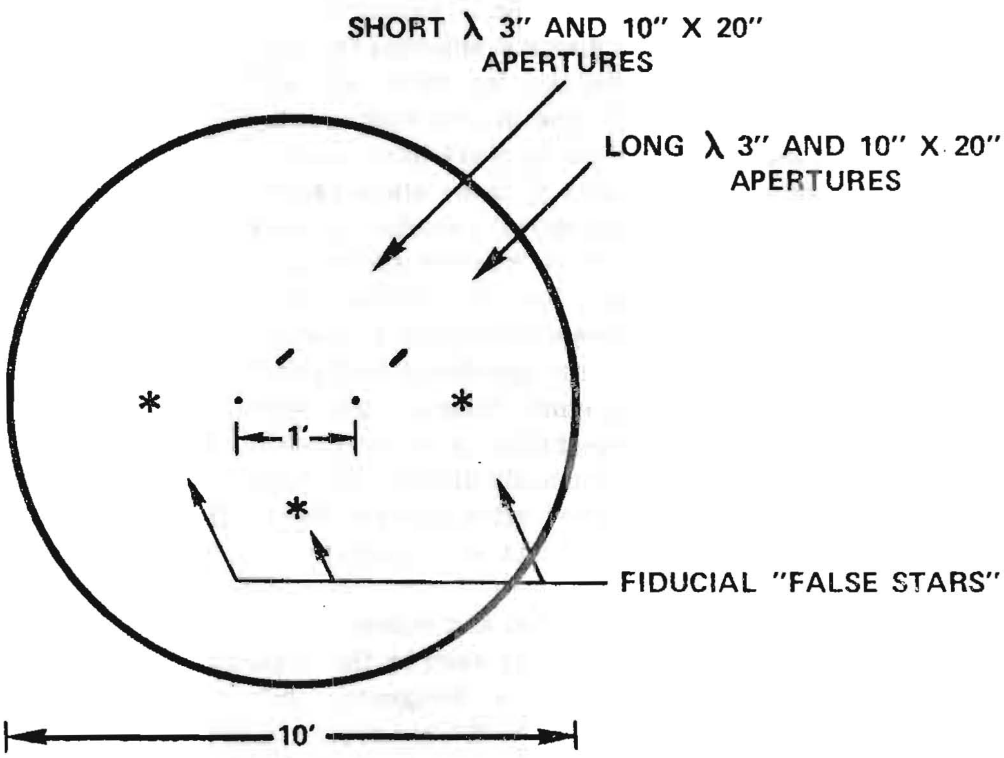

Figure 7. The Spectrograph Aperture Plate as it Appears From the Acquisition Camera

in combination with the gyro package, is designed to provide ± 1 arc sec guidance (one sigma) on fourteenth magnitude stars. The tracker only provides guidance information about the pitch and yaw axes. Control of roll about the optical axis of the telescope is much less critical and can be maintained adequately by the roll gyro with occasional update from a sun sensor that monitors the position of the sun to about one arc minute. The tracker field of view is large enough so that a suitable guide star can almost always be found, even at the galactic poles. In the rare event when a guide star does not exist, two other guidance techniques are possible. For stellar targets, spacecraft stability will be maintained by the gyros and the tracker will be adjusted to monitor the entrance aperture. When the star drifts out of the aperture, the tracker can detect star presence and trigger a slew command to drive the star back into the hole. For extended targets, spacecraft stability will still be maintained by the gyros, but images from the acquisition camera will periodically be examined to determine the position of the aperture on the extended object. Slews to maintain position can then be manually commanded from the control center. These last two guidance modes are general enough to be applicable in any conceivable field, but they are less efficient operationally than the principal offset tracking mode which will normally be employed.

The location of the plate containing the spectrograph entrance apertures is shown in Figure 6, and the appearance of that plate as seen by the acquisition camera is illustrated in Figure 7. There are four apertures in the plate: a small hole and large slot feeding the short wavelength spectrograph and a second small hole and large slot feeding the long wavelength spectrograph. The two spectrographs are physically separate and a spectrograph is selected by pointing the telescope so that the image of the target star enters an aperture for that spectrograph. The small 3 arc second apertures are normally used, the larger apertures being shuttered. The larger apertures are available so that a larger solid angle can be utilized on extended objects at some sacrifice in spectral resolution. The larger apertures would also allow observations to be made even if the spacecraft guidance should become badly degraded. Operational aspects of using the two apertures will be discussed below. The positions of the fiducial sources that appear as artificial stars in acquisition camera images are shown in Figure 7. In order to reflect light into the acquisition camera and fine error sensor relay optics, the aperture plate is tilted 45° with respect to the telescope axis. The axis of tilt is through the 3 arc sec apertures and the fiducial sources that flank them. As a result, these apertures and sources appear properly in focus while the third source, which is away from the tilt axis, will be slightly de-focussed. Its light center can still be accurately determined, however. Similarly, the edges of the larger slots will appear slightly out of focus to the spectrograph cameras, even though an object viewed through these slots is in good focus. In other words, the edges of a large slot will not be sharply defined when projected against an extended source.

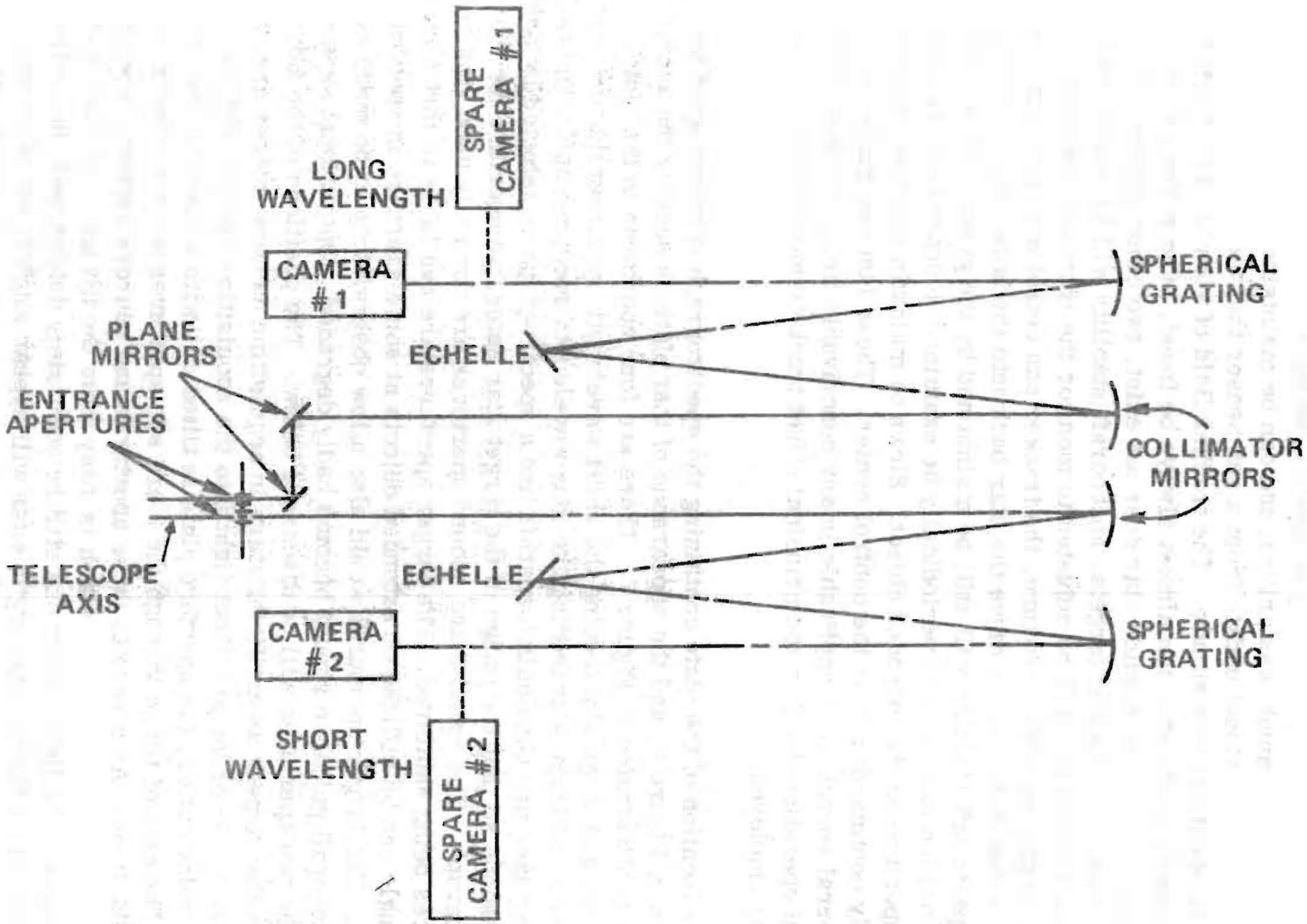

Figure 8. Schematic Arrangement of the Spectrographs

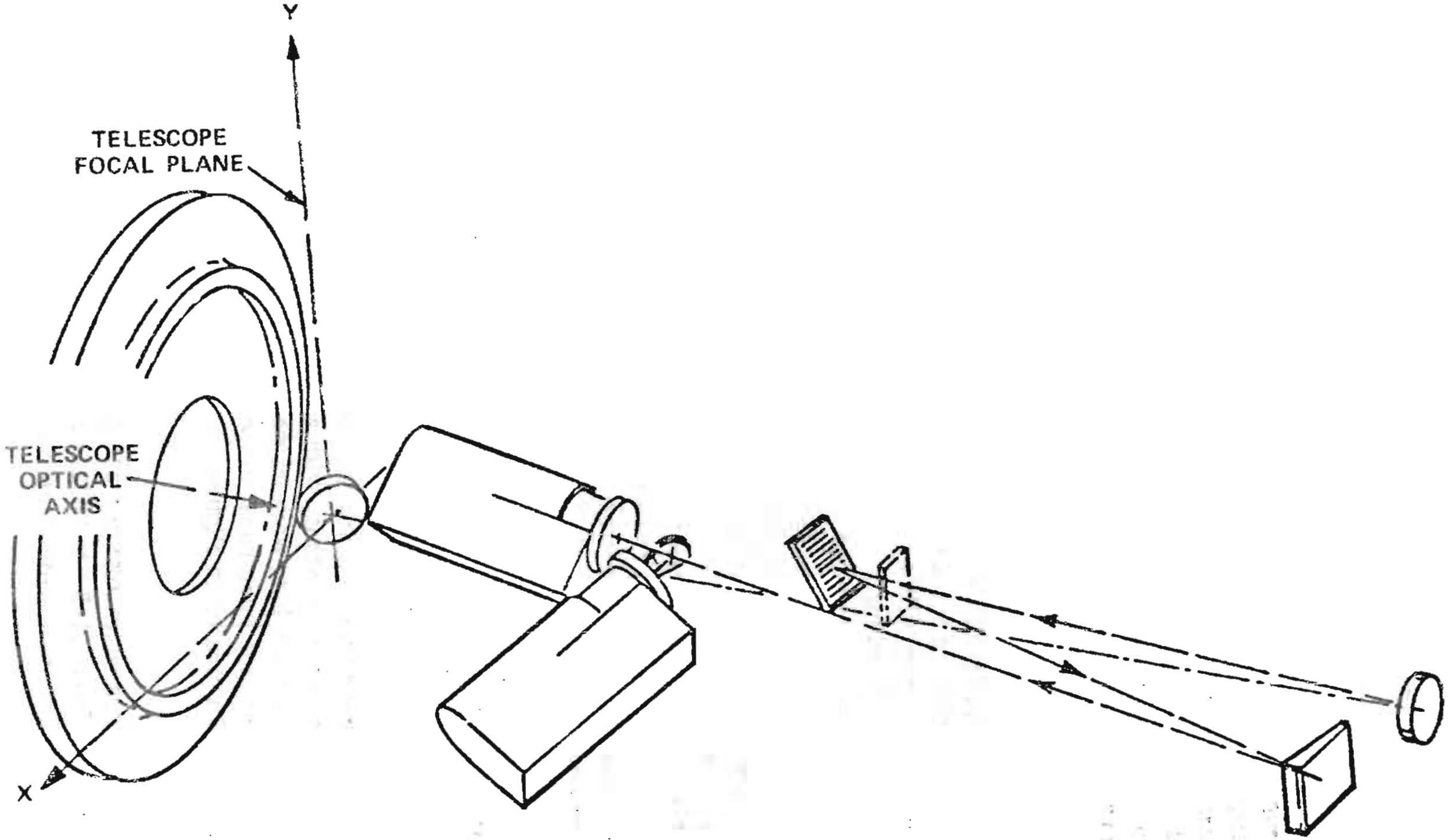

Figure 9. Spatial Configuration of the Short Wavelength Spectrograph

A simplified schematic of the arrangement of the spectrographs is shown in Figure 8. The short wavelength spectrograph is a three element echelle system, containing an off-axis paraboloid as collimator, an echelle grating, and a spherical first order grating that is used to separate the echelle orders and to focus the resulting spectral display on the television camera. The long wavelength spectrograph is identical, except that two 45° flats are inserted to shift the light rays diverging from the entrance aperture so that they will not interfere with the rays falling on the short wavelength collimator. Either spectrograph may be converted to a low dispersion instrument by inserting a flat in front of the echelle grating so that the only dispersion is provided by the spherical grating. The spatial arrangement of the elements of the short wavelength spectrograph is shown in Figure 9. In this figure, all other optics have been deleted for clarity.

The present choices for grating rulings are not necessarily final. As more detailed test data on the television cameras becomes available it may become desirable to adjust the spectrograph dispersions to better match detector resolution. The final values will not be greatly different from those described here, though. The short wavelength high dispersion format is shown in Figure 10, in which the echelle array is drawn inscribed within the 25 mm diameter sensitive area of the television camera. Spectral data is not confined within the trapezoidal outline, of course. Rather this outline represents the region containing a continuous display of wavelengths. Discrete segments of spectra will be seen to longer wavelengths at the top of the display and to shorter wavelengths at the bottom of the display. In addition, the left and right edges of the TV image will contain additional information redundant to that found inside the trapezoid. The reciprocal dispersion is proportional to wavelength and has a value of 1.2Å/mm near the center of the format, at 1670Å.

When the low dispersion flat is inserted in front of the echelle grating, the spectral array collapses to a single first order spectral as shown in Figure 11. Normally, only the spectrum of energy coming through the 3 arc second hole will appear. However, when the larger slot is uncovered, spectra corresponding to the two apertures will appear side by side as illustrated. The angular separation of the two apertures is 2 arc minutes. The reciprocal dispersion of the low dispersion spectra is constant, with a value of 40Å/mm. Figure 12 shows the echelle format for the long wavelength spectrograph. At 2590Å near the center of the format, the reciprocal dispersion is 1.7Å/mm. The low dispersion formats are illustrated in Figure 13. Here, the reciprocal dispersion is 60Å/mm.

The two spectrographs together can provide continuous high dispersion spectral coverage from 1192Å to 3031Å and intermittent coverage down to 1135Å and up to 3255Å. A comparison lamp has been included to provide wavelength standards over this spectral region. It will be a hollow cathode lamp, probably containing a Ne carrier gas and an Fe-Cu cathode. The final lamp materials will be selected to provide an adequate distribution of sharp lines over the echelle formats. The location of the lamp is shown in Figure 6. It is mounted behind the primary mirror, where it illuminates a diffuse surface on the back of the sun-protect shutter. When the shutter is closed, radiation from the lamp then floods the acquisition plate so that it appears like a diffuse source filling the spectrograph entrance apertures. As a result, if a stellar spectrum and a comparison spectrum were recorded on the same image, they would be superimposed. The spectrograph will be sufficiently stable that sequential images, first of star and then of comparison, will permit accurate wavelength determinations. In fact, during routine observing, comparison spectra will be recorded only as often as needed to maintain the wavelength calibration. How often comparison exposures are needed will be determined by experience. No photometric standards will be carried on the spacecraft. Photometric calibration will be accomplished by observing standard stars whose spectral fluxes have been accurately determined by other means. It will be possible to measure the response linearity of the detectors by recording graded exposures to flood lamps.

The detector systems used to record the spectrograph images consist of a proximity focussed image converter attached to an SEC Vidicon television tube, as shown in Figure 14. The image converter is a Bendix 8040 tube with a magnesium fluoride faceplate and cesium telluride photocathode. The white light image produced by the converter is transmitted through the fiber optic output of the converter directly into the fiber optic faceplate of the TV tube. The TV tube is the Westinghouse WX32224 tube, a space qualified version of their commercially available WL30893. The useful sensitivity of the detector system starts about 1150Å and begins to fall off rapidly above 3000Å. As a result, the system has a high rejection to longer wavelength scattered radiation, which would include most scattered sunlight or earthlight.

Since the SEC target has storage capability, it can be used to integrate an extended exposure and retain the image until it is read out directly into the telemetry system and processed by the ground data computer. No intermediate buffering or storage on board the spacecraft is used. In order to prepare the TV tube for an exposure, the target must be erased to remove all vestigial traces of prior exposures. The preparation procedure consists of exposing the tube to an incandescent floodlamp which uniformly irradiates the faceplate. The tube is then rapidly read out four times, which removes nearly all charge from the target. This flood-erase cycle is itself repeated four times, the entire process taking about 1.5 minutes, and it restores the target to a pristine state, ready to begin a new exposure. Exposures are shuttered by turning on and off the camera high voltage. The shortest possible exposure time depends on the

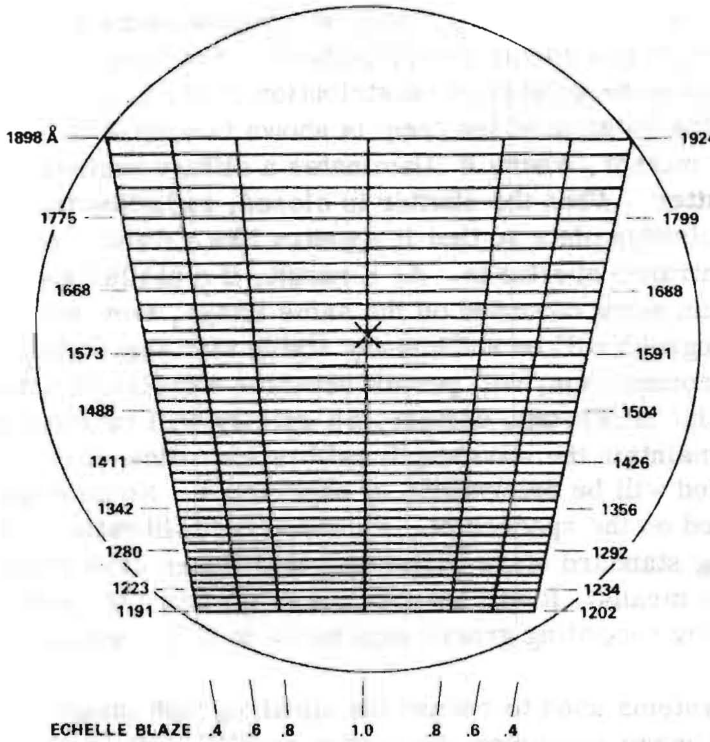

Figure 10. Short Wavelength Echelle Format

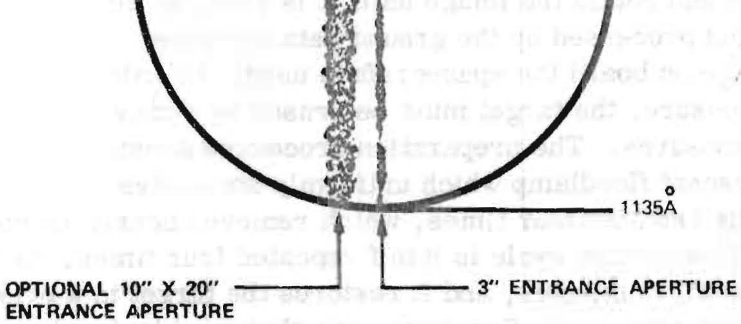

Figure 11. Short Wavelength Low Dispersion Format

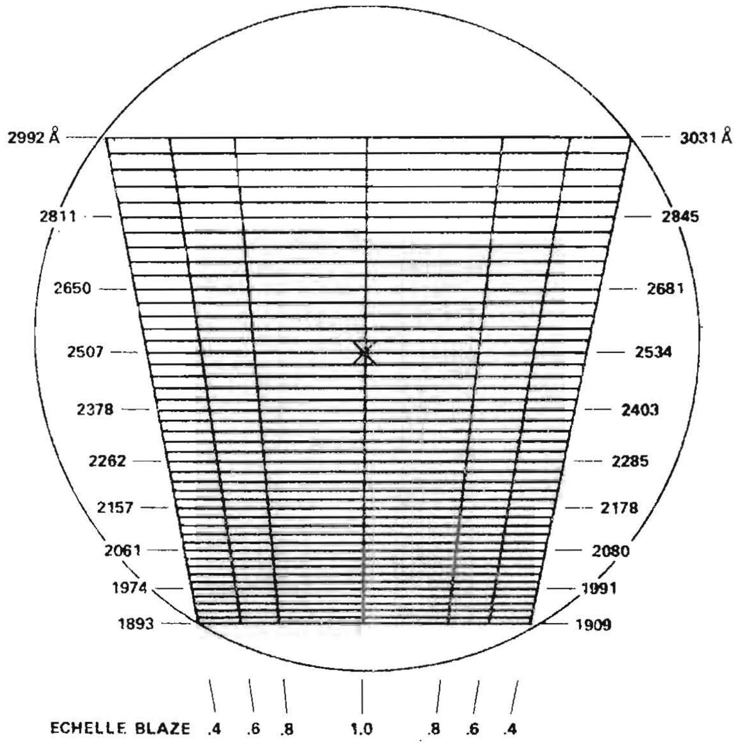

Figure 12. Long Wavelength Echelle Format

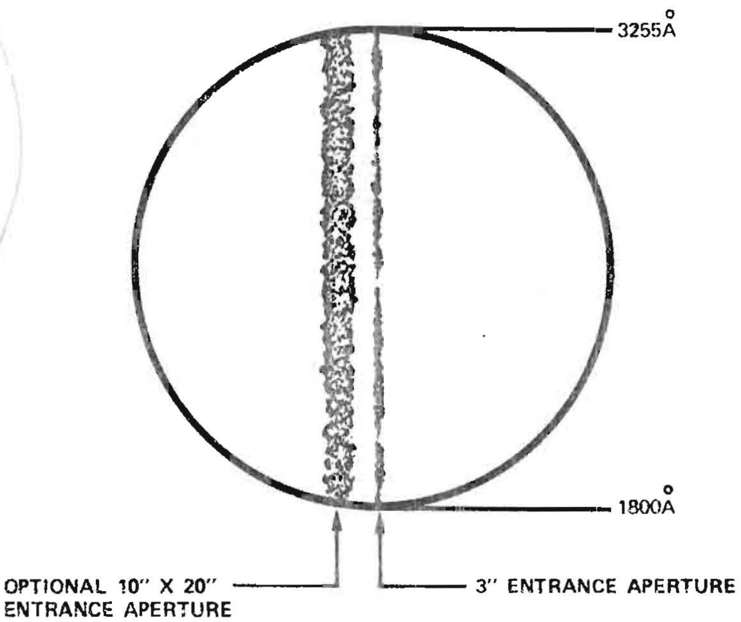

Figure 13. Long Wavelength Low Dispersion Format

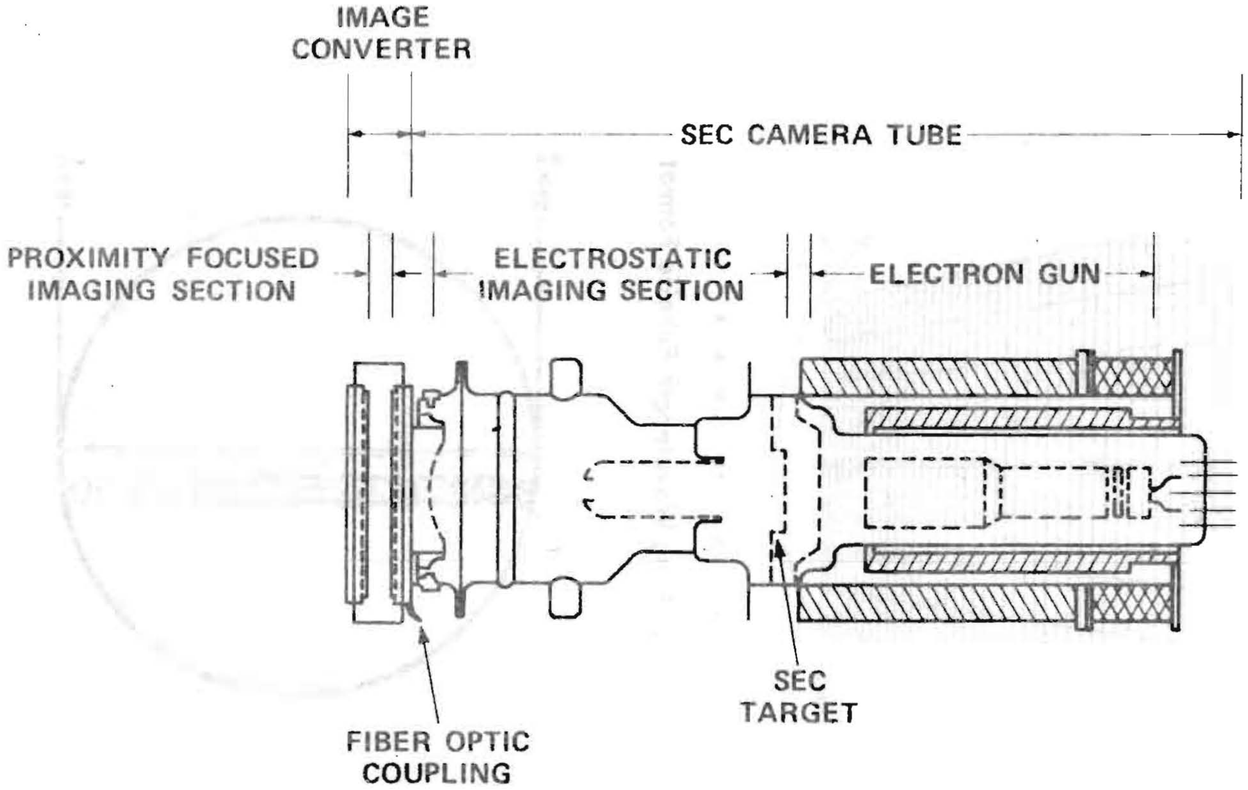

Figure 14. A Spectrograph Sensor, consisting of a Proximity Focussed Converter and an SEC Television Tube

rise and fall characteristics of the high voltage power supply and is expected to be between 1 and 5 seconds. The longest possible exposure will be limited by the rate at which background noise builds up on the SEC target. Tubes of this type have been exposed as long as ten hours under laboratory conditions with acceptable results; however, they should not be expected to perform this well in the IUE environment, particularly under the influence of the high energy cosmic ray flux. Performance predictions for the scientific instrument assume a limiting exposure of one hour, but that limit may be increased after launch as a result of operational experience. The only factors other than tube background that should be expected to limit an exposure are the approach of the sun, earth, or moon.

At the end of an exposure, the image is read out and transmitted directly to the ground. The readout consists of a digital scan of the target in an array of 768 x 768 image elements. This scan corresponds to sampling the optical image of the spectrum in 33 micron steps. The readout rate is controlled by telemetry and can proceed at speeds up to 5000 steps per second. The read beam is pulse modulated, being switched on for 5μsec at each step, and the signal current is transmitted to ground with 8 bit quantization. A complete readout requires 2.7 minutes. The camera can then be commanded through the 1.5 minute preparation procedure and be ready to commence another exposure.

INSTRUMENTAL PERFORMANCE

The spectral resolution that can be expected with the scientific instrument results from a convolution of the point spread profiles corresponding to guiding errors by the spacecraft, aberrations and misalignments in the optical system, and the point spread function of the detector system. Table 3 shows the predicted full width at half maximum of the total profile resulting from this convolution. It should be emphasized that these are predicted resolutions which have yet to be verified. They are based on ray traces and misalignment analyses of the optical design, preliminary tests of the resolution of the detector system, and on the assumption that the guidance errors will produce an integrated image equivalent to uniformly filling the 3 arc second entrance aperture. If the 10 x 20 arc second aperture were used, the spectral resolution for stars would be unaffected, but for extended sources filling the slit the resolution would be 3 times worse in the low dispersion mode and 6 times worse in the high dispersion mode than is shown in Table 3.

The sensitivity of the instrument depends on the net collecting area of the telescope (1100 cm^2), the efficiencies of the three mirrors (five in the case of the long wavelength spectrograph) and two gratings, and the sensitivity of the

TABLE 3

Full Width at Half Maximum of Instrumental Profile

	Δλ (High)	Δλ (Low)
Long λ Spectrograph		
3000Å	0.20Å	6.0Å
2500Å	0.16	6.0
2000Å	0.16	7.2
Short λ Spectrograph		
1800Å	0.15	4.4
1500Å	0.14	5.2
1200Å	0.10	4.4

camera system. In predicting sensitivities, the greatest uncertainties are the efficiencies and scattered light properties of the flight gratings, which have not yet been ruled, and the rate at which noise background will accumulate in the TV cameras in orbit. Assuming the expected values for these various quantities and taking a signal-to-noise ratio of 50 as the requirement on data quality, the short wavelength spectrograph at 1500Å should be able to record a flux of about 8 photons/cm^2 sec Å in a one hour exposure. At 2500Å the long wavelength spectrograph should be able to record a flux of about 2 photons/cm^2 sec Å in one hour. These flux values are approximately equivalent to those from an unreddened B0 star of eighth to ninth magnitude. In the low dispersion mode, the flux levels necessary for a one hour exposure are about 0.03 photons/cm^2 sec Å at 1500Å and 0.02 photons/cm^2 sec Å at 2500Å. Of course, fainter sources can be recorded if one accepts a lower signal-to-noise ratio. Since the TV image is read out and recorded digitally, it is also possible to reach fainter fluxes at the expense of spectral resolution by addition of adjacent image elements with the ground computer. Finally, the limiting sensitivity depends on how long it is possible to expose the TV cameras in orbit. We believe our assumptions are conservative in this regard, but cannot be sure.

The sensitivities quoted above were calculated at 1500Å and 2500Å near the maximum grating blaze efficiencies for the two spectrographs. Each spectrograph is less efficient near the ends of its range because of the blaze properties of the spherical grating. The sensitivity of the short wavelength spectrograph drops rapidly below 1200Å due to the decreasing reflectivities of the five surfaces in the telescope and spectrograph. The sensitivity of the long wavelength spectrograph drops rapidly above 3000Å because of the decreasing sensitivity of the cesium telluride photocathode. A further complication is that each order in the echelle spectrum is also blazed, peaking at the center of the order and dropping in theory to 40 percent of the peak value at each end of the order. This effect is indicated on the echelle formats in Figures 10 and 12, where the points are marked at which the theoretical echelle efficiency is 80, 60, and 40 percent of peak. In practice echelle gratings do not show such strongly peaked blazes in the ultraviolet, but the exact performance of the IUE gratings cannot be known until they are ruled. To illustrate these various effects, Figure 15 shows the expected relative sensitivity curves for the low dispersion spectrographs. Figure 16 shows a curve drawn through the expected relative sensitivities at the blaze wavelengths in each echelle order of the high dispersion spectrographs. This curve represents the maximum sensitivity envelope. Figure 17 shows the continuous relative sensitivity curve for a short section of the high dispersion long wavelength spectrograph to illustrate the expected effect of the echelle blaze.

Basically, the instrumentation options available to the observer are: long wavelength or short wavelength spectrograph, high or low dispersion, and large or small slits. Exposures may be made with the two spectrographs simultaneously, but it must be remembered that the entrance apertures are separated by one arc minute. An additional restriction is that data can be read out of only one camera at a time. However, other cameras may be exposing while one camera is being read out. The choice of high or low dispersion can be made independently for the two spectrographs, so that one spectrograph could be operating in the high dispersion mode while the other is in the low dispersion configuration.

The shutters on the entrance apertures are connected together so that they must be opened and closed together. Furthermore, since the 3 arc sec apertures are considered prime, they cannot be closed. As a result, two configurations are possible: (1) the two 3 sec apertures are open and the two 10 x 20 sec apertures are closed, or (2) all four apertures are open. In the low dispersion mode, having the large and small apertures open together poses no problem. Spectra from the two holes fall side by side as illustrated in Figures 11 and 13 and, in fact, one hole may be used to record sky background while a target is observed in the other. The spectrograph is nearly stigmatic and the spatial resolution of the TV cameras corresponds to about 5 arc seconds. As a result, some small spatial discrimination within the 10 x 20 arc second slot should be

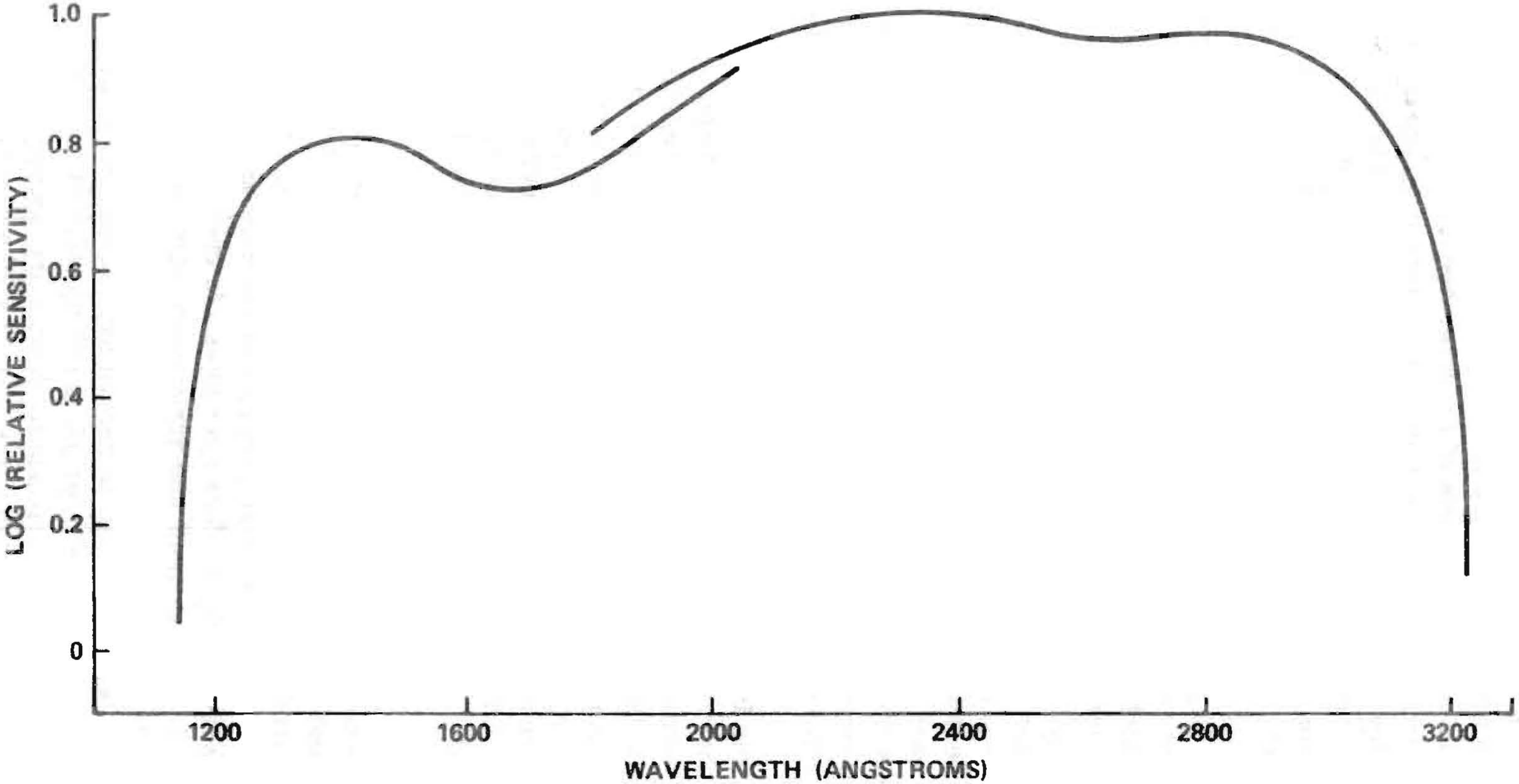

Figure 15. Predicted Relative Sensitivity Curves of Low Dispersion Spectrographs

possible. The large aperture is oriented with low dispersion observations in mind. The long dimension of the slot is perpendicular to the low dispersion direction, and the displacement between the large and small holes is also perpendicular to the low dispersion direction. The slot length and direction of displacement are parallel to the echelle dispersion, however. In the high dispersion mode when both large and small holes are open, the spectrum from the small hole will be superimposed on the spectrum from the large hole, with a displacement of about 1.5 mm, corresponding typically to around 2Å. Generally, the large slot would not be opened for high dispersion spectroscopy except perhaps for observations of extended emission line objects. On the other hand, if the guidance system degrades so that the larger hole must be used for stellar spectroscopy, the superposition of the very faint sky background from the 3 arc second aperture would rarely cause a problem.

OBSERVING PROCEDURES

The configuration of the Observatory Control Center and the procedures for observing with the IUE are only beginning to be developed. The present plan is that observing time will be assigned by a scheduling subcommittee of the IUE Astronomy Working Group, the subcommittee being chaired by the Observatory Director. Schedules would be worked out in six month blocks, based on examination of detailed observing plans from the observers. Prior to coming to the Observatory, the user will submit his planned observing sequence to the Observatory staff, and they will examine the plan for feasibility and safety, verifying that it can be merged with the plans of other concurrent observers. Since the Observatory will operate 24 hours a day, observers will operate on a shift basis, taking over use of the observatory from the observer on the prior shift and passing it over to the observer scheduled for the following shift at either the U.S. or the European Control Center.

With the prior planning accomplished, the observer will arrive at the Control Center in time for a final review of his schedule with the staff and, if he has not used the IUE before, a short training period. During his shift, the observer will direct the activities of the spacecraft and scientific instrument operators and a data reduction specialist. An observing sequence will start with the observer requesting that the telescope be slewed to the coordinates of his first target. After the slews have been accomplished, an acquisition camera image will be commanded, resulting in a display on the TV monitor, with 2 arc sec resolution, of the positions of all stars brighter than a pre-determined magnitude. The observer can compare this display with a finder chart, identify his target star, and designate a suitable guide star. The telescope operator will then command the acquisition camera to transmit localized high resolution

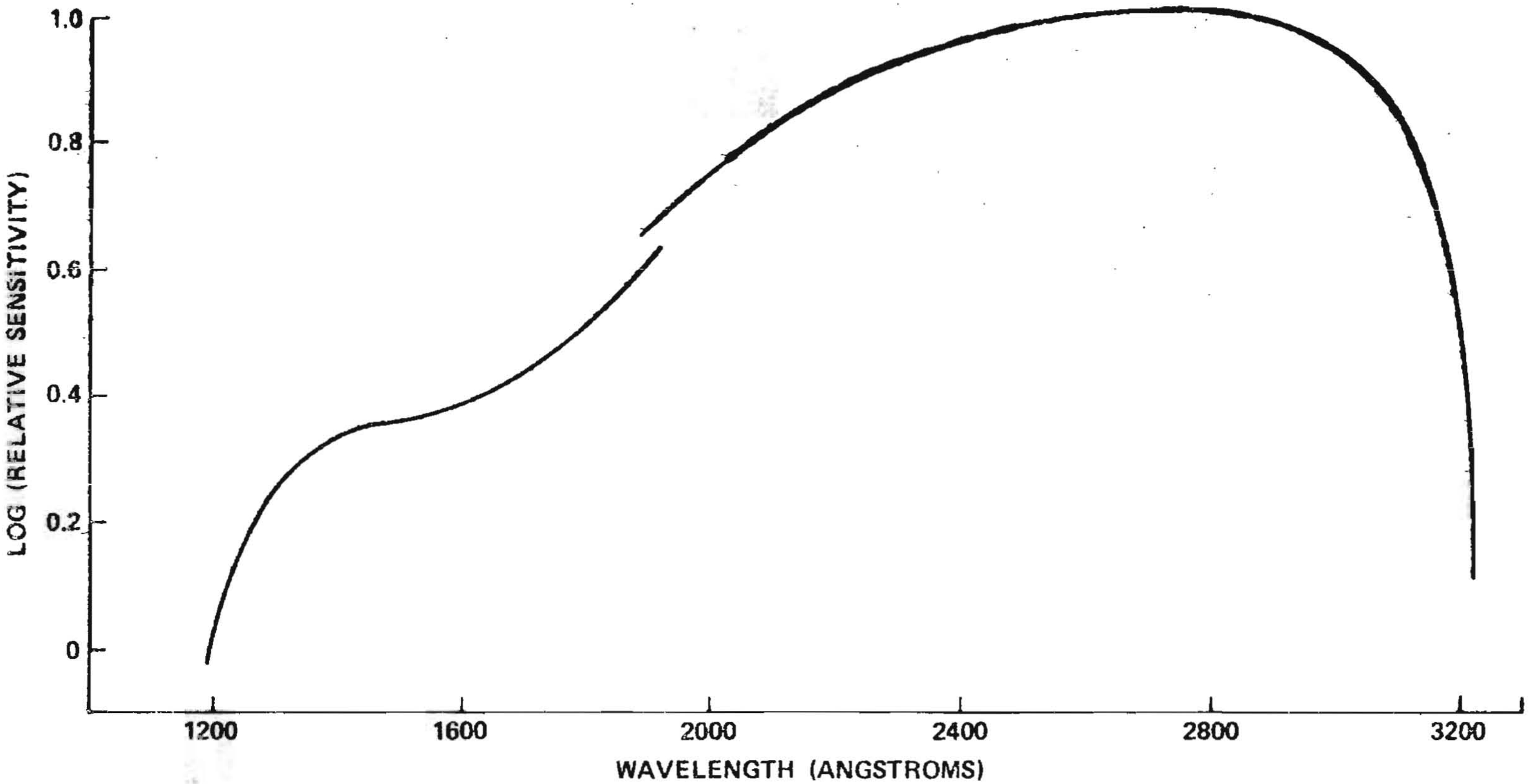

Figure 16. Predicted Relative Sensitivities at Blaze Wavelengths of High Dispersion Spectrographs

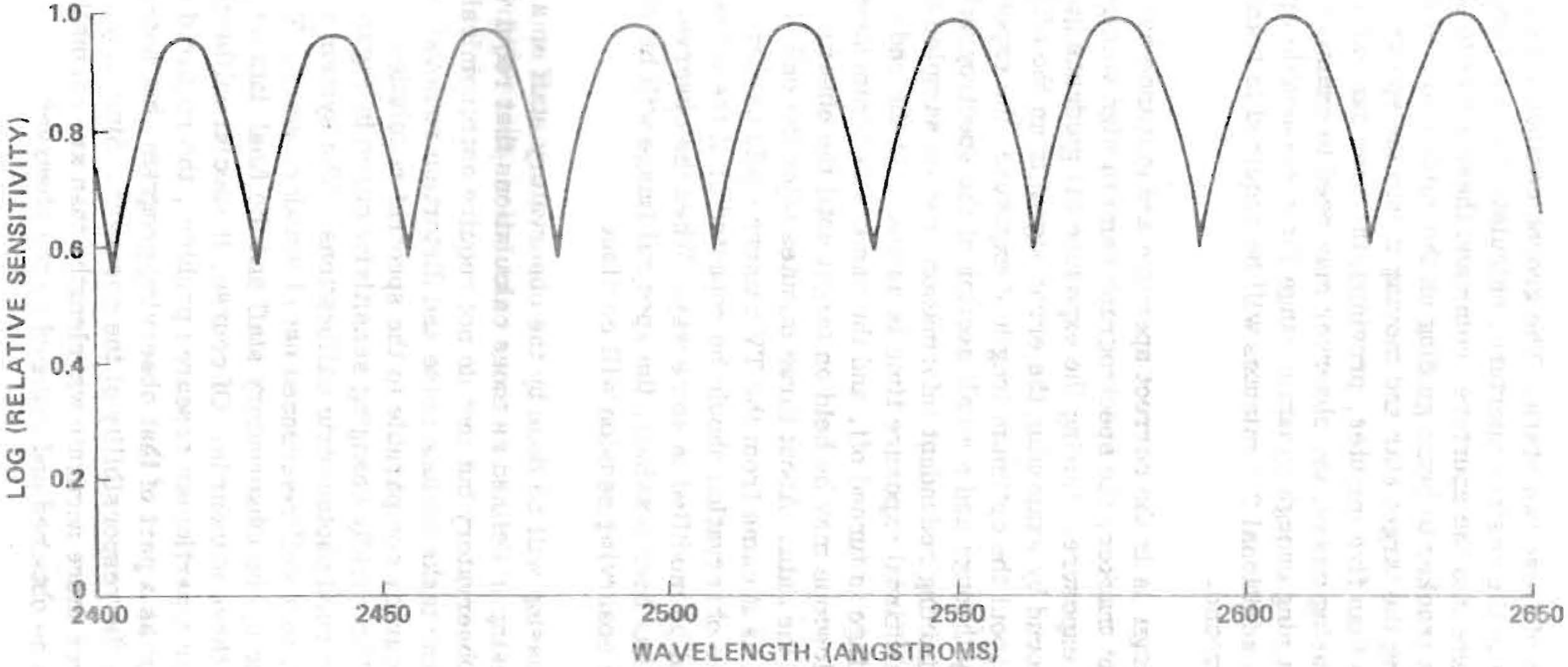

Figure 17. Predicted Relative Sensitivity of High Dispersion Spectrograph from 2400Å to 2650Å

images in the vicinities of these two stars. The ground computer will determine their positions relative to the desired aperture, calculate the fine slews required to move the stellar image into the aperture, command these slews to take place, and command the offset tracker to begin guiding on the guide star. Normally this process of selecting the target star and moving it into the spectrograph aperture should take less than five minutes, providing the user can easily identify his field. In very confusing cases, the observer may need to examine a detailed acquisition image containing enough dynamic range for a reasonable gray scale. On these occasions, an additional 2.7 minutes will be required to transmit the detailed image to the ground.

After the target image is in the correct aperture and guidance has been turned over to the offset tracker, the spectrograph camera high voltage is commanded on to start the exposure. During the exposure the guidance quality may be monitored on the ground by examining the error signal from the offset tracker. If there is uncertainty about the optimum length of exposure, the exposure can be interrupted part way through and a small section of the spectrograph camera image to one side, containing redundant information, can be sampled in order to determine how much additional exposure time is needed. At the end of the exposure, the tube high voltage is turned off, and the camera is commanded to read out the image. The telescope may be held on target until the observer has an opportunity to examine the data. About three minutes after the end of the exposure the raw spectrum as it came from the TV camera could be displayed on a TV monitor to see if the observation should be repeated or if the subsequent observing schedule should be modified in some way. When the observer determines that useful data has been obtained, the spectral image will be stored for full processing and the observing session will continue.

Routine data processing will be done by the observatory staff on a production basis. Routine processing is defined as those calculations that require special knowledge of the IUE Observatory but that do not require astronomical interpretation of the data. These tasks include noise and distortion removal, wavelength determination to an accuracy comparable to the spectral resolution, and photometric calibrations. The rapidly changing sensitivity curve in Figure 16 indicates the importance of good photometric calibrations. The system will be calibrated with respect to a well referenced set of standard stars. The calibrations will be maintained by the Observatory staff and the final data output will be expressed in terms of these standards. Of course, if special calibration procedures are necessary for a particular research problem, the required observations can be carried out as a part of that observing program, but non-standard data reductions will be the responsibility of the observer. Similarly, if a particular problem requires more accurate wavelengths than are normally provided, the necessary data can be obtained and reduced by the observer.

The final reduced data is intended to be available normally within 24 hours of the observation so that spectra taken on one day could be delivered to the observer during his shift the following day. Of course, if many short exposures were taken during one observing shift, the data reduction work might fall behind temporarily, but the backlog would be eliminated during the next series of longer-than-average exposures. Data output may take a variety of forms depending on the preference of the observer. Magnetic tape, analog strip chart records, and photographic prints of the raw and corrected images can be obtained.